MODELLING AND SIMULATION OF INFORMAL HOUSING GROWTH

GIS/CA Based Integrated Approach

By
Eng. Ibrahim Mohamed Badwi Mahmoud

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirement for the Degree of

DOCTOR OF PHILOSOPHY
In
ARCHITECTURE ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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ABSTRACT

There exists a vital need to increase our understanding of the fast-growing **I**nformal **S**ettlements **(IS)** within the growing mega cities of the less developed countries. To study and define the factors that plays the promising rule in urbanization and growth. Previous studies have used **descriptive approach** about economic, social, political and cultural factors, **but they have not produced sufficient understanding to underpin useful and effective management tools.**

A result from these studies, there are many applications, policies, and planning procedures that were developed to model the spread of planned settlements in cities for developed nations, such as **Marseilles** in France, **San Francisco**, **South Carolina Washington/Baltimore** in USA, **Hervey Bay** in Australia, and others.

This thesis will explain why these procedures and tools not suitable to work and use in the context of informal settlement growth in developing countries.

Now, the recent studies of complex urban systems in developed countries, combined with the **power of modern computer simulations**, facilitate new insight into the **IS** dynamics of developing nations. So that, a similar approaches can proposed and implemented to suite the case of informal settlement in poor countries. Accordingly, this research will design and apply a **Cellular Automata techniques (CA)**, joined to a **Geographic Information System (GIS)**, to simulate the spread of **I**nformal **H**ousing **(IH)** in **G**rater **C**airo **R**egion **(GCR)**, **Egypt**.

The proposed predictive model is directly focused upon the case of **popular or informal housing in developing country**, so it can potentially lead to better understanding of the dynamic processes involved and the development of more systematic and effective policies for managing them. Specifically, the proposed **Informal Housing Growth Model**, **(IHGM)** uses **GIS** to **capture**, **generate**, **analyze**, and **visualize spatial** and **temporal information**, and then combines with a **C**ellular **A**utomata program **(CA)**, in form of a **V**isual **B**asic **(VB)** macro, to model informal housing dynamics and so predict their future expansion patterns.

The proposed model adopts a new vision for popular and **I**nformal **H**ousing **(IH)** expansion, it is flexible, simple to apply, and entirely transparent, also it will advance our understanding of the informal housing problem especially in **LDC** cities.

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LIST OF ABBREVIATIONS AND ACRONYMS

AABGR: **A**verage **A**nnual **B**uilt-up **G**rowth **R**ate.

ANSI: **A**merican **N**ational **S**tandards **I**nstitute.

ANUDEM: **A**ustralia **N**ational **U**niversity **D**igital **E**levation **M**odel.

APGR: **A**nnual **P**opulation **G**rowth **R**ate.

ASCII: **A**merican **S**tandard **C**ode for **I**nformation **I**nterchange.

AUDI: **A**rab **U**rban **D**evelopment **I**nstitute.

BSQ: **B**and **S**equential.

CA: **C**ellular **A**utomata.

CAAE: **C**ellular **A**utomata **A**nalytical **E**ngine.

CAD: **C**omputer **A**ided **D**esign.

CAM: **C**ellular **A**utomata **M**achine.

CAPMAS: **C**entral **A**gency of **P**ublic **M**obilization and **S**tatistics.

CAS: **C**ellular **A**utomata **S**pace.

CAUM: **C**ellular **A**utomata **U**rban **M**odels.

CBD: **C**entral **B**usiness **D**istrict.

CBO: **C**ommunity **B**ased **O**rganization.

CDA: **C**ommunity **D**evelopment **A**ssociation.

CDS: **C**ity **D**evelopment **S**trategy.

CFS: **C**enter for **F**uture **S**tudies.

CID: **C**ommunity and **I**nstitutional **D**evelopment **C**onsulting.

CPT: **C**entral **P**lace **T**heory.

CUF-I: **C**alifornia **U**rban **F**uture-I *(first generation)*.

CUF-2: **C**alifornia **U**rban **F**uture-II *(Second generation)*.

CUM: **C**ellular **U**rban **M**odels.

DEM: **D**igital **E**levation **M**odel.

DLT: **D**irect **L**inear **T**ransformation.

DSS: **D**ecision **S**upport **S**ystems.

DUEM: **D**ynamic **U**rban **E**volutionary **M**odeling.

ECHR: **E**gyptian **C**enter for **H**ousing **R**ights.

EDI: **E**gyptian **D**ecentralization **I**nitiative.

ERIM : **E**nvironmental **R**esearch **I**nstitute of **M**ichigan.

ESRI: **E**nvironmental **S**ciences **R**esearch **I**nstitute.

EPA: **U.S. E**nvironmental **P**rotection **A**gency.

ETM: **E**gyptian **T**ransverse **M**ercator.

FDOT: **F**lorida **D**epartment of **T**ransportation.

FTP: **F**ile **T**ransfer **P**rotocol.

FPP: **F**amily **P**lanning **P**rogram.

GCP: **G**round **C**ontrol **P**oint.

GCR: **G**reater **C**airo **R**egion.

GDP: **G**ross **D**omestic **P**roduct.

GIF: **G**raphic **I**mage **F**iles.

GIS: **G**eographic **I**nformation **S**ystems.

GO: **G**eo-**C**omputation.

GOPP: **G**eneral **O**rganization for **P**hysical **P**lanning.

GPS: **G**lobal **P**ositioning **S**ystems.

GTOS: **G**lobal **T**errestrial **O**bservation **S**ystem.

GUI: **G**raphical **U**ser **I**nterface

GUO: **G**lobal **U**rban **O**bservatory.

HRSI: **H**igh **R**esolution **S**atellite **I**mages

HUDS: **H**arvard **U**rban **D**evelopment **S**imulation *(model)*.

HW: **H**ardware *(Computer Hardware)*.

IH: **I**nformal **H**ousing.

IHGM: **I**nformal **H**ousing **G**rowth **M**odel.

IKONOS: 1-m **H**igh **R**esolution **S**atellite **I**magery.

IMPEL **I**ntegrated **M**odel to **P**redict **E**uropean **L**and **U**se.

INP: **I**nstitute of **N**ational **P**lanning.

ISO: **I**nternational **O**rganization for **S**tandardization.

IS: **I**nformal **S**ettlement.

ITLUP: **I**ntegrated **T**ransportation **L**and **U**se **P**ackage.

LANDSAT: **L**and **S**atellite

LDC: **L**ess **D**eveloped **C**ountry(s).

LTM: **L**and **T**ransformation **M**odel.

LUCAS: **L**and **U**se **A**nalysis **S**ystems.

LUD: **D**evelopable **L**and **U**nits.

MCAG: **M**erced **C**ounty **A**ssociation of **G**overnments.

MCE: **M**ulti **C**riteria **E**valuation.

MIT: **M**assachusetts **I**nstitute of **T**echnology.

MSD: **M**ilitary **S**urvey **D**epartment.

MSS: **M**ulti-**S**pectral **S**canner.

NGO: **N**on **G**overnmental **O**rganizations.

OOP: **O**bject-**O**riented **P**rogramming.

RAM: **R**andom **A**ccess **M**emory.

PBR: **P**opulation **B**uilt-up area **R**atio.

PGR: **P**opulation **G**rowth **R**ate.

PLUM: **P**rojective **L**and **U**se **M**odel.

PS: **P**opular **S**ettlements.

QB: **Q**uick-**B**ird **S**atellite

RMS: **R**oot **M**ean **S**quare error.

ROM: **R**ead **O**nly **M**emory.

SW: **S**oftware *(Computer Software)*

TIN: **T**riangulated **I**rregular **N**etworks.

TM: **T**hematic **M**apper.

UCA: **U**rban **C**ellular **A**utomata.

UDM: **U**rban **D**ynamics **M**odelling**.**

UGM: **U**rban **G**rowth **M**odel.

UNICEF: **T**he **U**nited **N**ations **C**hildren's **F**und.

UNDP: **U**nited **N**ations **D**evelopment **P**rogram.

UNCHS: **U**nited **N**ations **C**entre for **H**uman **S**ettlements *(UN-Habitat)*.

USGS: **U**nited **S**tates **G**eological **S**urvey.

UTM: **U**niversal **T**ransverse **M**ercator.

UTPS: **U**rban **T**ransportation **P**lanning **S**ystem.

VB: **V**isual **B**asic.

VHR: **V**ery **H**igh **R**esolution

WHO: **W**orld **H**ealth **O**rganization.

WUP: **W**orld **U**rbanization **P**rospects.

X, Y, Z: **3-D** **G**round **C**oordinate.

Chapter 1

Introduction and Research Objectives

(1-1) Research problem

The world population has more than doubled in the last **50** years, from **2.535** billion in **1950** to **4.076** billion in **1975 to 6.671** billion in **2007**, and now **6** of every **7** people reside in a **low-** or **middle-income** country [(1)]. According to the **U**nited **N**ations **P**opulations **D**ivision (2002a) projections, **the world's total population will rise substantially**. The world population is expected to reach **8.27** billion in **2030**, this being a net addition of **2.2** billion persons to the **2000** population. Almost all of this growth **(about, 86%)** will occur in **L**ess **D**eveloped **C**ountries **(LDC)**, whose governments and economies are generally ill equipped to deal with it.

Now, **the cities population is nearly half of the world's total population** and over **three-quarters** of them in high-income countries. The **UNPD, 2007** estimates that about **98%** of the world population growth occurs in the cities and towns of **LDC**. The rapid population growth and its concentration in cities are changing the spatial distribution of human settlements, and show a marked increase of the percentage of people living in **urban** and **peri-urban** areas *(i.e., the world is becoming increasingly urban).*
This rapid urban phenomenon is particularly common in most **LDC** in **Africa, Asian,** and **Latin America** continents.

Africa for example, a continent where the vast majority of countries are considered ***"poor countries"*** has the highest regional population growth rate with **2.2%** compared with the total world annual average of **1.2%.** African countries will also account for **21.7%** of the expected world's future population and by year **2030** (UNPD, 2007).

By **2030** the developing countries as a whole is likely to have become more **urban** than **rural**. **These changes are not only a matter of percentages, but also of scale**. At the beginning of the twentieth century, just **(16)** cities in the world are the vast majority in industrial economies contained a million people or more. Today, almost **(400)** cities are of this size, and about three-quarters of them are found in low and middle income countries (Mark R., *et al.,* 2003).

[(1)] In this thesis, I will take as synonymous the phrases ***low-*** and ***middle-income countries, poor countries, developing countries*** *and* ***less developed countries (LDC),*** to refer to the same type of national economy, *"one that has yet to fully industrialize and where a large portion of the population continues to live in poverty"*, also the terms ***urban areas, cities,*** and ***towns*** to refer the great size of urban places.

In many developing countries cities, at least **one in four urban residents** is estimated to be living in absolute poverty. The aspects of poverty are clearly visible in all major cities: **overcrowded neighborhoods**; **pollution**, **inadequate housing**, **insufficient access to clean water**, **sanitation**, **electricity** and **other social services**.
In addition, each year cities attract considerable numbers of new migrants who, together with the increasing native population, **expand squatter settlements and shanty towns, which expand the informal urban pattern, and prevent the ability of local authorities to provide infrastructure and basic services**.

Historically, urban growth has been most rapid where economic growth rates have been highest. This is clearly the case today in **Pacific Asia**, where urbanization is accelerating and being accelerated by a newly globalized economy that is changing the face of the planet.

From the view of future distribution of urban and rural population. Figure (1-1) shows, over the next **30** years the world's cities will expect to absorb the additional billions of population. Also the total **rural population** is likely to undergo little net change over this period, decreasing by **30%** in **high-income countries** and increasing by an expected **3%** in **low-** and **middle-income countries**.

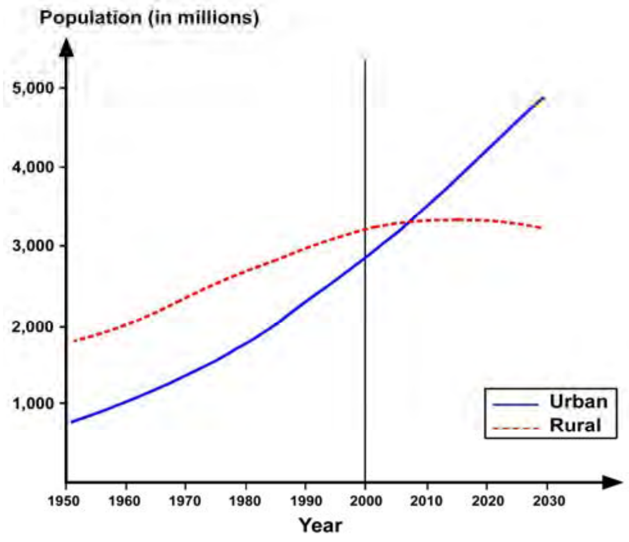

Figure (1-1) Estimated and projected urban and rural populations, world totals from 1950 to 2030
(Source: United Nations, 2002a)

Relatively small changes are also expected for the cities of **high-income countries**, whose populations will rise from **0.9** billion in **2000** to **1** billion in **2030**.
Hence, figures (1-2) and (1-3) shows that, the net additions to the world's population will be found mainly in the **cities and towns of LDC**. **The expectation for the near future stand in stark contrast to what was seen during the period 1950 to 1975, when population growth was much more evenly divided between urban and rural areas**.

The **U**nited **N**ations predicts that the total urban populations of **Africa**, **Asia**, and **Latin America** will double in size over the next **30** years, increasing from **1.9** billion in **2000** to **3.9** billion in **2030**.

These changes in totals will also be reflected in the urban percentages. In **1950** less than **20%** of the population of poor countries lived in cities and towns. By **2030**, this percentage will have risen to nearly **60%**.

Rather soon, it will no longer be possible to speak of the developing world as being mainly rural.

Significantly, more than **80%** of new settlements fall into the informal category [1] *(in other words, Popular Settlements* ***'PS'****, Informal Settlements* ***'IS'*** *and Informal Housing* ***'IH'****)*, that represents new settlements in urban areas which are essentially unplanned and do not respect formal planning regulations and markets.

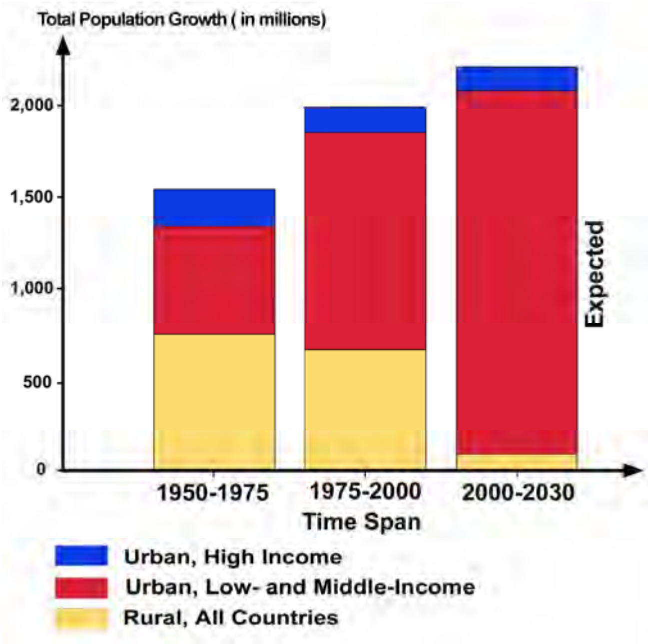

Figure (1-2) Distribution of world population growth by urban/rural and national income level projections from 1950 to 2030 (Source: United Nations, 2002a)

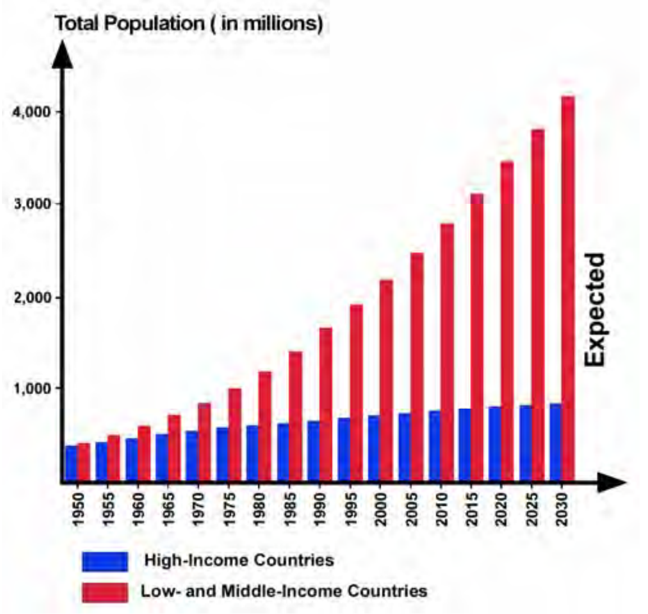

Figure (1-3) Total urban population growth by national income level from 1950 to 2030 (Source: United Nations, 2002a)

[1] In this thesis, I will use briefly the term **IS**, **PS**, **PH** and **IH** to refer to the same type of housing, that built **informally** or **illegally** and suffers from infrastructure, public services, transportation means, accessibility, high population density and high levels of overcrowding.

These population and urban growth trends will increase the expansion of informal urban pattern and will make the sustainable development of the inhabited areas more complex in **LDC** cities.

This research suggests that population growth and other factors that participate in spatial spread of the urban form will generate a predominantly self-replicating and uncontrolled growth that will increase the opportunity of informal and popular housing to expand (Kaplan *et al.*, 2004).

The reproduction of informal and popular housing represents one of the most complex and pressing challenges facing developing countries. **Because, 30-60% of urban settlements in LDC are informal, and up to 80% of new settlements are created outside the official guidelines** (UNCHS, 2003), such guidelines are themselves ill to prevent the rapid urban expansion. Also, many researches show that living conditions in **IH** are causing a direct and daily threat to the well being of the community and thus creating cities defined by **poverty** and often **violence** (Jenkins, 2001).

It is clear that, **IH** requires greater recognition and improved responses. **There is a gap in the literature on understanding the future expansion and management of IH.** In particular, the policies and available tools to predict their spatial extension, to assist the planning responses are limited. These limitations raise two important questions:

1) **Where will the ongoing influx of people in LDC cities be settled?**
2) **What are the tools that can assist urban planners to respond to the influx of people and the consequences impacts on the urban expansion?**

To begin to answer these two questions, it is important to briefly consider the processes and actors contributing to the generation of **IH** in **LDC**.

- The main factor, which affect on the informal spreading in urban spaces is the **popular housing projects, *(up to 90%)*** rather than the public sector or development agencies (UN-Habitat, 2003). [(1)] *For example, the rural incoming populations, create their own spaces, as no other housing is possible or accessible, they design their own houses as they find themselves outside the formal planning boundaries.* In doing so they ignore town planning routines,

[(1)] This article available at: http://www.unchs.org/unon/unchs/habrdd/contents.html.

layouts, and regulations this leads to massive demand for infrastructure, transportation and other social services.

- Another aspect is the **omission in public sector** from urban management practices increases the complexity of the **I**nformal **H**ousing **(IH)** situation.
- Additionally, it is clear that the ignoring from local authorities against these areas, and the failure of city authorities to provide the necessary **infrastructure** and **services** to the new urbanized areas has participated the increasing of informal dwellings.

For these reasons, the decision makers are unable to take the appropriate decision for this type of urban pattern, and provide the needs of their dwellers. As a result, cities have rapidly expanded outside the planning context, making between **30%** and **60%** of urban areas in **LDC *"informal"*** (UN-Habitat, 2003).

Current practices and strategies to respond the **IS** expansion are **ineffective**, and they **fail to curb or stop the slums generation**. Also previous and current research on **IS** in **LDC** are mostly **descriptive** and fail to develop a predictive approaches to predict the growth patterns and expansion of **IS** in order to design appropriate response and long term strategies to improve the management of fast growing cities (Abbott & Douglas, 2003).

In this way, it could be argued that, the study of rapid urban changes in **LDC** suffers from a **globalization view** and have a **Limited viewpoint** (Jenkins, 2001). Whilst this is partly due to the lack of research and implementation techniques, as well as, insufficiency of the planning and management resources have played an important part in the deterioration of the situation.

Therefore, this research adopts the exploration of new approaches or tools that can used to improve the understanding and management of informal and popular housing growth.

Particularly in Egypt, the Egyptian population has almost **tripled** between **1950** and **2006**, from about **25 MP** in 1950 to more than **73 MP** in 2006, (CAPMAS 2006); However the rate of population growth has been steadily **leveling off** during the previous **two decades**, from **2.4%** in 1976-1986 to **2.1%** in 1986-1996 and **1.9%** in 1996-2006. At the moment, most of the increase comes from the rural governorates in Lower and Upper Egypt, as well as in the Frontier governorates

Now, the Egyptians population reached to **77.7 MP** at the beginning of **2010,** this means the Egypt's **overall population density** more than 77 people per square kilometer, considering that, close to **99%** of all Egyptians lived along the banks of **Nile River** in **3.5%** of the country's total area. Thus, the **average population density** in the Nile Valley exceeded **2,200** people per square kilometer, **which represents one of the world's highest densities**. **In addition, Egyptians population expected to reach to 136.5 MP by 2050** (CAPMAS, 2008).

Based on of the above facts, the popular and informal housing was spread in all cities and towns over all the country, and the good example for informal and popular housing is **Cairo**, the capital city of **Egypt**, which is growing rapidly and where unplanned areas are the rule and planned areas the exception. where there are more than **81** slums areas spread inside and around the **G**rater **C**airo **R**egion (Madbouly, M., 2005), represents more than **65%** of the **GCR's** population lives in informal / squatter zones (GTZ, 2009), including **unlawful subdivision** of agricultural land, squatting on desert land, and other types of informal pattern. There is a clear indication of ongoing expansion of informal and popular housing in **GCR**.
In the context of **GCR**, as in many other cities in **LDC**, town planning tools are lacking, obsolete, and out of context.

GCR represents special case from all views; the view from any of the city's many minarets reveals a metropolis seething with life at every **hour** of the **day** or **night**. As the demographic, economic, political, cultural, and symbolic capital of a country that have between **70** and **80** million inhabitants, **GCR** has been tellingly described as *"an essay in entropy"* (Golia, 2004). **Also, this phrase seems to summarize the essential problems of the city's *"urban excess"*** (Denis, 1996), which includes **traffic, pollution,**

infrastructure and services that is inadequate to the needs of its nearly **20** million inhabitants (GTZ, 2009), and the increasing dominance of informal over formal residential patterns.

Despite the rapid expansion of **IH** and urban areas in **LDC's** cities, little researches have yet been done about developing a **comprehensive predictive model of future distribution and expansion of IH**. Although some studies have looked at ways in which urban dynamics in **D**eveloped **C**ountries **(DC)** can be simulated and modelled by means of modern techniques, few studies investigating and reflecting the urban dynamics in the unplanned context of **LDC** have been reported.

In this research, I need to demonstrate that, by using modern and computer technologies, new planning strategies incorporating IH could be designed, with emphasis on the factors and criteria, that produce the emergence and expansion of IH and the development of scenarios of slums future distribution.

This research tries to full the gap in both the literature and the application of urban planning tools to understand and handle the unplanned developments and the affecting factors in **GCR**. **The rapid expansion of urban areas, especially IH in GCR will become increasingly difficult to study and manage if traditional tools and methods are not replaced by new approaches**.

<u>(1-2) Research Importance</u>

As cities grow and expand, the task of managing them becomes ever more complex, therefore, many urban **problems** and **conflicts** arising from the expansion of cities outside the existing administrative and official boundaries.

By **2030**, more than **50**% of the population of **Asia** and **Africa** will be living in urban areas. [1] In the long run, no doubt, this will be good news for global development. Over the next **30** years, **the challenge will be to take full advantage of the expected urbanization and reducing the risks of negative impacts.**

Meeting this challenge will require **<u>effective planning and reliable up-to-date information</u>**, which is the basic requirement for effective urban management. **R**emotely **S**ensed **(RS)** and **G**eo-**R**eferenced data gave some promise for measuring the spatial extent of cities and certain aspects of urban change. **To date, these issues have been given inadequate attention**.

Now, the computer science strongly intervene in urban and city planning and many software and tools were developed to serve all the planning stages, such as field data collection or data updating from the ground, mapping and preparing infrastructure maps, preparing planning alternatives and scenarios, forecast the future growth, ….. etc., so there are many programs for mapping, data collection, analysis and others to predict the future.

The recent information revolution and the diversity of its techniques led to the necessity to change the management of planning techniques, and the desired change can not occur except with incorporating the modern applications and tools in all the various planning stages.

On the other hand, the need for this research stems from the need to keep up with **global development** in linking **computer science** with **urban and regional planning**, where this scheme will help to study <u>many variables</u> and <u>factors influencing that affect the future growth and urbanization</u>.

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[1] In the same context, By 2030 more than **80%** of the population of **North America**, **Europe** and **Latin America** will be living in urban areas (Sietchiping, R. 2004)

Thus, the importance of this research comes from **the importance of considering the modern technologies, especially, Geographic Information Systems (GIS) and Cellular Automata (CA) in urban and city planning**, in order to serve the effectiveness and efficiency of the planning process, <u>especially the planning for future</u>. in addition highlights the recent global trends that developed to predict and forecast the future society in **DC**, (Clarke *et al*., 1996). [(1)] So we can benefit from these experiences and experiments **to guide us to restructure these trends and procedures with the factors and variables that affect on the IH growth to make them suitable for use within our context.**

<u>(1-3) Scope and Research Objectives</u>

Most cities in **LDC** suffer from the spreading of unplanned districts, that are grow up randomly inside and outside the cities official boundaries. As a result, **Slums** or **Informal Settlement**, that are lack to services, infrastructure *(water, sewage, electricity …etc.,)* and healthy conditions, are become the dominant urban pattern in most cities in **LDC**, and exhibit complex unplanned features facing the local government.

On the other hand, until now understanding of the informal housing characteristics and behaviors are limited. This thesis will embrace the point of view that one way of gaining a better understanding of **IH processes**, **behavior** and **its growth**, however, **is to embrace modelling technologies, which use past and current IH patterns, spatial conditions, site topography, socio-economics and demographic factors that generate IH, then explore scenarios of future distribution**.

Based on the above discussion, the main objective of this research is to develop a **new predictive model** capable for simulating the future expansion and spatial distribution of **informal housing** in **LDC's** cities.

While it is recognized that, models have their limitations in fully representing the <u>complexity and contemporary nature of **IH**</u>, new technologies, particularly **computational** and **simulation techniques** offer new possibilities to develop more <u>suitable urban tools</u> that can provide new approaches into more complex geographical problems such as **IH**.

[(1)] This article available at: http://www.ncgia.ucsb.edu/conf/Santa_ef_CD_ROOM/main.html

Now, there are many recent attempts in the study of complex urban systems supported by the increase in the power of computer modelling, which offers opportunities to bring new methodology to study the **I**nformal **H**ousing.

For instance, the **C**ellular **A**utomata **(CA)** technique in combination with **G**eographical **I**nformation **S**ystems **(GIS)** has been used to analyze the urban dynamic processes in planned cities of **D**eveloped **C**ountries. These technologies were usefully applied to model future urban growth in developed country cities such as: **Marseilles** in France (Meaille & Wald, 1990), **San Francisco Bay Area** (Clarke *et al.*, 1997), **the Washington/Baltimore corridor** in USA (Clarke & Gaydos, 1998), and **Hervey Bay** in Australia.

I wish from this thesis to develop a similar approach and principle with the appropriate modifications, so it can be implemented to explore the IH dynamic process in GCR.

Because the **GIS modelling** capabilities often described as **static features**, so the integration with a **dynamic approach** such as (**CA)**, will help to build more suitable representation of **IH** which reflect the reality of the fast informal growth in **GCR**.

In particular, the goal of this integration is to achieve a real predictive model for future unplanned growth to assist urban planners and policy makers to understand the behavior and the growth directions of IH, in order to have chance to plan to reduce the unplanned growth and improve the associated economics, social, service and health issues.

To achieve the thesis objective **two main** approaches will be used.

- **First,** the **GIS** approach will use to study the **I**nformal **H**ousing historical trends, and display its possible future directions.
- **Second,** a **C**ellular **A**utomata **(CA)** technology will be used to calibrate **IH** growth factors and to simulate future development processes.

We can summarize the thesis goals as follows:

- Develop and implement a ***Growth Model*** that will contribute to the future prediction of popular and informal housing to facilitate its management strategies.

- Develop an approach and principle, similar to which developed in developed countries with the appropriate modifications, **so that it can be implemented to explore the dynamic process of IH in GCR.**

- This research will show the **dynamic visualization** of the simulation results will improve our understanding of **how** and **where** **IH** emerge and expand, and therefore provide more information for the better expectation of services, economic opportunities and infrastructure responses before the unplanned growth.

- **Finally**, application of the **suggested model** could have important social justice results by enhancing the management of complex urban forms *(such as, IH)* through the prediction of unplanned areas and their impact upon the organization of urban space in **GCR**.

In doing so, this approach would increase the opportunities to improve the living conditions of IH dwellers, and lead to expect and simulate the IH future expansion, therefore policies and strategies can be taken to curb their occurrence and expansion.

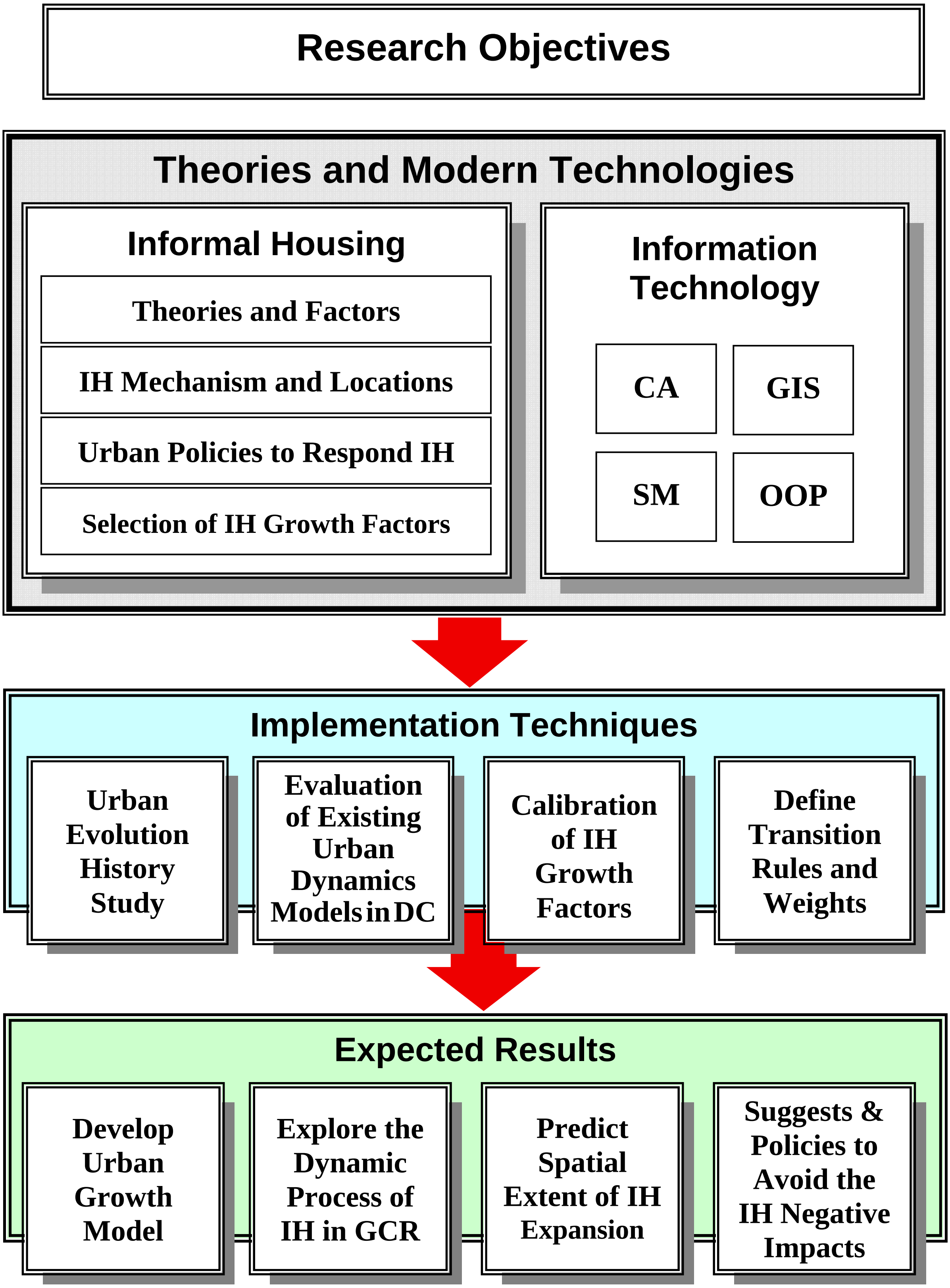

Figure (1-4) Thesis methodology

<u>(1-4) Research Approach and Questions</u>

To achieve the research objectives, this study is structured around the investigation of two research questions.

<u>First,</u> are the existing urban dynamics models suitable to simulate IH emergence and growth in the context of unplanned areas such as LDC?

<u>The following points will clarify this question:</u>

- **a)** What are the methods, techniques and resources currently available to explore urban dynamics in general and in **LDC** in particular?
- **b)** Are the existing urban dynamics models suitable to simulate the **IH** growth in **LDC's** cities?
- **c)** Which rules and criteria can be used to describe, simulate and model the **IH** growth in the context of unplanned areas in **LDC's** cities?
- **d)** How useful are the forecasting and dynamic visualization of **IH** models in raising awareness of issues inherent in **informal** rapid expansion?

<u>Second,</u> what are the potentialities of <u>GIS</u> and <u>CA</u> technologies in developing a spatial dynamic model for visualizing informal spatial expansion in the context of unplanned regions such as GCR?

<u>The following points will clarify this question:</u>

- **a)** How can historical and potential growth within unplanned areas in **GCR** be documented via computer modelling technologies?
- **b)** What are the relevant growth factors that affect the expansion of **IH**?
- **c)** What could be the contribution of the **GIS** and **CA** technologies in handling historical and predictive aspects of a proposed spatial dynamic model?

To explore these questions, GIS and CA have been selected as appropriate methods to gain a better understanding of IH through a modelling approach.

Till now, some researchers have used **qualitative** and **quantitative** approaches to describe the **IH** problems facing unplanned areas, <u>but they have not placed sufficient emphasis on the expected analysis of the phenomenon and how this could improve our understanding to response the **IH** rapid expansion</u> (UN-Habitat, 2003).

This thesis tries to develop a new approach to fulfill the current gap in the literature and in the practical capacity of policy makers and urban planners to effectively respond to the rapid expansion of **IH**.

The proposed model is an important step forward because it will show how to integrate **GIS** and **CA** to design urban dynamic model capable to predict the **spatial location** of the **expected Informal Housing growth** and **its directions** of in the context of unplanned areas.

The integration of **GIS** and **CA** enables the exploration of previous and current growth behavior, and the capacity to suggest the future distribution of **IH**.

(1-5) Thesis Hypotheses

The recruitment techniques and modern technologies associated with the revolution of communication and **I**nformation **T**echnology **(IT)**, in particular, **C**ellular **A**utomata **(CA)** and **G**eographic **I**nformation **S**ystems **(GIS)**, as a tool in the planning for future, can produce useful tools to assist the processes of prediction the future urban expansion.

Therefore, the main hypothesis of this thesis is, it can design and implement a computer program used to predict and simulate the future urban growth, especially the informal urban sector in GCR. The outputs and results from this model can use as Decision Support System (DSS) in the decision-making process to avoid the negative impacts of IH.

Since the recruitment of such systems in all phases of regional and urban planning will lead to change work from the traditional manual scheme to planning continued scheme. These tools and systems may provide us more **effective and flexible methodologies** in dealing with the affecting factors on **I**nformal **H**ousing emergence and growth, and help to understand the nature of unplanned growth, in order to develop the necessary policies to control and guide its growth directions.

(1-6) Expected Results from Research

1) **Develop a predictive dynamic model for Informal Housing growth**.

   Develop a predictive dynamic ***Growth Model*** to determine and allocate the most suited areas for popular and informal housing growth in the unplanned context, and its development over time periods. **This model use the integration of GIS and CA to simulate, visualize and modelling the unplanned sprawl in LDC, especially in GCR.**

2) **Simulate future urban growth in the city based on a set of factors and criteria**.

   Simulate the future urban development of the region, according to set of growth factors and criteria based upon their respective influence on the emergence and **IH** growth**,** such as **existing land use**, **spatial conditions**, **land cover**, **existing transportation networks**, **watercourses**, **site topography** and **demography aspects**.

3) **Predict spatial extent of future urban expansion through the year 2046.**

   Results and information learned from this research, about the **future development of urbanization** could be used as a powerful tool for decision support planning. **Particularly**, **to control and guide the unplanned sprawl, as well as the future urban development and the environmental studies.**

4) **The strategy should be followed now to avoid the negative impacts of future informal growth.**

   Through the current status of the urban pattern and the future vision for informal growth, that expected by the proposed model, we can put a lot of policies to avoid the negative effects of the expected unplanned growth, or modify the current policies to change the growth directions, and prevent the growth in some areas.

SECTION 1
NON-TECHNICAL

<u>Chapter 1:</u> Introduction

This Chapter presents the thesis overview, containing the research problem, objectives, research approach and questions, expected results through this research, thesis hypotheses, and **finally** the thesis structure.

<u>Chapter 2:</u> The Problem of Informal Housing

Discusses the location and mechanisms of **IH** dynamics, and illustrate the rapid expansion of **IH** in **GCR**, including the spatial structure of **GCR** and types of slums. Also, highlights the successive strategies and policies for **IH** management.

SECTION 2
TECHNICAL

<u>Chapter 3:</u> GIS and CA Urban Models

This Chapter reviews the concepts, theories, practices and methods with an emphasis on combining **CA** and **GIS** for urban modeling and simulation.

<u>Chapter 4:</u> Previous Dynamics Models

Presents and evaluates the existing models that used in developed countries and explore their limitations, when use it in the context of unplanned areas.

<u>Chapter 5:</u> Application of SLEUTH Model on GCR.

Presents an attempt to use an existing urban dynamics model in **GCR** case, and presents reasons why it is unsatisfactory.

SECTION 3
PRACTICAL

<u>Chapter 6:</u> A Proposed IHGM

Using the material from the **non-technical** chapters *(one and two)* and **technical chapters** *(three, four and five)*, to design and implement the proposed **IHGM** and apply it to **GCR** case.

<u>Chapter 7:</u> Model Evaluation

Discuss the proposed **IHGM** strengths and weaknesses based upon the **Reliability**, **Sensitivity**, **Efficiently**, and **Utility**. Also, the main limitations of the proposed model were discussed.

<u>Chapter 8:</u> Conclusions

Provides a brief summary of the thesis, highlights the major findings, and suggests some recommendations for further research.

Figure (1-5) Thesis structure

(1-7) Thesis Structure

This thesis consists of **three** main sections (*non-technical, technical and practical*), divided into **eight** Chapters, as follows:

- **Section One:** *(Theoretical and inductive approach)*

  This section discusses the thesis overview and the problem on the **I**nformal **H**ousing phenomena. This section contains chapters **one** and **two** as follows:

  - ***Chapter One,*** presents the thesis overview, containing the research problem, objectives, hypotheses, research approach and questions, expected results through this research, and **finally** the thesis structure.
  - ***Chapter Two,*** reviews of the **I**nformal **H**ousing characteristics including their **physical appearance, patterns, health threats**, **legality**, and **socio-economic mechanisms**, in addition to the **topographic** and **demographic** factors that produce the unplanned sprawl. As well as the various urban **policies** and **strategies** that have been undertaken to improve these areas and decrease their spatial expansion and growth in **GCR**.

- **Section Two:** *(Analytical and comparative analytical approach)*

  This section reviews the concepts, theories, practices and **IH** mechanisms, as well as, the current urban dynamics models and prediction techniques. This section contains chapters **three**, **four**, and **five** as follows:

  - ***Chapter Three,*** advocates the integration of **GIS** and **CA** techniques, and highlight the characteristics of **GIS** and **CA**, as well as their potentialities for developing comprehensive and realistic urban dynamics modelling.
  - ***Chapter Four,*** reviews the existing urban dynamics models in order to evaluate their suitability for implementation in the context of unplanned areas in **LDC**. This Chapter also highlights the **limitations of existing urban dynamics models according to some selected criteria** in dealing with the spatial patterns of rapid expansion of **IH** in the context of unplanned areas.
  - ***Chapter Five,*** describes the application of ***SLEUTH Model*** [1], which is one of the famous models designed to predict the urban growth for planned cities, to investigate its applicability and capacity in simulating the **IH** expansion of

(1) **SLEUTH** *(**S**lope, **L**and use, **E**xclusion, **U**rban, **T**ransportation, **H**ill-shading),* model and relevant materials can be obtained from http//:www.ncgia.ucsb.edu/projects/gig/

Greater **C**airo **R**egion, and demonstrates why the model is not appropriate for simulating **IH** growth in the case of **LDC** especially **GCR**.

- **Section Three:** *(Practical and experimental approach)*

This section presents the proposed model and its application on the case of **GCR**, and discusses the proposed **IHGM** strengths and weaknesses upon some evaluation techniques. This section contains Chapters **six**, **seven**, and **eight** as follows:

Chapter Six, discusses and illustrates the proposed **IHGM**, its **concepts**, **assumptions**, **rules**, **structure**, **components**, **different modules** and **functions**, as well as, the model implementation procedures including:

- **Definition module**,
- **Growth factors calibration module**,
- **Probability to change module**,
- **Prediction module**,
- **Display simulation results module**.

In addition, this chapter tests the proposed model on a real world data to achieve its capacity to simulate and predict the future **IH** expansion in selected future years. Also, this chapter presents the ***"Greater Cairo Region"*** study area, and the steps to run the proposed model.

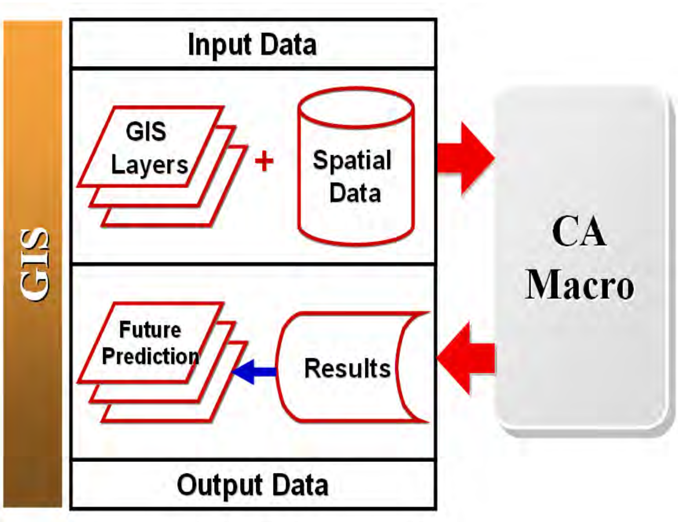

Figure (1-6) **GIS** and **CA** proposed integration

- ***Chapter Seven,*** evaluates the performance of the proposed model to measure its range of accuracy. Also, assesses the model's strengths and weaknesses based on four evaluation criteria: **the model reliability**, **sensitivity**, **efficiently**, and **utility**. In addition, the main limitations of the **IHGM** are also discussed.

- ***Chapter Eight,*** Provides a brief summary of the thesis, highlights the major findings, and suggests some recommendations for further research.

Chapter 2

Exploring Informal Urban Dynamics and Policies in GCR

(2-1) Introduction

Cairo is one of the largest cities in the African continent. When arrive by plane over the region, the observer can sense by the **city's size** and **urban density**. The vast dimensions of the urban agglomeration reach to the horizons. Also, viewing the city from outer space using **Google Earth** reveals a variety of urban patterns, indicating the huge development in many districts.

Cairo represents the principal city of Egypt; it takes this status from **its physical size** and **the number of inhabitant**. The country's **economic**, **political life** and the most of Egyptian industry are concentrated there, as well as many jobs in the secondary *(manufacturing)* and services sectors, are located in the capital. In the past, this **centralization** of jobs has led to a **massive migration of rural populations to Cairo** in search of jobs and tries to improve their economic and living situation.

According to the **2006** census, about **quarter** of Egypt's approximately **73** million inhabitants live in **GCR**, equivalent to nearly **half** the country's urban population. Although the size of the actual population is disputed, the official **2006** census puts the number at more than **16** million inhabitants (CAPMAS, 2006). But local experts, however, believe that **20** million is a more accurate figure.
Also the **2006 census** shows the informal housing areas are estimated to contain more than **62%** of the population of the region *(10 out of 16.2 millions inhabitants)*, and the rate of population growth in these areas is higher than other Egyptian cities averages *(about 2.5%)*.

Perhaps the most characteristic of Cairo's urban pattern is its alignment to the Nile River. **Satellite images show the city expanding out in every direction**, expanding in the **north** toward the **Nile Delta** and encroaching upon its rich agriculture land. Since ancient times, the Nile River has been the lifeline of Egyptian society, particularly with respect to agriculture and water supply. Since the completion of the **Aswan High Dam in 1976**, the annual flood cycle can be controlled.
By reinforcing the Nile's banks, **construction along the river became possible, thereby increasing urban sprawl and expansion on private-owned agricultural land** (GTZ, 2009).

The origin of this urban process *"informalization"* is going back to the **1960s** and **1970s** when Cairo, as well as other major Arab capitals, witnessed the emergence of outer form of urbanization. This process was led **by private actors** and developed **outside**, and **without regard** for, state building laws and regulations (GTZ, 2009), particularly those prohibiting the conversion of agricultural land into housing plots. Informality became the solution to the housing needs of the city's lower and middle classes.

In the majority of cases, this irregular urbanization has not meant land occupation or squatting on public land, but has developed around a non-official land market starting from private landholders.

The aim of this Chapter can summarized as follows:

1- Explore the informal housing mechanisms and its locations,
2- The historical development of informal housing zones in **GCR**,
3- Discuss the common characteristics of **IH** areas, from the economic, legal and demographic aspects,
4- Discuss and classify the informal housing types in **GCR**,
5- Finally, illustrate and evaluate the Egyptian government **urban policies** and **planning responses** to informal housing zones.

<u>(2-2) Informal Housing Mechanisms</u>

The definition of **I**nformal **H**ousing **(IH)** varies widely from one country to another and depends on various parameters and aspects. **I**nformal **H**ousing **(IH)**, or **I**nformal **S**ettlements **(IS)** usually described as **shantytowns**, **slums** or **squatter settlements**. Administrative and legal officials often use terms such as **illegal**, **irregular** or **unauthorized settlement**, **unplanned development**, **land invasion**, and **temporary settlement**. In contrast to planned development areas.

<u>For this study, an informal housing can be described as follows</u>:

- **Any building constructed on a parcel of land not designated for residential development**. *(i.e., agricultural land, state desert land, …. etc.,)*
- **These buildings are not following either planning or construction laws or technical codes**.
- **Consequently**, **all informal buildings have not been recognized by the government or local authorities and have not been recorded**.

So that, the term **"unplanned development"** will be interchangeably used with **I**nformal **H**ousing **(IH)** or **I**nformal **S**ettlements **(IS)**, also the term **"slum"** will be used to express the <u>poor conditions of these areas</u>. Similarly, **"squatter settlement"** will occasionally be used to refers the illegally occupy a property *(land or building)* prepared for a residential use.

In **GCR**, the informal settlement areas are occupied by the poorer section of urban dwellers, where living conditions, services and infrastructures are below the legal and official standard (UN-Habitat, 2003). **For the purpose of this thesis**, the term ***"informal housing"*** is the most suitable because it covers many aspects of this phenomenon in **GCR** from the **regional**, **legal**, **administrative**, **socio-economic**, and **physical** perspectives.

Particularly, **in Egypt**, the term ***aashwa'i*** *(meaning disordered)* is used officially to indicate **inhabitable** or **under-served** urban areas. It actually means **"random"**, implying that these areas are unplanned and illegally constructed (GTZ, 2009). The construction of these areas being <u>**informal**</u> or <u>**illegal**</u>, also they tend to be the least well served in terms of **infrastructure** and **public services**, as well as, they **suffer from transportation means**, **weakness of accessibility** and **high levels of overcrowding**.

The term ***aashwa'i*** has also become a synonym for slums in **unofficial** and **popular language**. Government officials and the national press frequently see these areas as *"black stains"* and refers to them a whole set of **social problems**, such as crime, drugs, illiteracy, and ignorance. In addition, the Egyptian popular language uses the term ***shaabi*** to describe ***popular*** or ***working-class*** districts. In addition, the term ***baladi*** is popularly used to describe areas where ***poorer inhabitants***, especially those of rural origin, are found (Sims, D.2003).

After **1992** earthquake, where large number of buildings and homes in many areas in **GCR** were destroyed and collapsed, the Egyptian government launched a program to improve ***informal*** areas throughout Egypt. In **Greater Cairo Region** a total of **81 informal areas** were identified, of which **63** were considered up-gradable *(mostly in agriculture and desert land)* and **18** smaller pockets were slated for demolition and resettlement of the inhabitants (Ministry of Local Development, 2005).

In general, there are several factors that are considered the main engine of emergence and expansion of **IH**. Such factors are related to their **location**, their **socio-economic conditions**, and their **legal status**; these items will be discussed below.

(2-3) Location of Informal Housing Areas

Informal housing can be characterized by their site and situation. Usually, they are situated in locations that are normally considered unsuitable for housing and urban development such as **steep slopes**, **areas of garbage collection**, **abandoned** or **unused land**, along **rail networks**, and **near the industrial areas**. They are also found in neglected areas such as **cemeteries** (Garr, 1996). Overall, therefore **IH** expands on marginal or any vacant lands within the existing urban areas.

Despite the variety of situations that define slums and **IH**, they share common site characteristics such as:

- **Overcrowding** *(for example in Bolaq Al-Dakrour, Shubra Al-Khaima),*
- **Insufficient infrastructure and services** *(e.g., water supply, electricity, roads, sanitation, health centers, services, and schools),* (World Bank, 2002)
- **The absence of vacant land and open spaces**,
- **Very high residential densities**,

- Informal areas suffer from **problems of accessibility** and **very narrow streets**,
- Informal areas are also spreads **near the places of worships and religious activities**.

  Recently, **the religious groups** are the second most important form that represents and reflects *(after economic factors)* newly formed **IH districts** in many **LDC** cities (Berg-Schlosser and Kirsting, 2003).

In **GCR**, the informal housing areas are mostly established on the region margin. Such housing typically occurs on privately owned agricultural land, desert state land, around the tombs of the City of the Dead, and on roof-tops, particularly **it emerge on the areas that adjacent to the historical core of Cairo**.

This knowledge of factors contributing to the location of **IH** is critical to the design of the proposed **informal housing growth model**. The understanding of the socio-economic conditions of informal housing areas can also assist in the formulation of the proposed predictive model.

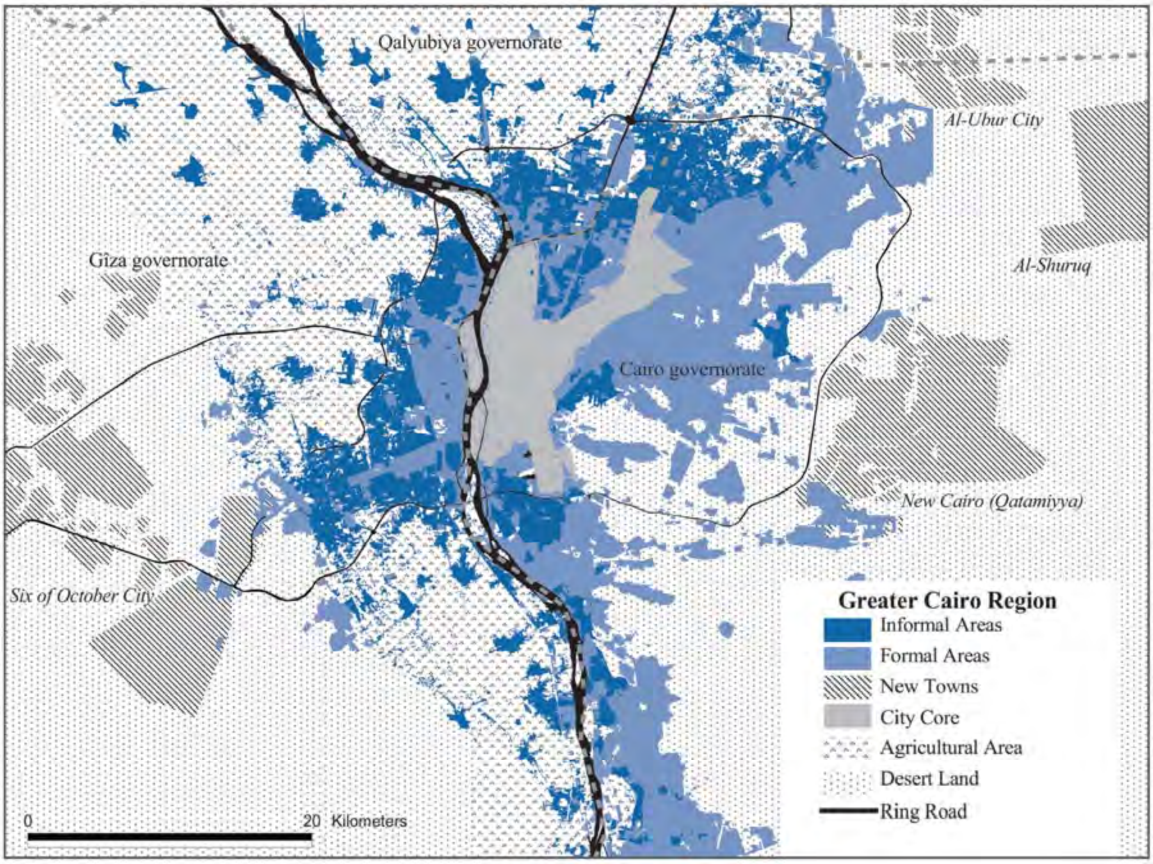

Figure (2-1) The location and geographical extent of **Informal Housing** in **GCR**

(Source: Woodrow Wilson, 2006)

(2-4) Historical Development of Informal Areas in GCR

Informal development has been, and continues to be, the dominant pattern of urbanization in many **LDC**, including Egypt. **It occurs especially on the urban boundaries**, on privately owned agricultural land, rather than in desert areas, which would be considered squatting or ***"hand claim"*** on state-owned land.

Despite **30** years of attempts by the government to limit unplanned growth and urban expansion on agricultural land around **GCR**, informal housing areas around **GCR** contained more than **7** million inhabitants in **1998**. As of 2006 census, **IH** areas are estimated to contain more than **62%** of the region population *(10 out of 16.2 millions inhabitants, CAPMAS, 2006)* and the rate of population growth in these areas is higher than other Egyptian cities averages, **increasing 2.5% between 1996 and 2006** (Sims & Séjourné, 2008).

Historically, this phenomena began just after the Second World War, when migration from **Upper Egypt** and the **Delta** caused housing pressures on the region (Sims & Séjourné, 2000), migrants attracted by economic development and the massive industrialization policy that launched after the **1952** revolution by the Egyptian government.

The earliest of these migrants, mostly young men, settled in the region central areas or historical districts, where they rented and shared flats or rooms. Later, after gathering some savings, some were able to **buy** and **build** upon land on the fringes of the villages located in the outer part of the region, such as **Al-Kit Kat** in Imbaba or **Mit Okba** in Agouza, both of which are in **Giza** governorate, where the land market was cheaper than in the central districts. This period also saw the beginning of the phenomenon of **squatting** *"hand claim"* on state-owned land, mostly in the eastern part of the region, in places such as **Monshat Naser** in **Cairo** governorate (GTZ, 2009).

The next period, between **1960 - 1970,** the informal urbanization process on the region boundaries sped up, with a huge increase of rural migration to **GCR**. The annual growth rate of **GCR** attained **4.0%** between 1960 - 1966 *(as shown in table 2-1).*

<u>This period represents the first expansion phase of informal housing, mostly on agricultural land</u> (GTZ, 2009), in the western section *(Bolaq Al-Dakrour, Waraq Al-Hader, Waraq Al-Arab, Munira)* and northern section (*Shubra Al-Khaima, Matariya)* districts of the city. <u>In spite of the good productivity of agricultural land, selling these lands for building was more profitable than the revenues from farming</u>, **this fact encouraged farmers to divide their agriculture lands and sold it to individual owners as building lots**.

Urbanization on agricultural land was the result of a **horizontal extension** of villages surrounding the region, combined with the urbanization of Cairo itself. <u>From that period, the state reinforced legislation forbidding informal construction on agricultural land.</u> Nevertheless, these **laws** and **decrees** were ineffective, while housing demand was still growing because of migration and high demographic growth in the region. As a result, some new informal districts appeared and continued to grow rapidly, *(like: Dar Al-Salaam, Zawyah Al-Harma, Imbaba, Baragil, Saft Al-Laban).*

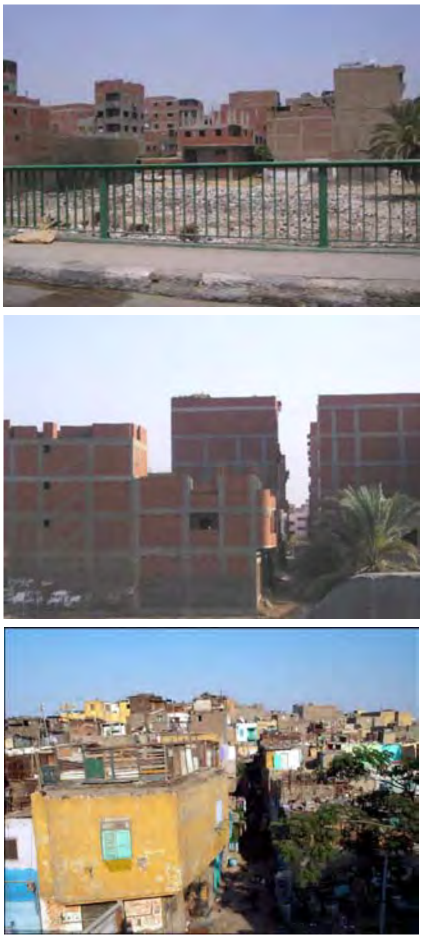

Figure (2-2) The characteristics of **IH** on agriculture areas

On the other hand, the **populist housing policy** implemented by the government *(which called public housing or masakin sha'biyya and cooperatives)* was **inadequate** to create shelter for low-income families and rural migrants.
From other viewpoint, families who could not afford an agricultural plot built a house on land owned to the state *(the processes of hand-claim)*, almost all of which was desert land, or bought a parcel from local brokers, *(like **Monshat Naser, Al-Dewika** and **Ezbit Al-Hagana**)*. Thus, informal areas on desert land continued to grow heavily.

Starting in the **1970's**, a new phase of informal urbanization began, larger than that of the previous decade. In **GCR**, **84%** of new units built during the **1970s** were considered illegal (ABT et al., 1982). As a result of savings from work in the neighboring **oil-producing countries** such as **Saudi Arabia, Iraq and Libya**, which had been suddenly enriched during the oil booms in **1973** and **1979**, as well as, many Egyptians invested in informal land and constructions supported by the economic liberalization policy (*infitah*), that started in **1974**.

In addition, the **1967** and **1973** wars were allocated all the government investments to the war effort against Israel and so public units were massively lacking, so that, the private sector capital stock, didn't meet the popular housing demand. Most of the units built were **luxurious housing** for sale, rather than for rent.
On the other hand, the **informal land** and **real estate sector** answered the demand of both **poor** and **middle class families** who could not afford shelter in the legal city. Since then, the number of informal districts has emerged, growing rapidly on private agricultural land.

In 1977, the Egyptian government introduced the New Towns policy. The goal was to solve urban problems that had become critical, particularly in GCR, and to address the housing crisis and the urbanization of agricultural land. The challenge was to relocate the demographic growth that will occurring inside, and on the rural areas around the region into public housing in the New Towns that built on the desert fringes of the region.

Beginning in the **1980s**, the growth of informal areas in **GCR** slowed down to some extent. However, **the New Towns policy** had no <u>effect at all</u> on the slowing of their growth. The main reason is the decreased emigration of Egyptian workers to oil countries due to the decreasing of oil prices in **1983-1984** (Sims & Séjourné, 2000).

On the other hand, starting in the mid-1980s the national demographic growth rates and those of big cities began to decrease *(the annual demographic growth rate of Cairo decreased from **2.9% per year** between 1976 and 1986, to **1.9% per year** between 1986 and 1996)*, and rural migration almost stopped. This had a significant impact on demographic pressure in urban informal districts (GTZ, 2009).

Figure (2-3) The characteristics of **IH** on desert areas

During the **1990s**, although no new informal zones appeared as in **1970s**, <u>the **growth of informal areas** did not really slow down</u>, in spite of coercive measures taken by the government against illegal urbanization such as the very strict **Military Decrees**, which forbid encroachment on agricultural land.

In Cairo, for example, informal areas extended considerably [(1)], becoming very dense and continuing to grow significantly. Between **1986** and **1996**, the demographic growth rate of informal areas reached **3.4%** per year compared to **0.3%** for legal areas, and informal construction growth was estimated to be **3.2%** per year, compared to **1.1%** in formal districts (GTZ, 2009).

From reviewing the **New towns policy** in the last decades, there are many reasons explaining the growth of informal areas, as follows:

- The **inadequate public housing policy** implemented by successive governments,
- The produced housing in the New Towns is still **unaffordable for poor** and **low-income families**,
- **The lack of accessibility** *(transportation means)* between the job opportunities located in **Cairo's** center and the **New Towns**. *(for more details see section 2-8)*

Overall, the informal sector has **"greatly benefited the urban poor, both in producing a massive amount of housing which offered a range of choices affordable to most if not all, and in allowing those of the poor with at least some equity to participate in the process and enjoy its rewards"** (GTZ, 2009).

[(1)] Between 1991 and 1998, **2.6** hectares were urbanized illegally all around Cairo. The share of informal build-up was then estimated to be **13000** ha or **43.5%** of the region agglomeration (Denis & Sims, 2002).

<u>(2-5) Social, Economic, Legal and Demographic Characteristics of IH</u>

The understanding of <u>informal dwellers characteristics</u> helps to understand the factors of this informal development that evolves outside the legal system and leads the expansion and growth of **IH**. Generally, **IH** represents a series of unorganized individual behavior resulting from self-help strategies without reaction by the government. Analysis of the existing **IH socio-economic** characteristics reveals that, specific **IH** dwellers have similar **socio-cultural** backgrounds (UNCHS, 1982).

The **U**nited **N**ations **C**entre for **H**uman **S**ettlements *(UN-Habitat),* 1982 survey highlighted the social profile of an **IH** dweller as being a **less educated**, **unemployed** or **low-income earner** *(working in the informal sector),* who has often **migrated from rural areas to the city for work**; and **spends over two-thirds of their annual income on food**.

There are a correlation between the emergence and expansion of **IH and urban informal economic sector**, **urban poverty, rural migration**, and the **rapid growth of population** (UN-Habitat, 2003), the following sections will demonstrate the main forces that affect the **IH** expansion, to guide in exploring the desired predictive **IH** model.

(2-5-1) Informal Economic Sector and IH

Informal housing grows in parallel with the informal economic sector. In most **LDC** cities, the informal economic sector is mostly concentrated in popular market places and small businesses in informal areas, where **labor knowledge**, **skills**, and **experience** are not required to access to the job markets, as they would be in the formal economic sector.

Rural migration to the urban areas has supported the informal economic sector, with the urban authorities sometimes turning a **"blind eye"** to the informal economy. While this situation has changed in <u>the past two decades</u> due to the **economic crisis** facing most **LDC**, <u>the informal economic sector is still one of the last options left for other social groups such as school and university graduates, and laid-off workers from the formal sector to gain employment</u> (Badshah, A., et al., 1991).

As previously stated, research shows that there is a clear correlation between the **informal economic sectors**, **employment**, **market places** and **IH**. The popular market places, where the informal economic sector is predominant, play an important role in the emergence, expansion and formation of **IH**, and should be incorporated in the urban models that predict and simulate the growth of **IH**.

Greater **C**airo **R**egion also has a large informal economy, made up of hundreds of thousands of small and micro-enterprises. The informal sector absorbs over half of the city's labor force and **informal employment is expanding at a faster rate than formal employment**.

In terms of employment, the informal economic sector account for up to **70%** of the region labor force, and contributes an average of **40%** of the region GDP (Sims, D.2003). Also, as estimated in the recent work of **L**ima's **I**nstitute for **L**iberty and **D**emocracy, informal investment in **residential real estate** in **GCR** is valued at over **36** billion US$, representing **39%** of the region's total.

On the other hand, female participation in the labor force is slightly higher in **Cairo** than the nation as a whole *(19.7% versus 15.3%)* the civil service fields have a marked concentration from female employment *(59 % of Cairo's female labor force)*, (Institute of National Planning, 1998).

(2-5-2) Legal Aspects of IH

Understanding the legal aspect of IH is also an important issue for the evaluation of strategies and policies designed to *"curb"* their expansion, as well as, in developing the proposed predictive model that might be useful to simulate the **IH** expansion and avoid their negative impacts.

Many researchers agree on the **unlawful status of IH**, as implied by the terms used to define them (UN-Habitat, 2003). Informal settlements are referred to as *illegal or irregular settlements, squatting and unlawful occupation*. The illegal status of this type of urban pattern can take one of **three** different ways, as follows:

- **In the first type,** the occupant of a given plot *(parcel or area)* does not have a legal right to occupy the land. In such a situation, the illegal status expresses the non-recognition by the law of traditional ownership or other mutual arrangements by individuals that are not considered legally valid. **Often, the occupants are not aware of the illegal status of their occupation of the plot or land that they are settled on**.

- **<u>The second type</u>** of illegality is usually known as **squatting**, which refers to the *"hand claim"* or **invasion**, this type is found in Latin America and throughout the third world. In this case the legal owner is known, but owner neglect the land without any specific purpose, this status of the land or property attracts the urban dwellers in search of housing, *(for example: Azbit El-Hagana in nasr city).*

- **<u>The third type</u>** deals with non-compliance with **land subdivision**, **building regulations**, and **infrastructure standards**. This situation is widespread in unplanned sections of the **GCR**.

There is also increasing evidence that even planned areas in some districts are slowly ignoring building regulations and standards to a point where some sections of the region are gradually transformed into <u>illegal dwellings</u>, which could gradually evolve into, and become associated with, **IH**. The degradation or the **informalization** of housing could also be the result of poor maintenance and management.

(2-5-3) Demographic Aspects of IH

UN-Habitat (2000) estimated that **three billion city dwellers** worldwide live in substandard conditions, associated with **IS**. In **2000**, the **W**orld **H**ealth **O**rganization **(WHO)** and the **U**nited **N**ations **C**hildren's **F**und **(UNCF)** surveyed **129** large cities around the world included **Cairo**, and reported that,

- **The high population growth is directly correlated to the level of IH concentration**,
- Since the **1950**, the proportion of the population living in **IH** has not shown any sign of <u>slowing down</u> in most **LDC** cities,
- The **Informal urban** housed between **32** and **85%** of the urban population. The population growth in such cities is also very high *(up to 14 % per year).*

Focusing on GCR, Cairo experienced rapid population growth in the latter part of the **20th** century, the **GCR** population is around **15.5** million inhabitants in **2006** census, which represents almost a **quarter** of Egypt’s population of **73** million inhabitants and almost **half** of the country's **urban population**. Cairo is a *"primate city"* and has maintained its urban dominance over the last few decades.

The common feature for all informal areas in **GCR** is **the high population density, among the highest in the world**. The average population density is **640 per km²**, twice the density of the old city core, and reaches **1500-2000** inhabitants **per km²** in a few areas (Woodrow Wilson, 2006).

Historically, the region population was increasing at the astonishing rate of **2.9%** per year according to **1986** census. Although results of the **2006** census indicate that this rate has slowed to **1.6%** per year, the region population grew from **10.8** million in **1986** (Ibrahim, 1985) to **15.5** million in **2006** (CAPMAS, 2006).
Although the successive censuses have recorded the increase in population, the resultant change in the extent and spatial configuration of the urban area is poorly understood.

Rural migration has been the major driving force behind urbanization in **GCR**. One of the explanations for such growth is the **urbanization level of GCR**, which was contributed to attract large numbers of **rural immigrants** in order to improve **living conditions, income level** and their **social level,** as results from the concentration of economic activities *(i.e. the employment opportunities),* **services**, and **political power**.

These rural migrants are relatively young and lacking in **skills demanded by urban labor markets**, thus often increasing the proportion of urban poor, as well as, the most rural migrants have kept their traditional way of life at their urban spaces, creating what has called **"ruralization of urban areas"** (Yousry, M and Aboul atta, T. 1998). [(1)]

GCR had grown with uncontrolled high rates, that a combination of factors now explains why **IH** are the dominant land use pattern in most districts. **Insufficient infrastructure** *(especially housing)* and **services**, **the inconsistency of urban land use management**, **inadequate planning schemes**, **the poor vision of the region planners**, **clashes of land rights**, and **economic crisis** *(e.g., structural adjustment and unemployment),* all these factors are contribute to **IH** expansion and growth.

[(1)] This article available at: http://www.unu.edu/unupress/unupbooks/uu26ue/uu26ue0d.htm

The population of informal areas in **GCR** is characterized by its youth, over **33**% of the population of the region is under **15** years of age *(versus 37.6% nationally).* The sex ratio for **GCR** is approximately the same as that of the country as a whole *(48.8 % are females).* Table (2-1) shows the historical demographic growth of **GCR**.

The demographic composition of **GCR** is markedly homogeneous. That is, there are very few minority communities and these are mostly quite small, these minority groups do not concentrate in a specific district. On the other hand, Coptic Christians, who make up roughly **10**% of the population of Cairo, are distributed in the whole region and well integrated to urban life. Currently the population of **GCR** is estimated to be growing at **1.63%** annually. However, the labor force is probably growing at over **3.0%** per year, due to the large youth column in the population pyramid now reaching working age (Sims, D.2003).

Census Years	Greater Cairo population (in millions)				GCR Annual Growth Rate (%)	% of Egypt's total population
	in Cairo Gov.	in Giza Gov.	in Kalyoubia Gov.	Total GCR		
1947	2.062	0.668	0.281	3.013	n/a	**12.5**
1960	3.358	1.118	0.434	4.910	**3.82**	**15.7**
1966	4.232	1.420	0.560	6.211	**4.00**	**17.4**
1976	5.074	2.137	0.879	8.090	**2.68**	**18.5**
1986	6.069	3.332	1.460	10.860	**2.99**	**18.2**
1996	6.789	4.273	2.081	13.144	**1.93**	**17.3**
2006	**7.740**	**5.167**	**2.538**	**15.445**	**1.63**	**21.6**

Table (2-1) The demographic growth in **G**reater **C**airo **R**egion (GCR)

(Source: Sims, D. 2003, and CAPMAS, 2006 Census)

In fact, **G**reater **C**airo **R**egion is a rare phenomenon of a **third world mega-city** where, since the **1980** net rural migration has almost stopped. The region expansion is fuelled by natural increase and the incorporation of surrounding rural populations. **This fact is clearly supported by latest census figures and various demographic studies**.

(2-6) The Spatial Structure of GCR

The evolution of Cairo and its urban structure has long been the subject of academic research. This section focuses on the spatial structure of the **GCR** and its surrounding rural area. Ibrahim, S. (1985) identifies **three main periods** in Cairo's evolution up to the **1980s**:

- Pre-nineteenth century, *(Islamic Cairo)*
- The period between 1850 and 1950, *(European Cairo)*
- The urban development after 1952 revolution, *(contemporary Cairo)*

Prior to the 19th century, Cairo's **Islamic core** was the major urban entity. Although there had been considerable construction and redevelopment in the centuries after the city's founding in **969 AD**, much of this development took place in a very small area, because the city walls originally constrained growth. Cairo had expanded outside its walls by the end of this period, but only reached a size of approximately **5 km²** (Ibrahim, 1985).

Most of Cairo was constructed between 1850 and 1950. During this time, the new **"European"** central business was built some distance from the Islamic core, along the east bank of the river Nile. European influenced residential quarters including **Garden City** and **Zamalek** were also constructed near the city centre as well as the outlying upper-class suburbs of **Heliopolis** and **Maadi**. Bridges were built across Nile River, setting the stage for expansion to the west of the Nile after the **1952** revolution. At the end of this phase, the built-up area of Cairo had grown to about **100 km²**.

In the decades following independence, Cairo experienced explosive population growth, the city which had a population of **374** thousand in **1882** grew to over **2 MP** in **1960**, and By the **1980s**, Cairo had become a **mega-city** with a population of approximately **8 MP** (Dona J. Stewart, et., 2003).

In this period, new districts, such as **Nasr City**, were constructed in the **north** and **north-east** to accommodate population growth. The city expanded to **south**, reaching to the **Helwan** industrial complex. As well as, a dramatic western expansion is noted as **Giza** grew rapidly along roads such as the **Pyramids Road**. New residential districts to the west of the city, including **Mohandissin**, further contributed to the western expansion.

By the **1980s**, Cairo had expanded into **three** governorates *(similar to counties)*, **Cairo**, **Giza** and **Qalubyia**. The **G**reater **C**airo **R**egion (**GCR)** stretched approximately <u>**70 km**</u> north to south and <u>**60 km**</u> east to west (Sims, D. 2003).

In **1985** the urban area of Cairo was estimated roughly **350 km²** (Ibrahim, 1985).

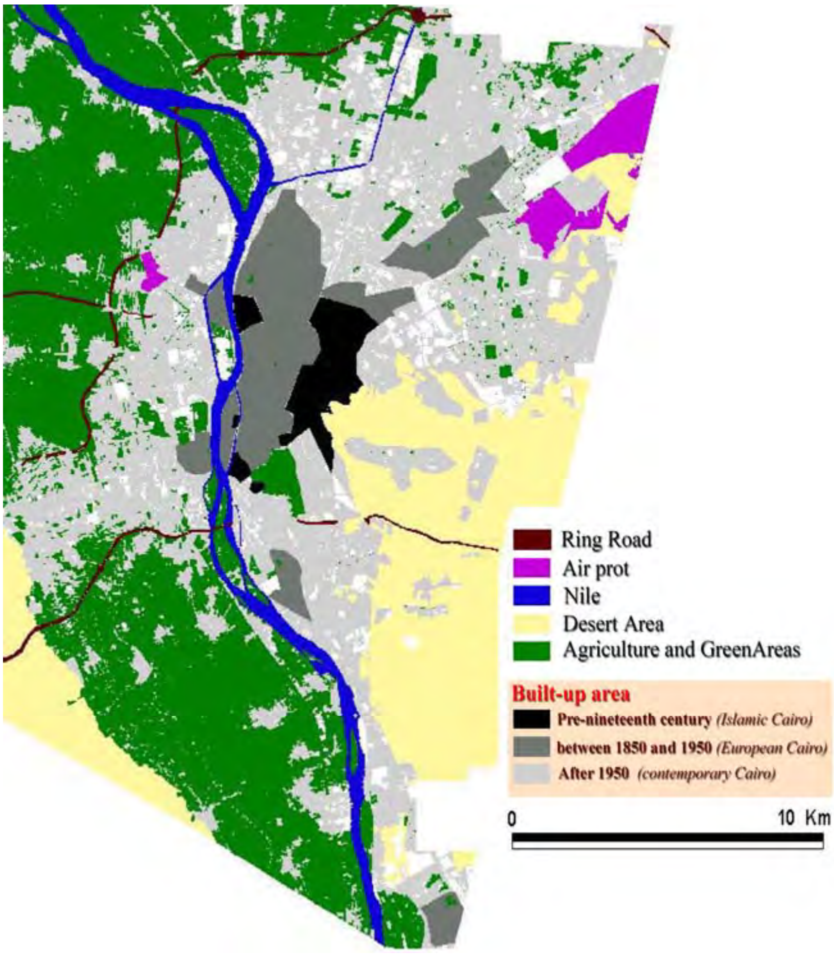

Figure (2-4) The expansion of **GCR** built-up area
(Source: Sims, D. 2003)

Despite the spatial expansion of the city in **post-revolution decades**, increases in the city's population have kept population density high; analysis in this research calculated population density for the entire urban agglomeration at **7159 persons/km²** in 1986 and more than **1000 persons/km²** in 1996.

Finally, in mid-April **2008**, the **G**reater **C**airo **R**egion was reorganized into **five governorates** with the creation of <u>two new governorates</u>. The region now contains a total population of **17.6 MP** (UN-HABITAT, 2008). The **GCR** new administrative division can be illustrated as follows:

1) The redefined **Cairo governorate**, on the **east** bank of the Nile, is limited to the area within the ring road with a total population of **6.6 MP**. To the **south** and **east** of the ring road,

2) A new jurisdiction has been created, **Helwan governorate**, with a population of **1.7 MP**.

3) To the **northeast**, the new town of Al-Obour has been integrated into **Qaliubiya governorate**, with an urbanized area of **3.5 MP**.

4) On the **west** bank of the Nile, **Giza governorate** has been reduced to the area within the ring road with a population of **3.15 MP**.

5) A new jurisdiction has been created, **October governorate**, with a population of **2.6 MP** includes all of the area **north** and **west** of the ring road.

This re-organization integrates the New Towns, that managed by special authorities under the supervision of the **M**inistry of **H**ousing, **U**tilities and **U**rban **D**evelopment, in the local administration framework.
Whether this reform will make the mega-city more manageable is debatable.

On the one hand, redistricting will divide the urbanized area into less spatially and socio-economically heterogeneous districts; from other viewpoint, **it may reduce cooperation and coordination in the delivery of services**. Urban and transportation planning will remain centralized.

Again, according to the previous discussion GCR is still in continuous growth, the current official policies to control such growth were unable to constrain the expansion in the private agricultural land and in government-owned desert land around the city.

(2-7) Types of Slums in GCR

The following section will present a short description of the **four** main types of slums found in **Greater Cairo Region** (Sims, D. 2003). The location and geographical extent of these types are presented in Figure (2-5).

In **GCR**, urban poverty is not concentrated in particular district, but it spreads along the whole region, except for a few small and marginal urban pockets.

Poor and ultra poor families are found mixed in with lower and middle income families in a wide number of older core districts and in the vast informal areas of **Greater Cairo Region**.

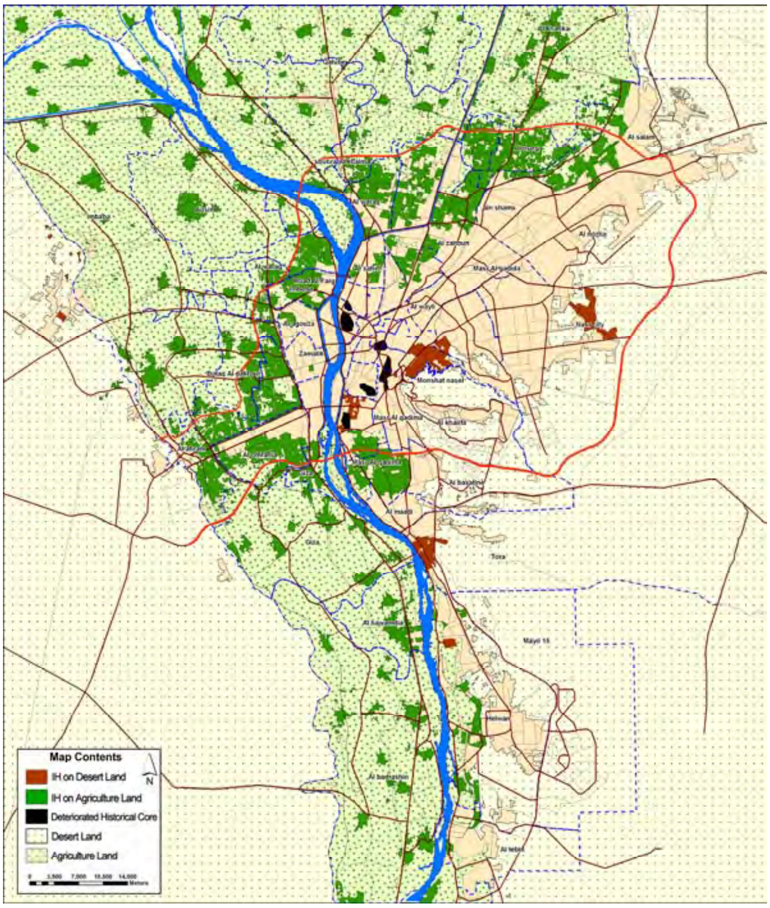

Figure (2-5) The spatial distribution of slums in **GCR**

A small percentage of poor families may also be found in older upper class districts. Conversely, in most informal areas a small percentage of well-off entrepreneurs and professionals will be found. This mix of income groups or *"income heterogeneity"* in geographical space is due to a number of **historical factors**, including:

- **The lack of residential mobility due to rent control**,
- **Imperfect real estate markets** (Sims, D. 2003),
- **The IH dwellers prefer housing near to their workplace**,
- **The IH dwellers often resort to join of more than one job in one place**, **in order to improve their income level**,
- **The living cost in IH districts is cheap compared with other districts**.

(2-7-1) Informal Housing on Agricultural Land

This class is defined as **private residential buildings** constructed on agricultural land purchased from farmers in areas where there were no subdivision plans and no building permits were taken. **<u>This type of informal housing contains over half the population of Greater Cairo Region and almost half the total residential area</u>.** So, it can hardly be considered a marginal phenomenon (Sims, D. 2003).

The phenomenon has its roots in the **1960s**, when small cultivated areas on the fringes of **"formal"** Cairo boundary began to be subdivided into smaller plots of **<u>60 to 120 m²</u>** by **farmers**, **land dealers** and **middleman** and **sold to individual owners as building lots**. This process accelerated dramatically after the Egyptian government moved to the open door ***(infitah)*** policy. This phenomenon was supported by increasing flows of remittances from the hundreds of thousands of Egyptians working in the Gulf, and other oil economies.

The process of **transfer and dividing agriculture lands to small land lots** and sold it as building lots *(or parcels)*, and the **construction of new residential buildings** on this divided lots **was totally <u>ignored by the real state local authorities</u>. This process was done without** <u>any legal paper work</u> or <u>legal permit</u>, **this process was completely informal**.

In these cases, the **'illegality'** does not stem from ownership rights, but from the illegal conversion of previous agricultural land into building plots *(for residential use)*, as well as from the ignoring of existing regulations concerning the <u>sizes of the divided lots</u> and the <u>standards of construction</u> (GTZ, 2009).

The government and local authorities was totally absent during the formative stages, in the form of **permits**, **fees**, **taxes**, and **services** (Sims, D. 2003). While these areas were spreads increasingly, the government began to look upon the phenomenon with disfavor, **especially because of the amount of agricultural land that was being eaten up by urban expansion.**

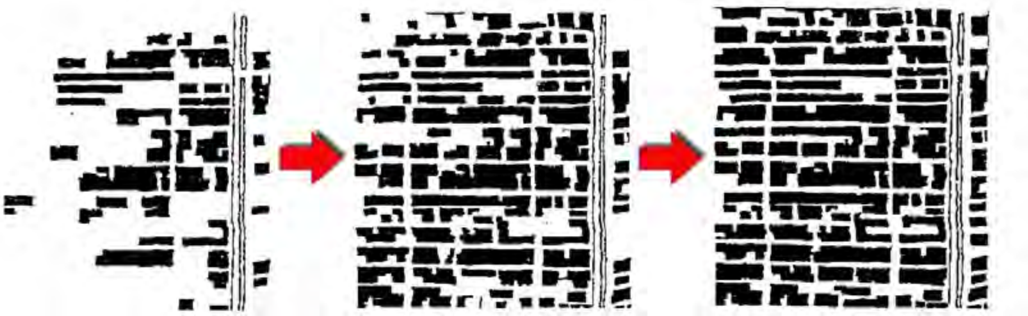

Figure (2-6) The evolution stages of **IH** expansion on agriculture lands

Starting in **1978** a series of laws and regulations was taken to avoid the increasingly illegal **IH** growth on agricultural land. The latest was promulgated in **1996** and made such building a criminal offence to be handled under military law (Woodrow wilson, 2006). (1)

From the view of urban pattern, the layouts of these informal areas are always restricted by the **agricultural domain and irrigation patterns**, with canals and drains becoming the only main streets, as shown in Figure (6-2). The patterns of these areas have the following characteristics:

(1) This article available at: http://www.wilsoncenter.org/cusp

- **Local streets are straight and very narrow** *(usually 2-4 meters)*, the minimum required to allow access,
- There are normally no **public open spaces** or areas for any type of services,
- **Plots tend to be small**, ranging from **60** to **140 m²** with **100 m²** being average,
- Frontages are usually **7** to **10** meters,
- There is **hundred percent plot coverage** except for small air or light shafts,
- Buildings are mainly of **reinforced concrete** frame and floor slab construction with red brick infill walls,
- Buildings may be **four** or **five** stories high, and are normally devised for future incremental construction,
- In some fringe areas a relatively new phenomenon is appearing of **taller buildings** *(up to 10 and 14 floors)* with larger footprints which are built for sale,

(2-7-2) Informal Housing on Desert Land

This class can define as **private residential buildings** constructed on vacant state land by citizens under the process of **"hand claim"**. This type is similar to the squatting and invasions process, which found in Latin America and throughout the third world (Woodrow wilson, 2006) [(1)], in all informal areas on desert land in **GCR**, the land was marginal desert without any specific purpose.

In **GCR**, the history of the phenomenon is particular to each location, which spreads out from an initial *"authorized"* nucleus. For example, **Monshat Naser** began as a site for relocated slum dwellers and garbage collectors, the first dwellers would claim a plot of **200** to **300 m²**, and build on **100 m²**, and dispose of the rest. In **Monshat Naser** case, rural migrants gathered with their families on these houses, and they began to build their own slums in the surrounding available land without permission or authorized official. The second example, **Ezbit El-Hagana** began as a small village for the families of coast guard soldiers stationed nearby (Sims, D. 2003).

In each case, the core area subsequently expanded due to **illegal squatting** and the **occupation** of the surrounding vacant land. In general, the core settlers were allowed to **take hold** on surrounding land through the process of **"hand claim"**.

[(1)] This article available at: http://www.wilsoncenter.org/cusp

Figure (2-7) The evolution and expansion of **IH** on desert lands

and slowly expanding their settlement, usually large plots on the fringes of the established core were walled, and then **sub-parcels** would be sold by these pioneers to new settlers, the rate of growth of these communities varied greatly, **with neglect of the government and local authorities towards its own property**.

Although land and housing markets eventually emerged in the 1980s. In other settlements, speculation was present at the very beginning and large portions of public land were seized, subdivided, and sold off in plots for construction (Tekce et al. 1994).

As in the previous type, the development process was completely informal, with no legal subdivisions, no legal ownership and no legal paper work. However, settlers have certain rights arising from the interpretation of the **Civil Code** of the service and squatters on land owned by the State for housing or residential. Also, settlers gather either the receipts from paying **“awayyid”** *(property tax)*, from **electrical and water connections**, and any other **legal instruments** to gain legitimacy as possible.

These **IH** areas have a set of features, such as:

- **Winding and narrow streets**, *(also it called popularly harah)*, and different levels along the streets, so **it looks like ramps**,
- **Different levels of the houses entrances and heights**, to be compatible with the topography of these areas, so it looks like gradient terraces,
- Many buildings of this informal housing type exposed to the dangers of earthquakes and mountain faults *(especially, Al-Mokattam Mountain)*.

In this type of **IH**, the housing conditions are in general worse than those are found in the agriculture type. There are higher incidences of **destroyed structures** and of **whole families living on one room**.

(2-7-3) Deteriorated Historic Core

In the historic city, that is Cairo before the expansions, which began after **1860**, are found neighborhoods with a high percentage of **old**, **crowded**, and **deteriorated** structures within the medieval urban fabric.

Examples include: **Darb Al-Ahmar** and **Al-Gamalia** *(especially the eastern sections along the Fatimya walls)*, and parts of **Masr Al-Qadima, Boulaq Abou Aala, Al-Khalifa**, ...etc,.

Also included many historic *“villages”* such as: **El-Fostat**, **Qait-Bey** and **Al-Tonse** which serve the vast historical cemetery areas, and large number of ancient homes such as: **Beshtak palace**, **El-Kredlyah**, **Al-Sadat home** ...etc,.

Figure (2-8) Examples of deteriorated historical areas

The deteriorated state of the buildings found in these areas, is due to severe outstanding maintenance resulting from **confused ownership** or **maintenance neglect** in the wake of rent control.

In addition, <u>many of the families inhabiting this type are quite poor.</u> However, it is extremely difficult to classify the whole areas where this phenomenon is found as distinct slums, since there are also mixed into the area newer and quite sound buildings. **Also, the populations of these historic areas are rented these areas as residential space, but they convert it to commercial and workshop use, so the buildings identity are completely collapse**.

(2-7-4) Deteriorated Urban Pockets

Deteriorated urban pockets mostly found in various inner-city areas of Cairo, especially those developed around the beginning of the 20th century and consisting of small pockets of very destroyed **one-to three-storey structures**, which accommodate poor families. Examples include areas around **Masr Al-Qadima, Hekr Al-Sakakini** in **Al-Wayli**, and **Teraa El-Towfiqia in Al-Mataria** (GTZ, 2009).

In every case, the existence of these pockets is due to precarious land tenure situations, which put in doubt the wisdom of serious housing investments, resulting in a very precarious type of housing, which in turn attracted **very poor families seeking the cheapest possible housing solutions**.

Although there are no overall studies of these areas, they represent an insignificant portion of the region population, probably not exceeding **1%** of the total (Sims, D. 2003). Most are slated for removal, and some have already been converted to parks *(with the inhabitants relocated in public housing estates).*

(2-8) Past and Current Informal Housing Policies: Limitations and New Directions

The review of past and current **urban policies** and **practices concerned with IH** reveals that they are ineffective in reducing the expansion of **IH**. As illustrated above, one of the key generators of **IH** is **non-availability and inaccessibility of planned urban lands**. Moreover, previous urban strategies did not create positive cooperation between all the actors in urban planning and housing markets.

This section discusses the motivations to consider a predictive approach towards the emergence of new **IH** areas.

(2-8-1) Past and Current Informal Housing Policies

This section will present the various urban policies and strategies that have constantly been undertaken to improve and decrease the socio-economic, physical, and political impacts of **IH in GCR**. The assessment of policies and planning strategies implemented in relation to **IH** will support the assumptions and rules of the proposed **IHGM**, which suggested from this thesis. It is important to have an understanding of the risks and achievements of the past policies that will inform future strategies.

Greater **C**airo **R**egion **M**aster **S**cheme in **1970** recommended that, the population growth must be diverted from **Cairo region** away from rich agricultural land **"green land"** to government built New Towns on desert land (Sutton and Fahmi, 2001). In addition, the development of the first **ring road** around the region was assist further in containing Cairo's growth by providing easy travel to the New Towns.

The Egyptian government adopted two concepts, which considered the bases for the GCR Master Plan in 1970:

- **a)** The **"Optimum Bulk and Containment"** concepts to make a barrier to uncontrolled urban expansion and **IH** growth,
- **b)** **"Self Sufficiency and New Urban Communities"** concepts to meet population growth and to encourage migration from rural areas and existing cities toward the new urban communities.

These two concepts were implementing some general policies, as follows:

First: **policies to curb the rapid expansion and growth of IH and directing the population growth outside the region**, such as:

- Protecting agricultural lands,
- Balancing the selection of industrial sites,
- Improving the transport and communication networks, using existing utilities as much as possible and construct the first **GCR ring road**,
- Protecting of the historical heritage. *(Islamic core)*

Second: **policies to improve the living conditions**, such as:

- Minimizing the urban growth attached to the existing urban areas of **GCR**,
- **Providing the proper housing for the low and medium income families**, *(such as: Mubark Housing projects and cooperative housing)*
- **Reorganizing the urban structure**, providing the houses with infrastructure especially for squatters, upgrading old housing areas and existing slums,
- **Relocation of polluting industries** to planned industrial zones along the outer **ring road** and beyond the urbanized zone, and the reuse of vacated industrial sites as workshop zones for craftsmen,
- the **delineation** of physically and environmentally deteriorated areas and informal housing areas,
- Protecting water resources and controlling air pollution.

On the other hand, The Structural Plan of GCR 1983 adopted an urban strategy to control and reduce big urban areas, and to improve their characteristics. This strategy depended on **four** main concepts; mainly:

1) The **"Urban Region"** to act as an integrated whole and to provide structural organization on the regional level that help to provide proper living conditions and to provide the region with the required services on all levels.

2) **"Axes of Development"** were designed to make a relation between the cities, and the new urban communities. These axes were supposed to link the urban area of **GCR** with other economic regions, thus helping to build new integrated settlements.

3) **The "New Settlements" to organize the population growth out of the existing urban areas**, to stop informal growth, and to meet the population growth of

existing cities. The structural plan had suggested **10** settlements; each of them has an area of **1,400** feddan and about **250,000** inhabitants. These settlements lay in the **east side** of **GCR** except for **No. 6** and **No. 7**.

4) The **"Homogeneous Sectors"** to put in order the existing urban areas and to attain a balance between inhabitants, job opportunities, and services to obtain **self-sufficiency**. Accordingly, the **GCR** was divided into **16** sectors, called the homogeneous sectors.

These New Towns were expected to absorb half the projected population growth between **1998** and **2017** (GOPP, 1998), but their distance from the core town, their lack of services, transportation means and economic opportunities, as well as, **the land price in the New Towns is very high compared with the agriculture land**, these factors made them unattractive **to low-income families**.

According to the previous census, the residents of all New Towns in **1996** reached to **149,000**, and reached approximately **600,000** in **2006**, an increase of **14.9 %**. This figure, about **3.7%** of the population of **GCR**, is well below the government's expectations. Hence, the Attempts to direct population growth to desert locations and the **"decentralization to the desert"** plans failed to attract **significant resident populations** and **slow the growth of Cairo** (GTZ, 2009).

In **1993** the Egyptian government created a **N**ational **F**und for **U**rban **U**pgrading. This fund, however, focused mainly on big infrastructural projects such as **roads** and **bridges**, which often **bypassed informal areas** to the advantage of richer neighborhoods (Madbouly, 1998). Moreover, the government, in an attempt to attract new financing for urban development, has tried to involve other international cooperation actors in the upgrading effort.

The failure of the **Egyptian government's housing policy** to provide affordable, viable housing for a significant number of families has led many to build homes either **semi-legally** or **illegally** on **privately-owned** or **public lands**. These contributes to spread the informal housing areas in **GCR**, that contains approximately **70%** of the inhabitants of the region, Despite the conceptualization and implementation of the previous policies, **IH have kept expanding spatially,** and urban planners are confused and ill-informed of the past, current and possible extent of **IH**.

(2-8-2) Lessons from Slum Policies: the Way Forward

So far, the implementation of all the approaches discussed has proven ineffective in addressing the growing problem of **IH**. Rather, the conception and implementation of slum and urban policies have largely supported the informalization of the urban pattern in **GCR**. As well as, the **informal housing** policies and strategies have been concerned with a *"quick fix-syndrome"* (GTZ, 2009).

<u>The review of the previous and current policies has shown the following facts:</u>

1) The previous policies and strategies addressing the housing needs of urban dwellers in **GCR** have been designed to <u>fit specific urban groups</u>, neglecting other social entities. <u>For instance</u>, the review of housing policies highlights the fact that the implementation of each of these strategies has largely benefited **middle** and **high-income** urban section of the society, not the **low-income** city dwellers as intended.

   Concomitantly, **low-income dwellers** had little or no option than other creating their own space, known as **IH**. <u>When the government interest was turned on the **IH**, the response was **too little** and **too late** to effectively curb its irregular trend.</u>

2) <u>The improvement in the environmental conditions of the slums</u> initially directed towards **low-income** groups, has ultimately been **taken advantage of by higher income groups**, and the initial target groups have been shifted away from schemes such as the **upgraded programs** that have been developed for **low-income** people were progressively invaded by **middle** and **high-income** urban dwellers. <u>The **low-income** section of the population was thus pushed out of upgraded planned areas</u> (GTZ, 2009). Consequently, an increasing number of urban dwellers are now living in **IH**.

3) Additionally, **informal housing policies** have been implemented with specific and often unrelated objectives, rather than using a more comprehensive approach towards the urban systems.

4) **Sectorial urban policies**, which so far address specific social urban groups, rather than considering the common needs of all urban dwellers *(low, middle and high)*, can only increase the crisis of urban land in **GCR**.

5) The previous **IH** policies have addressed specific physical components such as **housing**, **infrastructure** and **services** of the urban system, while other components *(for example land issue and income variation)*, have remained unchanged, or become obsolete.

For instance, the **upgrading approach** dealt with **infrastructure and services**, but housing conditions continued to neglect and new **IH** were generated in other parts of the region. These outcomes were a result of the weakness of the urban and slum strategies that did not consider factors such as **land availability**, **accessibility** and **legality**.

6) Previous and current policies have not yet suggested the necessary changes to legal and regulatory land frameworks, *such as **land markets**, **registry**, **land valuation** and **legal means*** that could have facilitated land acquisition for all urban dwellers. These changes could have helped capitalize and increase land value. Instead, **planned urban land** is very **limited**, **expensive**, and **the access procedure is too cumbersome** for **low-income** urban dwellers.

Therefore, two urban property market systems *(formal and informal)*; in spite of this **the informal sector driving the urbanization process**. There is a need to make property rights available for both market systems.

7) A major reason why local administrations in **GCR** have not coped successfully with **IH** growth that is because **they do not know what is going on in their local land markets**. The information base in many districts lacks accurate, current data and land conversion patterns, number of housing units *(informal and formal)* built during the last year, infrastructure deployment patterns, subdivision patterns, and so forth. Often, districts maps are **10** or **20** years old and lack descriptions of the new sections, particularly the new peri-urban areas.

8) **Eventually, current urban policies and strategies generate land shortages in the formal sector**, this means that, the **IH** will increase creating:

- **The environment for insecurity of land possession and illegality,**
- **Non-serviced housings,**
- **Decreasing land value of IH urban,**
- **The dark cycle of poverty.**

There is an urgent need, therefore, to develop a more comprehensive approach that addresses the urban housing crisis, not only in unplanned areas, but also in the broader context of the urban system. [1]

One of the most effective ways to address the informal housing crisis that affects the majority of urban dwellers in GCR is to develop tools that help represent the real picture of the spatial behavior of unplanned developments (Brennan, 1993). Such tools would assist the development of a long-term strategic planning for IH management.

It is also anticipated that such dynamic modelling of **IH** growth could make **urban authorities** more aware of the issues surrounding the spread of **IH**. With this increased awareness, **decision-makers** would be more willing to confront problems facing the urbanization process in general and the **informalization** of urban areas in particular.

[1] The **UN-Habitat (2000)** initiated the **G**lobal **S**trategy for **S**helter **(GSS)** in an attempt to bring all the components of the urban system together, so that they would be considered in future urban housing strategies. The strategy also aimed to synchronize the need and demand for urban properties across socio-economic groups

(2-9) Conclusions

This Chapter has described the informal housing phenomena through their **physical appearance, patterns, environmental** and **health threats**, **legality**, and **socio-economic mechanisms**.

It has been shown that there are many influenced factors have contributed to the emergence and expansion of **IH** in **GCR**. These factors include not only the following:

- **Population growth** *(associated with rural-urban migration),*
- **Accessibility and availability of transportation means**,
- **Availability of employment and jobs**,
- **Availability of land and the status of Land use**,
- **Poverty**,
- **Topography**,
- **Weakness of urban planning policies**,
- **Corruption, poor governance, and instabilities**.

The *informalization* of urban areas in **GCR** continued despite the attempts, which have been taken to curb the **IH** expansion. The successive policies have done little to find the right way to address the insufficiency of shelter and contain their expansion.

The temporal evaluation of these strategies has shown some variations, but it has been demonstrated that these measures perform poorly in reducing the spread of **IH**.

> The critical weakness of these policies is that, it suffers from the global view to incorporate all factors and conditions, that are produce the emergence and growth of **IH**. Moreover, all the major approaches towards **IH** are focus on **short-term** and *"quick-fix"* measures rather than the declaration of a **long-term** vision for the prospects of **IH**.

On the other hand, the urban authorities do not always have the means to estimate the social and spatial extent of **IH**. One of the reasons is the lack of suitable land management tools *(means)* and mechanisms.

Developing a predictive model represents a strategy to address **the weakness of urban land use management**. It is clear that, the proposed **Informal Housing Growth Model (IHGM)** would not intend to address other issues raised in this Chapter concerning why responses to the expansion of **IH** have failed, **such as** the lack of political will, corruption, poor governance, social disorder, legal and policy obstacles and funding issues.

However, an **Informal Housing Growth Model (IHGM)** could provide critical information to a range of key stakeholders for improved understanding and response to these complex urban dynamics processes in **GCR**.

The scope of **IH** could be supported from historical trends in order to inform future perspectives, such as forecasts of spatial expansion. This thesis suggest to formulate a model that will show historical growth patterns in the region and develop scenarios of future **IH** distribution, and hence aid the evaluation of the suited areas for unplanned expansion.

The proposed **IH growth model (IHGM)** will also consider contributing factors in the emergence and growth of **IH**. Importantly, it will take into account the **demographic factors** along with **physical**, **transportation networks**, **existing urban**, **and IH patterns**, as well as **IH dwellers income** and **employment** and **general topography** components.

Compared to other approaches, the modelling and simulation technique will result in better-informed policies and facilitate the decision support process. **The main challenge is how to design and implement a predictive model of IH growth? Can the dynamic representation and modelling of IH be achieved within GIS technology, in parallel with another technique, or through an integration framework incorporating both spatial techniques with simulation and modelling techniques?**

The next section will evaluate how the **spatial techniques such as GIS** can be used in combination with modelling and simulation techniques such as **cellular automata (CA)** to investigate the dynamic behavior of **IH**.

Chapter 3

A Conceptual Framework to Build Real Urban Dynamics: GIS and Cellular Automata (CA) Based Models

(3-1) Introduction

Urban simulation models aim to **seek to represent urban change and growth patterns of the city over time and space**. Many studies made clear that, although the traditional large-scale urban simulation approaches were based on solid theories, they had significant weaknesses such as:

- Poor handling of space time urban dynamics,
- These approaches were based on static theories and were impractical,
- Their representation of data was too generalized,
- Their **"top-down"** approach failed to produce realistic simulations of urban systems (Batty & Xie; 1997).

Urban dynamics modelling has gradually moved from theories based on static centralized approaches to hybrid-integrated systems. **Now**, **urban models are more sophisticated to convoy the complexity of urban system, which arises from urbanization factors, urban processes, forms**, and **systems**.

Indeed, the variety of factors that affect urban dynamics is now viewed as enriching the development of modelling approaches, and thus improving our understanding of urban changes.

Current urban simulation approaches are taking advantage of progress in information technology, **data availability and complex theories** *(such as: **A**rtificial **I**ntelligence, **S**imulation **M**odels, **R**emote **S**ensing, **C**ellular **A**utomata, and **GIS**),* with aim to address the criticisms raised for previous urban dynamics modelling attempts. To achieve a realistic urban models **"real world"** data *(such as: existing spatial and physical urban patterns)* must be integrated and mapped in comprehensive modelling scenario.

Geographic **I**nformation **S**ystems **(GIS)** have emerged as a prime framework to manipulate, store, retrieve and management large quantities of spatial **real world** data. Efforts to use **GIS** as a modelling tool have been received with doubts, especially because **GIS has limited modelling functionalities**, **and poorly handles the time factor in urban dynamic process**.

Cellular **A**utomata **(CA)** that were developed in the **1940s** to explore complex behavior and systems, is now progressively **adapted** and **adjusted** to address some modelling weaknesses that are found in the current **GIS** technologies. Recent studies are widely use **CA** approach in order to enhance urban dynamics modelling, especially when this approach integrated with **GIS** technologies (Torrens, 2002).

Many studies and researches have been used GIS and CA in combination to explore, **study**, **understand**, **and inform urban dynamics, with valuable results**.

<u>Chapter Two</u> argued that the **IH growth** represents one of the major spatial urbanization problems in **GCR**. Previous policies and strategies that were taken to curb their expansion were largely inefficient. We aim to use the modern modelling and simulation techniques to improve our understanding about **IH** process and growth in **unplanned** contexts, especially **GCR**.

The main hypothesis for this research is based on the understanding of factors, behavior, processes and theories underpinning the emergence and growth of IH can help to develop a predictive dynamic model that would assist IH policies and planning responses in cities that face uncontrolled IH growth.

Although **GIS** and **CA** have been applied in different fields of study, this Chapter will focus on the **theoretical** and **conceptual framework** of these technologies, because the integration between **GIS** and **CA** could produce a new vision of urban dynamics models that could assist and support the **IH** policies in the context of unplanned areas.

The purpose of this Chapter is to present the modelling and simulation capabilities of **G**eographic **I**nformation **S**ystems **(GIS)** and **C**ellular **A**utomata **(CA)**, as well as their integration in urban dynamics modelling. In particular, the main goal of this Chapter is to demonstrate new concepts and techniques to achieve better simulation and urban dynamics modelling.

So that, the proposed Informal Housing Growth Model (IHGM) can design and implement on the bases of the current GIS and CA technologies.

This Chapter will organize in the following sections:

- **Section one**: This section summarizes the conceptual and theoretical framework of urban dynamics modelling. In addition, it traces the origin and formulation of spatial models in urban studies. The discussion, also include the **old** *(earlier)* and **modern** urban dynamics models.
- **Section two**: Outlines the use of **GIS** technology in urban modelling and the various approaches to integrate **GIS** with urban dynamics modelling, also this section demonstrates the advantages and limits of **GIS** in urban modelling.
- **Section three**: This section discusses the use of **CA** in urban modelling, it also illustrates of **CA** rule to improve urban dynamics modelling. Also, discusses the advantages and limits of **CA** in urban dynamics modelling.
- **Section four**: Illustrates how the appropriate integration of **GIS** and **CA** technologies can lead to better urban dynamics modelling, especially the growth of **IH**.

(3-2) Theories of Urban Dynamics Models

This section traces the basics, theories and applications of recent urban dynamics modelling and simulation, in order to provide an understanding of their theoretical context and limitations. The discussion will focus on the following **three** points:

- **The first** gives a brief definition and classification of urban dynamics modelling,
- **The second** gives an outline of the earlier theories of urban dynamics modelling approaches,
- **The third** summarizes the new approaches and attempts towards urban modelling and concludes that whilst **recent** models have advanced than **earlier** modelling approaches, **they still lack a number of critical capacities**, which the proposed model in this dissertation seeks to address.

(3-2-1) Definitions and Classifications of Spatial Dynamics Models

Models can define variously, they can be considered as the formal representation of some theories. More broadly, **models can be considered as the abstractions**, **or approximations of reality**, **which is achieved though simplification of complex real world** *(sub-systems)* **to the point that they are understandable and analytically manageable** (Sietchiping, R. 2004).

It should be noted that the term "**model**" is used sometimes interchangeably with the term "**theory**" in the literature. However, the two terms are not equivalent.
The word "**theory**" means, "*looking at something*", "*observing something*". Consequently, it denotes "***knowledge***".

Chapin and Kaiser (1979) define theory as ***"a system of thought which, through logical constructs, supplies an explanation of a process, behavior, or other phenomenon of interest as it exists in reality"***. In addition, the theory provides a more general framework of **"connected statements used in the process of explanation"**.
Therefore, the use of the term "**theory**" to denote a mathematical operation is misleading and unsuccessful. On the other hand, the term "**model**" is ***"an idealized structure representing the reality"*** or ***"an experimental design based on a theory"***.

The representation of reality is expressed using symbols. **Mathematical techniques are used to manipulate the relationships among the real world entities represented by these symbols**. Hence, the term **symbolic model** *(operational or empirical model)* is used to distinguish it from other types of representation *(e.g., conceptual models)*.

In planning, a **model** usually studies the interaction between urban elements in order to simplify its understanding. **It is often stated that, a model represents a useful tool to gain better understanding and rapid perception of the complexity of urban system**.

Projecting land use patterns and transportation interaction has been the **major subject** of urban models for more than **forty years**. The goal of urban modelling is to help planners and policymakers to describe urban behavior and predict the spatial distribution of urban pattern in future.

City planners, transportation engineers, and social scientists have been interested in systematic knowledge and modelling of the spatial features in order to study the development of their cities since the **1950**s. The professionals began to develop **land use and transportation models** based on the **similarities** and **regularities** of spatial interrelations between cities, which were expressed in many mathematical formulas.

The early modelers wanted to suggest and develop **more accurate tools** for analyzing **population** and **employment distribution**, **economic factors**, **social patterns**, and **travel habits** which could be used to prepare land use and transportation plan. Later, the field of urban modelling became more specific and diverse.

Recent urban modelers use the advance of modern analytic techniques of **urban economics**, **regional science**, and **quantitative geography**.

Modelers have also begun to deal with many urban spatial activities including :

a) **Residential location**,
b) **Industrial location**,
c) **Retail trade location**,
d) **Business service location**,
e) **Public facility location**.

In addition, urban models have become more complex and comprehensive by incorporating multiple urban activities *(or sub-systems)* **into a single large scale urban model** (Klosterman, 1994).

One of the best advantages of **spatial models** is that they consider **space** and its **attributes** within a **discrete time frame**. Incorporating **space** and **time** in urban dynamics modelling, however, **it has not always been easy** (Batty et al., 2001). [1]

The integration of **space**, **time** and **spatial attribute data** in building urban dynamics modelling is seen a useful path for urban analysis and realistic model improvement. There are many efforts to develop theories, which reflect the appropriate spatial models, as well as, many ways for **classifying existing spatial models**.

For instance, Wegener, (2000), classified the existing spatial models into **three** groups :

a) The first group

This group of spatial models represents the way which urban sub-systems are formulated and is not concerned with the representation of real-world, especially spatial phenomenon; this group includes **three** main categories, as follows :

- **Scale models** replicate the earth's surface and some of its sub-systems,
- **Conceptual models** express the functionality and the connectivity of between many sub-system *(e.g., urban development compared with geography)* by using graphs, charts or documents,
- **Mathematical models** explain the system *(or sub-systems)* using formulas (Sietchiping, R. 2004).

b) The second group

This group of spatial models tends to provide solutions to real and specific problems. As a result, this group divided into **three** main categories, as follows :

- **Deterministic models** depend on the interconnectivity between the elements of urban system to guide the solutions.

[1] This article available at: http://www.cybergeo.presse.fr/ectqg12/batty/articlemb.htm.

- **Probabilistic models** generate possible solutions to a given situation based on the probability of **independent variables** that are taken into consideration.
- **Random models** use the probability and conditionally techniques to propose solutions for urban problems. This category takes into account the **assumptions**, **information**, **utilitarian**, and **operational sense** of spatial dynamics models (Sietchiping, R. 2004).

c) The third group

This group of spatial models deals with the movement *(change)* **within a system**. This group includes **two** main categories, as follows:

- **A static model** considers the system as in equilibrium with **one single state**.
- **A dynamic model** develops a **multiple discrete** or **continuous time-frame** within the system under investigation, this type of models treats the time factor as discrete, and known as simulation models. In this category, the time factor is the important one, while the theoretical and spatial factors are might be ignored (Harris, B. 1996).

There are many other possible classifications according to the field of research, the research objectives, the used techniques, and the type of applications. Not surprisingly, none of these single models or categories satisfactorily represented spatial dynamics patterns.

As a result, integrated spatial dynamics models have been developed which encourage the use of more than two of the above techniques.

(3-2-2) The Earlier Urban Models

The urban planning theories that discusses urban growth passed through many attempts to explain the growth and its direction, these attempts produced many **planning theories**, that illustrate the spatial distribution of land use activates.

This section will present an overview for these theories with focusing on the advantages and disadvantages of each of them, and particularly, when applying these theories in the case of **IH** growth in the context of **LDC**.

a) The Von Thünen Model

Early in the **19**th century **Von Thünen** developed a land use model, that showed **how** market processes could determine, and **how** land uses were spatially distributed over a **theoretical geographic area**, as shown in Figure (3-1). The agricultural regions are the best pattern to explain the concept of this model.

The model is based on the following limiting assumptions:

- The city is located centrally within an *"Isolated State"* which is **self-sufficient** and has no **external influences**.
- The **Isolated State** is surrounded by an unoccupied land.
- The **State land** has no barriers such as rivers or mountains.
- The **soil quality** and **climate** are consistent throughout the **State**.
- Farmers in the **Isolated State** transport their own goods to the markets, directly to the central city, across the land. Therefore, there are no roads.
- Farmers act to maximize profits.

If an **Isolated State** with the above conditions being true, **Von Thünen** hypothesized that, the agricultural land uses would arranged *(or ordered)* into a spatially hierarchic structure, as shown in Figure (3-1). Since vegetables, fruit, milk and other dairy products must get to market quickly; they would be produced close to the city. Since grains can be kept longer than dairy products and fresh products, they can be located further from the city center.

Grazing is located in the most peripheral areas surrounding the central city. Animals can be raised far from the city center because they are self-transporting, and can walk to the central city for sale or for butchering.

The farmers of the **Isolated State** balance the cost of transportation, land, and profit in order to produce the most cost-effective product for market.

Even though the **Von Thünen** model is simplistic and created in a time before factories, highways, and even railroads, **it is still an important model in planning**.

The **Von Thünen** model is an excellent illustration of the balance between **<u>land value</u>** and **<u>transportation costs</u>**.

The closer to the city center, **the land price increases**.

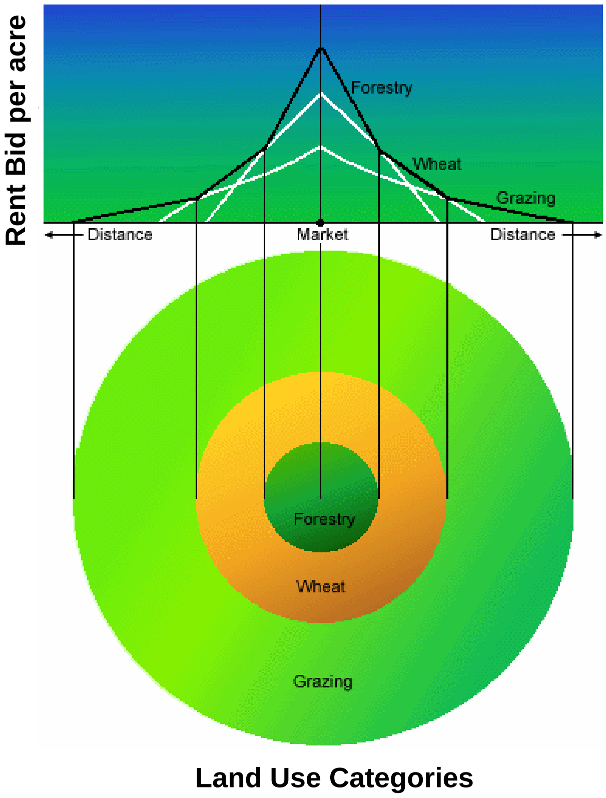

Figure (3-1) The **Von Thünen** hypothetical rent gradients and land use zones

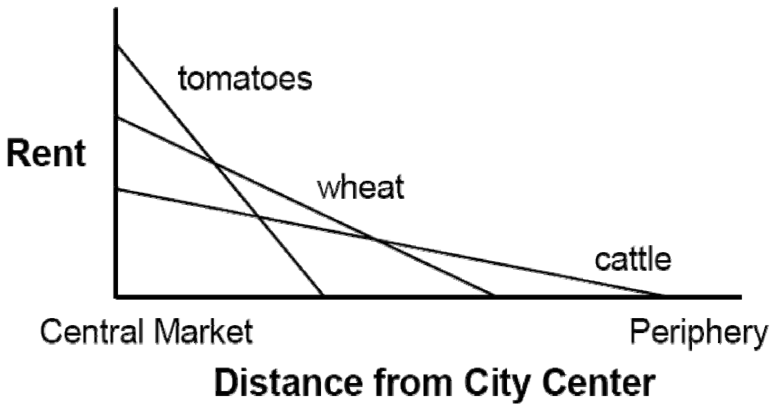

Figure (3-2) The **Von Thünen** spatial organization of agricultural crops

b) Concentric Zone Theory

This theory proposed by **E.W. Burgess** (1926), **Concentric Zone Theory** evolved as an explanation of historical urban land use development in Chicago. **Burgess offered a descriptive view rather than analytical account of the Chicago urban dynamics**.

Burgess suggested that the city land use may be classified as a series of concentric zones, and the city grows by expanding these zones outward, as shown in Figure (3-3).

- **Zone I** is the **C**entral **B**usiness **D**istrict **(CBD)** and lies at the center of the city.
- **Zone II** is the next, containing the multi use transitioning activities, with some **migrant residences** mixed with manufacturing.
- **Zone III** is characterized as the working class neighborhood. Amongst the factories, the second generation immigrants are living in old homes with low living standards.
- **Zone IV** is occupied by middle class residences. This zone's homes are newer and wider than those of Zone III.
- **Zone V** is for the upper class and is dominated by better quality housing.

The Limits of this theory confined to the main hypothesis, that Burgess assumes a generalized geographic space and strict action space. Additionally, the important influence of topography and transportation are not considered, and the centric city is unreasonable for representing real land use patterns.

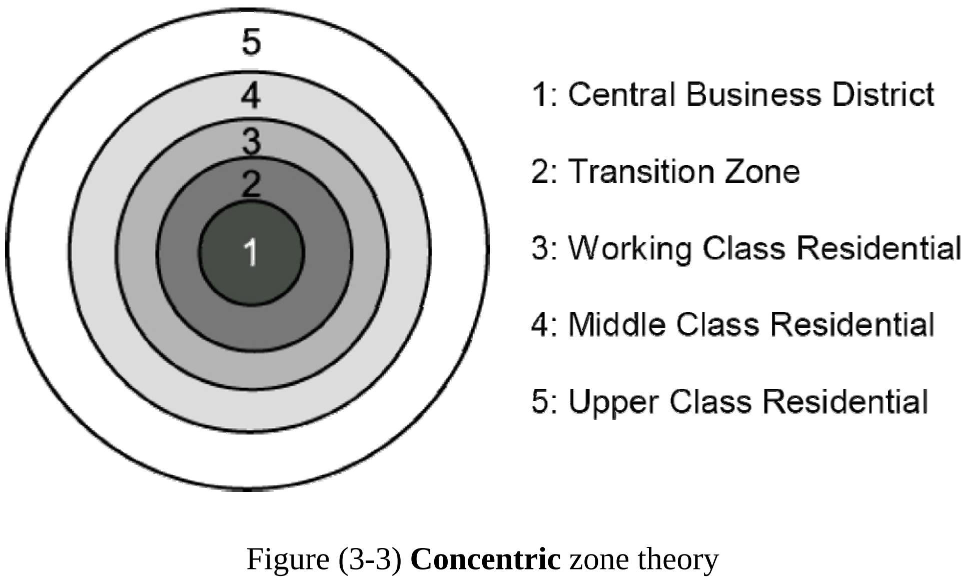

Figure (3-3) **Concentric** zone theory

c) Central Place Theory

Central **P**lace **T**heory **(CPT)** is an attempt to explain the spatial arrangement, size, and number of settlements. A German geographer **Walter Christaller**, who studied the settlement patterns in **Southern Germany,** originally published the theory in **1933**.
In the flat landscape of Southern Germany Christaller noticed that towns of a certain size were roughly equidistant. **By examining and defining the functions of the settlement structure and the size of the hinterland** *(or sphere of influence)*, he found it possible to model the pattern of settlement locations using geometric shapes, such as triangles or hexagons, as shown in Figure (3-4).

The theory defines a **central place** as a settlement having smaller towns at an **equal distance** away from it. These smaller towns use the central places **shops** and **services**. The **central place** offers more goods and services than a smaller town can.
Christaller assumed that all areas have:

- An isotropic *(all flat)* surface,
- An evenly **distributed population**,
- Evenly **distributed resources**,
- **Similar purchasing power of all consumers**, and consumers will take into account the nearest market,
- **Transportation costs equal in all directions** and proportional to distance,
- **No excess profits** *(Perfect competition)*, (Candau, J. 2002).

Central places are settlements **providing services** to their surrounding ***"market areas"***. The ordering of settlements based on the number and level of services they provide produces a ***hierarchy***.

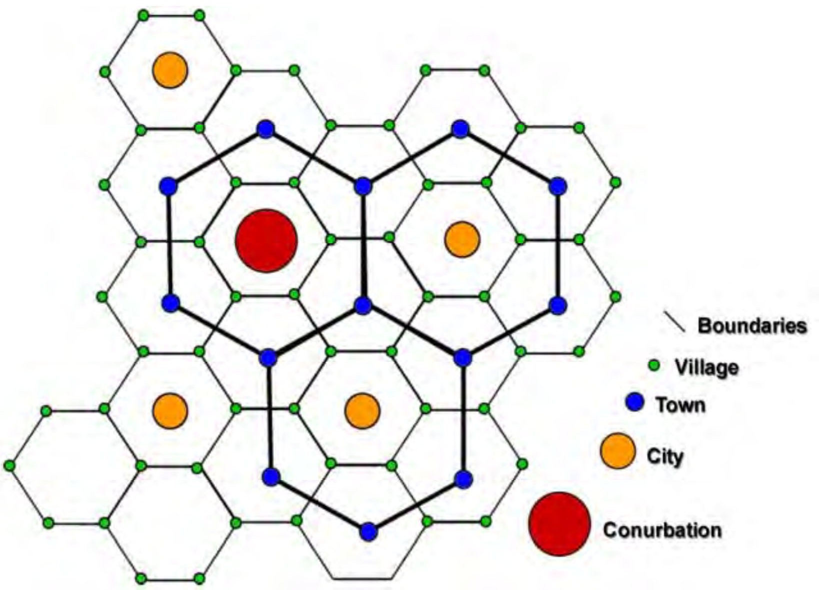

Figure (3-4) **Christaller's** central place theory

The cities, which have fewer services, **are more productive and have much smaller area of influence**. This pattern continues in a hierarchical form to include smaller settlements of towns and villages. Each type of settlement will place itself in relation to the next larger settlement equidistance from settlements of the same size. **In this way a hexagonal pattern of urban settlements are dispersed across the landscape**.

The pattern of cities predicted by **Central Place Theory** may not continue because of the failure to meet theory's initial assumptions. The theory assumptions limits includes:

1) **The area was considered to be homogenous**, assuming that all the attributes of space are evenly distributed within their respective areas,
2) **Production costs may vary** not only because of the economies scale but also by natural resource endowments *(i.e. not a homogeneous plain)*
3) **Transportation costs are not equal** in all directions,
4) **Rural markets** *(initially households)* **are not evenly distributed**,
5) **Non economic factors** *(culture, politics, leadership)* **may be important** but not evenly distributed (Sietchiping, R. 2004).

d) Sector Theory

This theory Proposed by **Hoyt** (1939), **this theory has given some improvements to the Burgess' Concentric Zone Theory by advancing the Sector Theory of urban land use**. Based on residential land patterns in the **United States**, <u>the location of business is referred indirectly to residential locations</u> (Candau, J. 2002).

"The model seeks to explain the tendency for various socio-economic groups to segregate in terms of their residential location decisions. **Also**, **the model suggests that**, **over time**, **high quality housing tends to expand outward from an urban center along the fastest travel routes"** (Torrens, 2000).

The sector theory, as shown in Figure (3-5) considers the **direction** and **distance** as the main factors that <u>shaping residential areas</u>. In addition, it recognizes that the **CBD** is not the only focal point of urban activities.

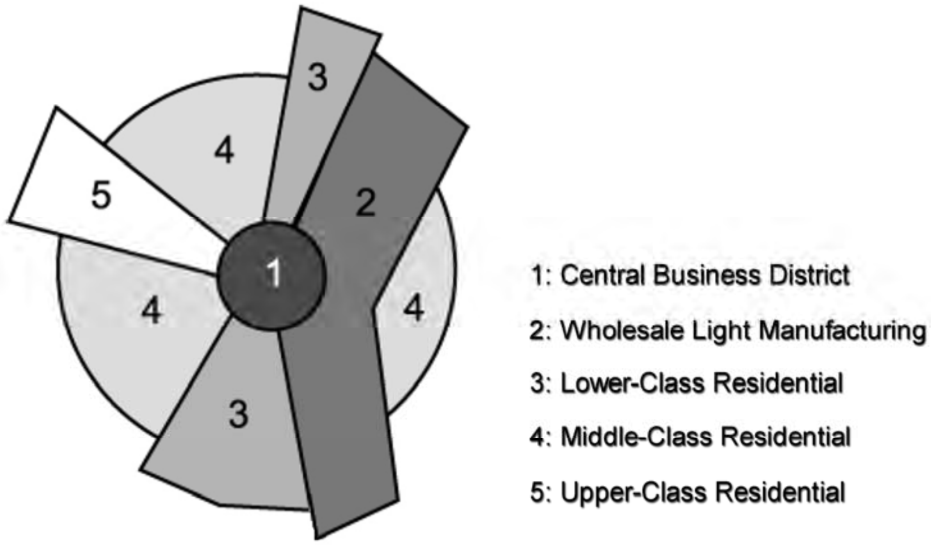

Figure (3-5) **The sector theory**

e) Multiple Nuclei Theory

The **Multiple Nuclei Theory**, that suggested by **C. D. Harris and E. L. Ullman** (1945) **is based on the fact that many towns and nearly all large cities have many nuclei**, **that serve as centers of agglomerative growth rather than a simple CBD and all urban activities revolves around it**, as shown in Figure (3-6). Some of these **nuclei** are pre-existing settlements, while others emerge from urbanization and external economies.

While the leading activities tend to spreading and expanding in the distinctive areas, the other activities cannot afford the high costs of these locations. (*i.e., high-quality housing does not generally arise next to industrial areas).* Therefore, new **industrial areas** develop in suburban locations since they require easy access, and **outlying business** districts may develop for the same reason (Mayhew, 1997).

From this work, the idea of city spatial structure as **predominantly cellular evolved**. This theory surpassed the previous attempts at explaining the spatial distribution of urban activity by incorporating the important influences factors such as **topography**, **accessibility**, and **historical trends**.

"Importantly, in recognizing the polycentric structure of cities multiple nuclei theory moves closer to explaining why urban spatial patterns emerge" (Torrens, 2000).

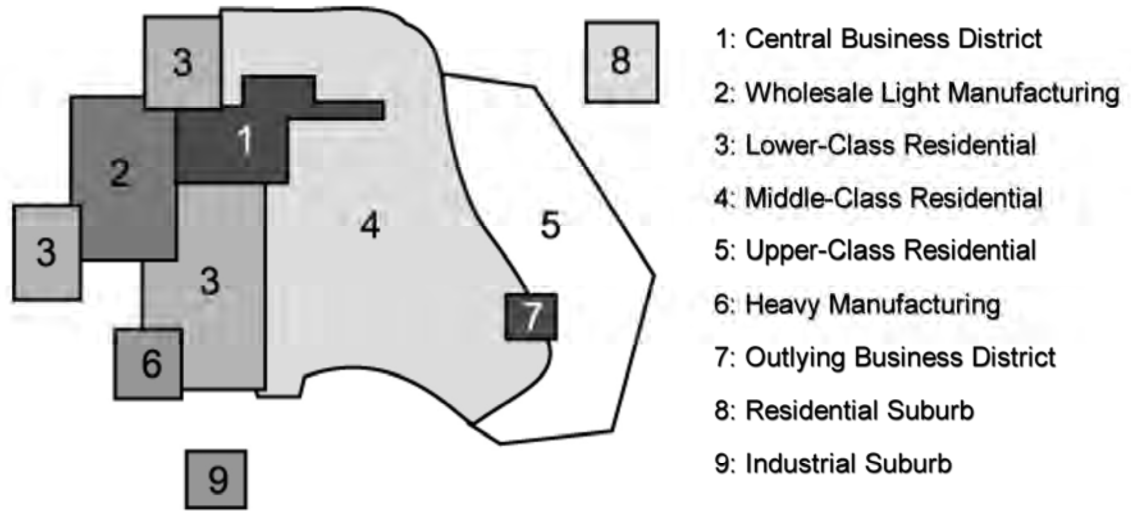

Figure (3-6) **Multiple nuclei theory**

f) Zipf's Rank-Size Theory

This theory first explained by **Zipf**, (1949). **The Rank-Size law of cities has been one of the most empirical facts in economics**, **and in the social sciences**. This law links, between **cities frequency of occurrence** to **their unit size** (1), by using a linear relationship. **According to Zipf**, **if the population of a town is multiplied by its rank**, **the sum will equal the population of the highest ranked city**.

Zipf's law is most easily observed by **scatter-plotting** the data, with the axes being log ***(rank order)*** and log ***(frequency)***. For example, if a variable at ***x = log(1)*** then ***y = log(69971)***. The data conform to **Zipf's** law to the extent that the plotted points appear to fall along a **single line segment**. Formally, assume that:

- ***N*** **be the number of elements**,
- ***k*** **be their rank**,
- ***s*** **be the value of the index characterizing the distribution**.

Zipf's law then predicts that out of a population of ***N*** elements, the frequency of elements of rank ***k***, is ***f*** **(*k*;*s*,*N*)**, is:

$$f(k;s,N)=\frac{1/k^{2}}{\sum_{n=1}^{n}1/n^{2}}$$

---

(1) This article available at: http://en.wikipedia.org/wiki/Zipf's_law

*To visualize **Zipf's** law, we take a country (e.g., the United States), and order the cities by population: __**No. 1**__ is New York; __**No. 2**__ is Los Angeles, etc. When we draw a graph; on the **y-axis**, we place the log of **the rank (N.Y. has log rank ln 1, L.A. log rank ln 2)**, and on the **x-axis**, the log of **the population** of the corresponding city **(which will be called the "size" of the city)**.*

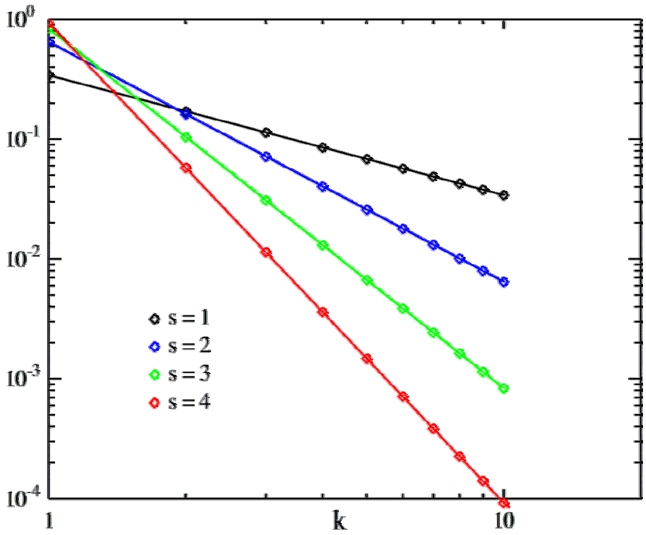

Figure (3-7) **Zipf P**robability **M**ass **F**unction **(PMF)**, for **N = 10** on a log *(rank order)* and log scale *(frequency)*, the horizontal axis is the index **k**.

The result is a strait line graph with a slope of (–1) and an (r^2) of nearly (1.0).

__What is so surprising about this result, where no **top-down** policy that would cause it to be in this form.__ Further, similar results can be achieved for other periods in **U.S.** history, as well as in other countries for different periods: **India** in 1911 and **China** (Candau, J. 2002).

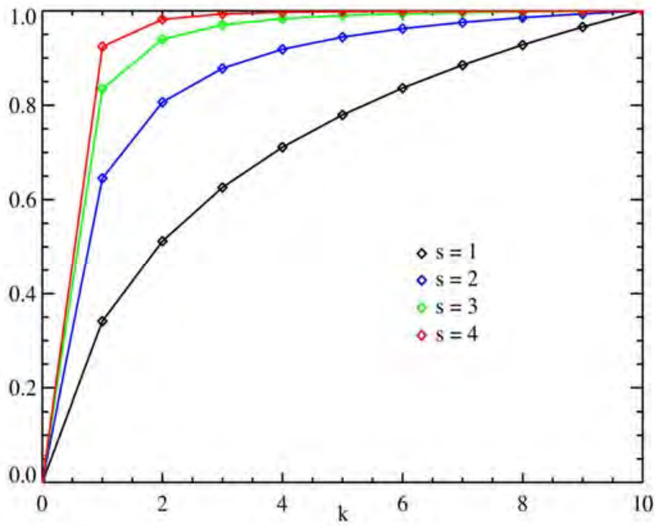

Figure (3-8) **Zipf C**umulative **D**istribution **F**unction **(CMS)**, for **N = 10**, the horizontal axis is the index **k**.
(Source: http://en.wikipedia.org/wiki/Zipf's_law)

Similar results can obtain when applying the theory on many countries in modern period.

Many attempts have been made to explain Zipf's law, what is important to this attempts is that Zipf's law shows that the distribution of cities can represented as a linear relationship between city size *(measured by population)* **and rank, also this relationship is true across scales and time**.

It is possible to modify this theory to a __**spatial metric phenomenon**__ by redefining the unit of measure as **area of urban cluster** *(where: **urban cluster** is the amount of land contained within an adjacent agglomeration of urban land use)* instead of city population. The **cluster size** could then be plotted against its **rank** to test how well the spatial distribution of the city follows the **rank size rule**.

g) The Bid-Rent Theory

Extending to **Von Thünen**'**s** theory, **Alonso** (1960) developed an **urban Bid-Rent theory**. The **Bid-Rent theory** offers an explanation of the spatial distribution for land uses that **Von Thünen** described in his theory. **Since transport costs rise with distance from the central market, and rents generally tend to fall correspondingly, thus different land uses** *(retail, service, industrial, housing, or agricultural)* **generate different Bid-Rent curves**, as shown in Figure (3-9).

Alonso (1960) developed **Von Thünen's** theory assumptions and framework to create a sophisticated **Bid-Rent** model for urban lands, through substituting **residential** and **industrial** land use instead of **Von Thünen's** farmland use. **The most significant assumption for this theory is that land rents were determined mainly by transportation costs and the distance to the central markets**, he recognized the importance of **accessibility**, which has a negative linear relationship with land rent.

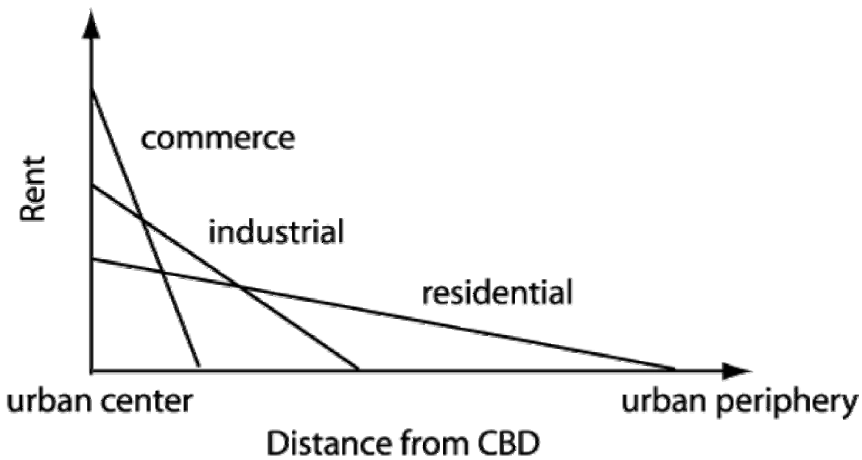

Figure (3-9) The Alonso model for housing stock based on **Bid-Rent** theory

Alonso'**s Bid-Rent theory was based on many assumptions including**:

- A single **C**entral **B**usiness **D**istrict **(CBD)** was assumed to be the location of all jobs and sales,
- The **available quantity of land** that may be bought should increase with distance from the center,
- The **land price decreasing with increasing distance from the city center**,

- **The travel costs will rise with distance from the center**,
- **Employment was located at the center of the city**,
- The **business and industry locations** were the only distinguishing factor,
- **Housing was homogeneous**, and **each household had one worker**,
- **Only work-trip travel was considered**.

From this basic principle, **Alonso** illustrated how **the rich persons** will choose the areas of **lower density housing** at the edge of the city, and pay the price of traveling over distance, while the **poor remain** in **high density** residences near the city center.

Each household represents a balance between **lands**, **goods**, and **accessibility** to the workplace. In **Alonso's theory**, the curves of rent gradients for all land uses are negatively sloped against the center *(i.e., the CBD)*. Many urban economists have improved the classical **Bid-Rent theory** by using more assumptions and observations. They have found that the assumptions of centric city in the classical **Bid-Rent** model are poor representation of contemporary metropolitan areas.

Finally, the earlier models were severely criticized as ***"largely descriptive models"***, and treated the city as **centralized node** with little interactions *(gravity model)* between the space components. In addition, the traditional models were too generalized and lacked detailed data, their spatial representation was primitive without considering the interconnection between the elements of space (Wilson, 2000).

Two main factors prevent the application of these models:

- They are weakened by the dependence upon **market value** for formulating hypotheses about urban dynamics, the market value data may be difficult to acquire, especially over multiple time periods.
- In the early spatial models such as **central place theory**, the settlements attributes were treated separately and then aggregated. In addition, the areas were considered homogenous, assuming that all the attributes of the space are evenly distributed.

From the previous discussion, **the earlier models provide a good powerful idea which is the two dimensional modeling approach**, **that linked each component of the space with specific information** "***attributes***", **especially with the emergence of computing technology**.

(3-2-3) Current Urban Modelling Approaches

Limitations noted in the earlier urban dynamics theories have led to the exploration of new ways and approaches to respond to the criticism directed at it. Current urban dynamics modelling borrows from modern technologies, such as **computer sciences**, **simulation techniques**, **data availability**, and **artificial intelligence** to better inform urban dynamics theory and generate more useful models.

From **1960s**, **spatial urban modelling** took the **advances of computer sciences** to develop empirical models from **small scale** to **large scale**. These models introduced new methodologies to urban modelling. Despite these advances, computer memory and speed slowed these attempts to move from small to large scale modelling.

In **1960s Lee**, reported that urban models were **complicated**, **expensive**, **data *"hungry"***, **mostly static**, **impractical**, and **unable to replicate their results**. After that, **Lee** (1973) announced the **breakdown** of large scale urban modelling.

Now, urban dynamics researchers are seeking to find the possible integration and compatibility with other technologies and tools. Therefore, several trends discuss the possible directions to incorporate the current technologies to predict the physical urban growth. Especially, the current progress in the theories and methodologies of urban simulation is helped by the current **computing technology** and **artificial intelligence**.

As a result, **six** main fundamental trends were considered for developing urban dynamics modelling :

a) **Spatial interaction models**, based on the **Gravity Theory**;
b) **Discrete choice models**, based on **Random Utility Theory**;
c) **Associative econometric models**, using regression and econometric techniques;
d) **Rule-based allocation models**, **Cellular Automata**, and **Artificial Intelligence** models, that builds upon the advance of **GIS** technology;
e) **Visual animation modelling approach**, based on the emergence of **computer-based simulation** technology and the development of **movie-making** industry;
f) **The Geo-Computation (GO) modelling approach**, based on **Remote Sensing** and data availability.

a) Spatial Interaction Models

Spatial interaction models are based on the gravity theory from physics, **Newton's law of gravity**, which assumes that the interaction between two bodies is directly relate to their masses and inversely related to the distance between them (Wilson, 2000). This type of modeling used to allocate **regional total households** or **employment** to the zones in a region by **comparing the accessibility and attractiveness between zones**.

Location scientists *(e.g., Lowry, 1964; Hansen, 1959)* **started to apply the principal assumption of the gravity law to model the locations of land use elements within the urban systems**.

The conceptual framework of the **residential location choice** in spatial interaction models assumes that employees working in employment zones choose particular residential zones *(or neighborhoods)* in order to **minimize** their work trip cost *(i.e., increasing their accessibility)* and **maximize** neighborhood characteristics *(or attractiveness).*

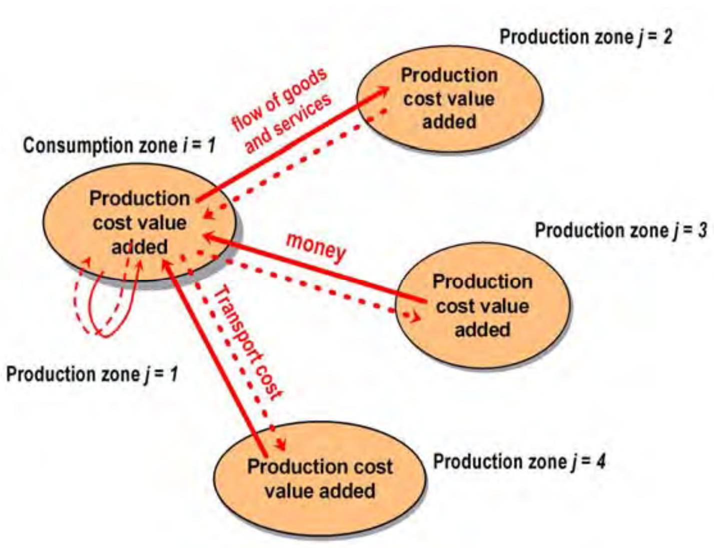

Figure (3-10) The concept of spatial interaction models that based on gravity theory

One of the limitations of this type of models is that many physical and spatial factors influencing location choices are not represented. In addition, the role of real estate markets and prices are not considered. These models also tend to be limited in the degree of spatial detail (Waddell, 2004).[1]

The **L**and **U**se **C**hange **A**nalysis **S**ystem **(LUCAS)** is one of the models that use the concept of spatial interaction models and examines the impact of **human activities** on land use change and the subsequent impacts on natural resource sustainability, *(more details about the **LUCAS** model will discuss in Chapter four, section 4-4-3).*

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(1) This article available at: http://www.urbansim.org/estimation_archive/estimation_main_2004_0917.pdf.

<u>b) Discrete Choice Models / Random Utility</u>

Discrete choice models employ **random utility maximization theory**, which was originally developed by **Daniel McFadden** (1974), to simulate the choice of development locations and the behavior of **land market agents** *(e.g., land owners, households, and developers).*

Random Utility Theory considers the **utility maximization behavior** of the agents to be a <u>probabilistic process</u>, not a <u>deterministic process</u> (Waddell, 2002).

Based on **McFadden**'**s** work on **R**andom **U**tility **T**heory and his conclusions for the generalized models, including <u>multinomial</u> and <u>nested logit</u> models, have resulted in <u>**discrete choice models** that have a **firm foundation** in the area of econometrics models.</u> This type of models has become a standard method for developing models to predict **individual choices** among a **finite set of alternatives** (Waddell and Ulfarsson, 2004).

Discrete choice models may also be applied for land use planning, such as making decisions for locations of households and firms. <u>For instance,</u> **employment location choice** may be modeled as a function of **business characteristics** *(e.g., industry size)*, **potential zones** *(e.g., density, accessibility, and employment levels)*, and **space** *(quantity and cost)* with a discrete choice framework.

UrbanSim, is one of the most advanced **D**iscrete **C**hoice **M**odels, that developed by **Paul Waddell** and others (2000), and has been applied to several metropolitan areas in **US** states, *(more details about **UrbanSim** model will discuss in Chapter four, section 4-4-7).*

<u>c) Associative Econometric Models</u>

This type of urban models is composed of one or more multivariate **econometric equations** or multiple regression models. The associative models are also called **linear models or econometric models**. <u>For example</u>, **EMPIRIC**, the most widely applied econometric model in the 1970s, was called a non-behavioral model because the model was not based on accurate theoretical causal relationships (Waddell, 2002).

The **CUF-2** *(**C**alifornia **U**rban **F**uture Model-II)* developed by **Landis & Zhang** (1998) is a recent example of associative econometric modelling, the model was applied on **San Francisco** and **California Bay Region**. [(1)]

[(1)] This article available at: http://www-dcrp.ced.berkeley.edu

d) Rule-Based Allocation Models

This modelling technique has demonstrated by the progress in **GIS** and related technologies, **especially the availability and handling multiple elements of space**. **Rule-Based** allocation models help to understand how site characteristics and other governmental policies affect the **quantity** and the **spatial distribution** of available redevelopment lands. By using simple spatial queries based on regular and empirical rules, by doing this, the model produce a set of the most possible developable lands.

The rule-based land monitoring systems have become an increasingly popular method for recording and estimating the potential development for each piece of land. These methods use **predefined rules** comprised of **market assumptions**, **local regulations**, and **policy constraints** to eliminate lands that is not suitable for future developments.

This type of models does not rely on traditional statistical or complex calibration approaches to determine the growth coefficients rates. Instead, they rely on a set of **practical assumptions** and **local knowledge** to identify the important factors that define **the suitable locations for particular land use and to allocate the projected demand to the most suitable location**.

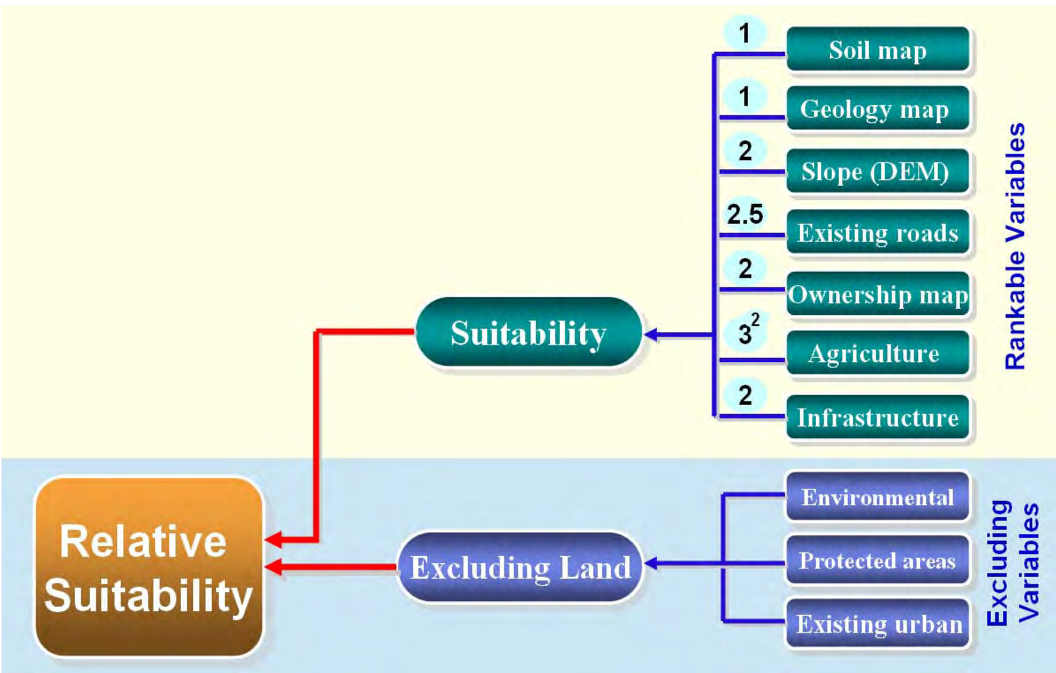

Figure (3-11) The concept of **rule-based** allocation models

Several land use models have been developed in recent years implementing a set of **rule-based** procedures *(or tools)* to allocate **population**, **employment**, and/or **land use** based on **GIS** platform.

The next Chapter will discuss some of the **rule-based** allocation models including the **CUF-1** and **What If? (PSS)** model. The **What if?** model is an example of this modelling type, which use an explicit set of allocation rules to allocate the **projected demand** *(e.g., projected population and employment)* to the most **suitable available locations**. *(e.g., developable lands),*
*(more details about the **What if?** model will discuss in Chapter four section 4-4-8).*

e) Visual Animation Modelling Approach

One of the purposes of urban modelling and simulation research is to improve urban **visualization**. Therefore, many researchers found the usefulness of using the **animation technique** to study spatial urban dynamics. The interest in using **visual animation** based on its ability to produce many patterns from **complex system** by using **simple rules**. The "**movie**" concept refers to the spatial changes in the state of real world elements through a **time series**.

This technique emerged in the late of **1990**, through a research group in **California's Silicon Valley**; **this group invented one of the most successful applications of urban dynamics animation using real-time data** (Clarke *et al.*, 1998). This team established together the **U**rban **G**rowth **M**odel **(UGM)**, that they tested on the **San Francisco Bay** area to study the impact of human activities on the spatial organization and change of land uses. This model simulates the growth of the region *(as a movie)* up to **2100**, which can be visualized in real-time.

The upgraded version of **UGM**, known as **SLEUTH** *(**S**lope, **L**and use, **U**rban extent, **T**ransportation and **H**illshade)* [1] has been applied to simulate urban dynamics in North American cities and in Europe, *(more details about **SLEUTH** model will discuss in Chapter four, section 4-4-4, and Chapter five presents an application of **SLEUTH** model to predict the urban growth of GCR, Egypt).*

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[1] **SLEUTH** model and relevant materials can be obtained from http://www.ncgia.ucsb.edu/projects_ /gig /index.html.

In addition, **Batty and Xie** (1994) show how the exploration of **C**ellular **A**utomata **(CA)** can **advance and expand the visual animation of urban dynamics modelling techniques**. They showed how **CA** considers **space**, **time**, **attributes**, and **the relationships** between real spatial components.
To date, applications have been limited for **research purposes** rather than <u>operational planning or policy planning,</u> although efforts are underway to make these models useful for planning purposes (Waddell 2004).

f) The Geo-Computation Modelling Approach

The development of **GIS** software and **Remote Sensing** techniques led to the emergence of the so-called **Geo-Computation (GC)**, it has been approved as a new urban dynamics approach, which imagines *"modelling systems at the scale of individuals and entity level units of the built environment"* (Torrens, 2000). **Geo-Computation** has benefited from **computer technologies and programming**, **data availability from remote sensing**, and **recent simulation models**.

(3-2-4) Experts and Researchers Criticism

Previous urban models represented urban dynamics as snapshots, **rather than as a system evolving over time**. Whilst spatial dimensions were well represented, <u>the poor dynamic representation of urban space constituted one of the **major limitations** of previous urban models</u>.
This weak point was represented by one set of data used for simulation *(one map)*, or there was a large gap between periods *(e.g., ten year periods for census data)*. **Representing urban change in that way was realistically and theoretically inappropriate** (Sietchiping, R. 2004).

Practically, it is vital for planners and decision makers to have **reliable**, **localized information** and **broad knowledge** of urban issues. In addition, any theoretical exploration of the <u>urban system complexity</u> requires **clarity**, **precision**, and **detail**, in that way, urban dynamics modelling can achieve its goals. **However**, **traditional urban models fail to respond to the needs of urban planners and decision makers**.

One of the strong **criticisms** of the previous dynamics models is that these models was designed **based on practical projects and studies** of various regions of the world and were based on a **selected criteria** and **specific data**. **Therefore**, **it was not possible to make these models as a general** *(standard)* **and it is difficult to apply these models on all regions and environments**.

Forrester (1969) suggests that, **the logic**, **consistency** and **clearness** that is embedded into the modelling procedure, helps to understand the interaction between urban elements, and testing hypotheses. This allows urban dynamics modelling to facilitate <u>the miss-representation of time, spatial relationships, space and its attributes.</u>

Finally, Wegener (2000), notes that urban models are organized based on theories that were largely influenced by **economics** *(especially market supply and demand)* or **transportation** *(origin and destination)*, <u>rather than taking into account the various components of the urban system or sub-systems</u>. In addition, he gives a detailed account for **operational** and **comprehensive urban system models**.

As a result, twenty-two urban models were selected with different levels of **sophistication** and **comprehensiveness** (US. EPA, 2000). Some of these, Wegener noted that only **twelve** could be considered as comprehensive and operational *(applied in real cities)* [(1)]

Although the **use of computer simulations for planning is seen as the next generation of urban modelling**, there is a suspicion on the used methodologies by these models. Some researchers are suspicious of using dynamic visualization because of the simplicity of some model and theory formulation (Torrens, 2002).

In urban planning, **these models could be <u>very effective and practical tools</u>. Real-time urban animation approach still remains in at an imperfect development stage**, but there is much hope for further researches, **especially in the area of incorporation and management of varied data sources with the assistance of modern spatial technologies such as GIS**.

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(1) More details about these models are available in **Chapter Four**.

(3-3) GIS as Spatial Modelling Technology

This section will evaluate the contribution of **GIS technology** in the development of realistic urban dynamics models; the discussion will focus on the following points:

- The role of **GIS** technology in urban planning analysis,
- The current approaches to integrate **GIS** with urban dynamics modelling,
- **GIS** and **U**rban **D**ynamics **M**odelling **(UDM)** including, the modelling capabilities of **GIS**, as well as the previous researches and studies.

(3-3-1) Role of GIS Technology in Urban Planning Analysis

Geographic **I**nformation **S**ystem **(GIS)** is the most advanced technology for data **acquisition**, **verification**, **compilation**, **storage**, **updating**, **management**, **exchange**, **retrieval**, **processing**, **analysis**, and **displaying** digital spatial information.
GIS organizes and represents **Geo-Referenced** spatial data stored in a relational database, the real world is described by using:

- **Spatial data**, which define elements positions in space *(vector or raster images)*,
- **Attribute data**, which usually consist of alphanumeric characters, documents, digital images, and multimedia files.

In addition, the **logical links** between geometric entities are described, such as **directions**, **connections**, and **neighboring characteristics** *(topology)*.

Since the introduction of **GIS** in the 1960s, the scientific community and practitioners have adopted **GIS** technologies in their work, such as compiling, managing, and displaying spatial data. **Therefore**, **the data handling capacity of GIS is critical for developing the desired urban models**.

The power of **GIS** lies in its ability to separate **real world** information in layers and combine it with other layers of information to support the decision making process. Thus, a **GIS** is much more than a software application; it can be described as **Decision Support System (DSS)** (Aronoff, S., 1993).

For instance, **GIS technology can help to organize and link the factors that affect the emergence and growth of informal urban areas**.

Not surprisingly, GIS has been used in various fields of science. Now, GIS applications cover nearly all fields of the geographical sciences and studies.

Generally, **<u>four points</u>** can summarize the role of **GIS** in urban planning analysis:

- **<u>First,</u> GIS acts as information system, it used to organize both spatial and attribute data. Local governments can organize their data in a multi sector and multi purpose GIS database**. Data from numerous departments, such as **land use planning**, **infrastructure**, **services**, **transportation**, and **economic development**, ..etc, can be integrated together, therefore, it can be analyzed and visualized, as a result, **better decisions** can be made.

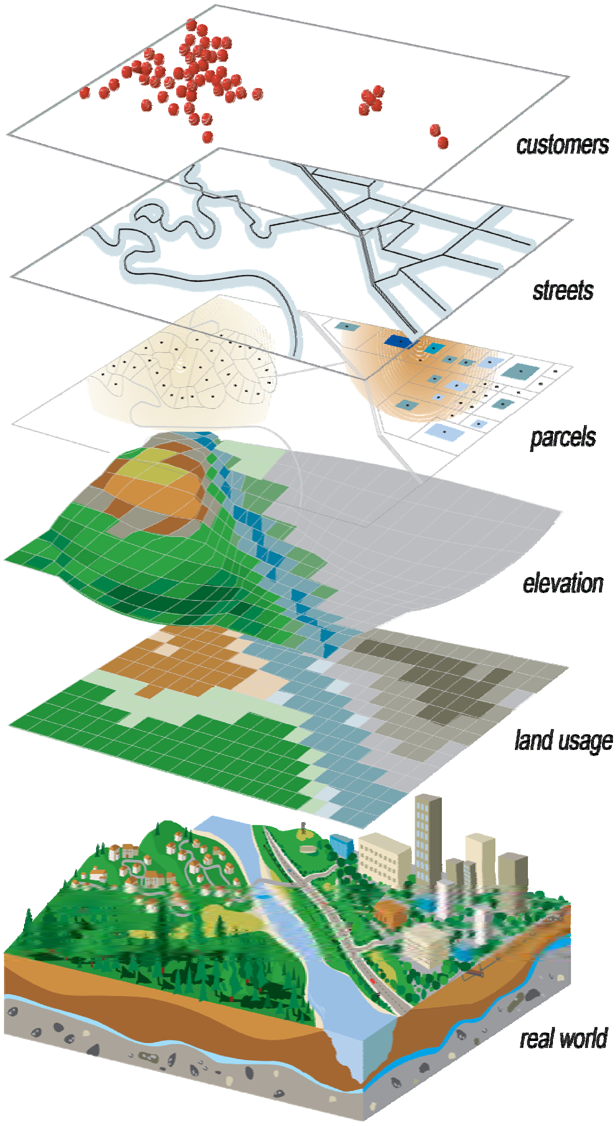

Figure (3-12) Transformation of the real world into **GIS**
(adapted from ESRI)

<u>For example</u>, *data such as the primary land uses of an area can be combined with the existing and planned major roads, highways, the planned residential and commercial developments to project how much open space will be lost, how much traffic will increase, and where more development will likely occur.*

- **<u>Second,</u> GIS can be employed as a stand alone set of spatial storage and manipulation tools, which useful for a variety of purposes and at different scales.**

Using **GIS** classic functions, such as weighted overlay, classification, buffers, map algebra, cell statistics, and cost allocation these functions can used together to explain **events**, **visualize trends**, **project outcomes**, and **formulate long term planning goals**.

For example, *the slope information, soil conditions, existing vacant lands, and distance from roads and water bodies can be* ***overlayed*** *to determine the most suitable land for development. In addition, a planner can map population density along a transportation corridor and evaluate whether there will be sufficient to support public transit or not.*

- **Third, GIS also can operate as a visualization and summation tool for larger data warehousing enterprises**.

  GIS software combines **land use mapping** capabilities with **relational databases** and **statistical analysis tools** to enable planners to link numerous types of information, rapidly perform sophisticated analyses, and effectively communicate complex information with maps and graphical reports. **They are powerful tools that could be a component of a modelling system**.

- **Fourth, GIS feeds model development**.

  A number of attempts were implemented to incorporate **mathematical** and **statistical** models into **GIS** to improve its spatial analysis and increase the GIS capacity toward map trends and future projections.

  These attempts can be classified into **three** main classes:

  a) Many modern **GIS software packages** offer user friendly, Windows based environments. They are general software systems or "**tool kits**" from which users may select components suited to their own specific applications.

  GIS software packages vary in **structure**, **price**, **functions**, and **data accepted**. Hundreds of **GIS** software exists in the market and others are under development, several modifications and enhancement are periodically made for commercial **GIS** software packages. Among the **GIS** software packages popular with planning professionals are **ESRI** (ArcGIS, Map Objects, …etc), **Autodesk** (AutoCAD Map, Map Guide), **GeoMedia**, **MapInfo**, **Atlas GIS**, **Erdas Imagine**, **Image Analyst**, ...etc.

b) Inside these packages, there are **GIS-centric models**, which support urban and land use planning. The **3D**, **Spatial**, **and Network Analyst** extensions, which execute through **ArcGIS** software contain sophisticated functions that do many useful tasks.

c) The last decade has also seen the development of **planning macro tools** embedded into **GIS** environments, and the trend is towards greater compatibility and flexibility of **GIS** software tools with popular external programming languages, *(next Chapter will presents, how* ***GIS*** *functionality is embedded in* ***CUF-1*** *model by Landis, and in* ***What if?*** *model by E. Klosterman).*

The considerable advance in computer technologies in the last three decades has also expanded the development of various **GIS** software. Despite the overall similarities in **GIS** software, the emphasis put on operations, functionality, sophistication and the integration of the components of the system (Heywood *et al*., 2002).

Today's the standard **GIS software** includes features that assist **urban planning analysis,** such as :

- **A database** *(layer and attribute),*
- **A management capability,** and **cartographic display tool** *(edit and display),*
- **A map digitizing interface**,
- **A database management system facility** *(to input, query, manage and analyze the attribute data),*
- **A spatial analysis capability** *(for overlaying, network analysis, and relationships between database and features),*
- **An image processing tools** *(e.g., process and integrate remotely sensed data),*
- **A statistical analysis tools** *(e.g., for comparative analysis),*
- **A decision support functions to guide the allocation of resources**.

An important question, however, is how to integrate GIS with urban modelling? Moreover, whether GIS can simulate and model complex urban dynamics, such as informal urbanization processes.

(3-3-2) GIS and Urban Dynamics Modelling

In this section, we will introduce the previous studies and researches to verify whether the current **GIS** technologies have the ability to produce urban dynamics modelling or not. Investigating this ability is very important for two main reasons:

- If **GIS technology** by itself were sufficient to develop urban dynamics models,
- If **GIS technology** were not sufficient, then we should have to identify another technology that could complement the spatial capacity of **GIS**.

<u>a) The modelling capabilities within GIS</u>

The term modelling in **GIS** usually refers to the basic spatial functions such as **buffer**, **overlay**, **Digital Elevation Model (DEM)**, **Triangulated Irregular Networks (TIN)**, and **interpolation**, **surface analysis** *(slope, aspect, hill-shade…etc,)*. In addition, **GIS** uses equation-based functions such as, **image calculators**, **cell statistics**, and **map algebra** as modelling capabilities.

Figure (3-13) **GIS** buffer analysis

The main advantage of GIS is the ability to represent and build mutual relations between irregular **spatial forms and patterns**, some researchers have proved that, this ability gives **GIS** models a <u>descriptive characteristic</u>, and a <u>decision support system</u> for spatial problems analysis (Geertman & Van Eck, 1995).

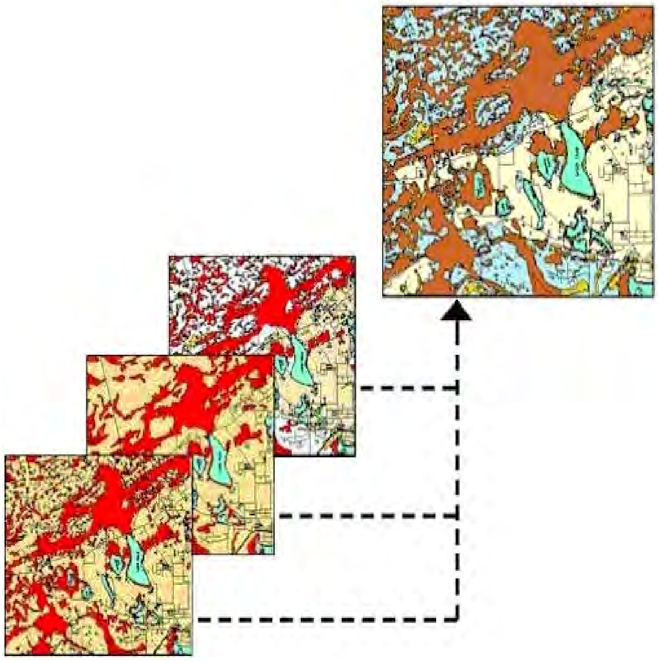

Figure (3-14) **GIS** overlay analysis

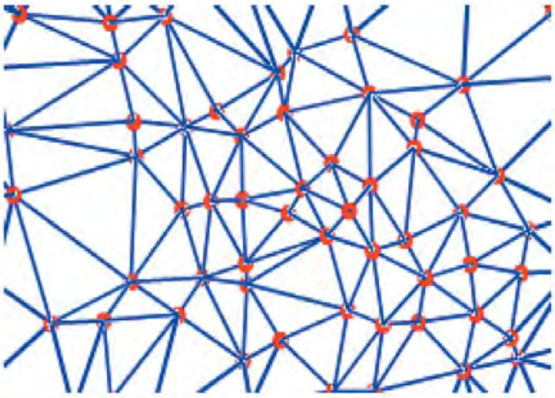

Figure (3-15) Nodes and edges of a **TIN** (Adapted from ESRI)

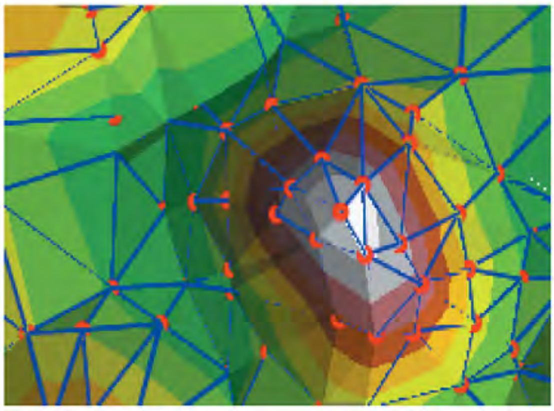

Figure (3-16) **DEM** overlayed by nodes and edges of **TIN** (Adapted from ESRI)

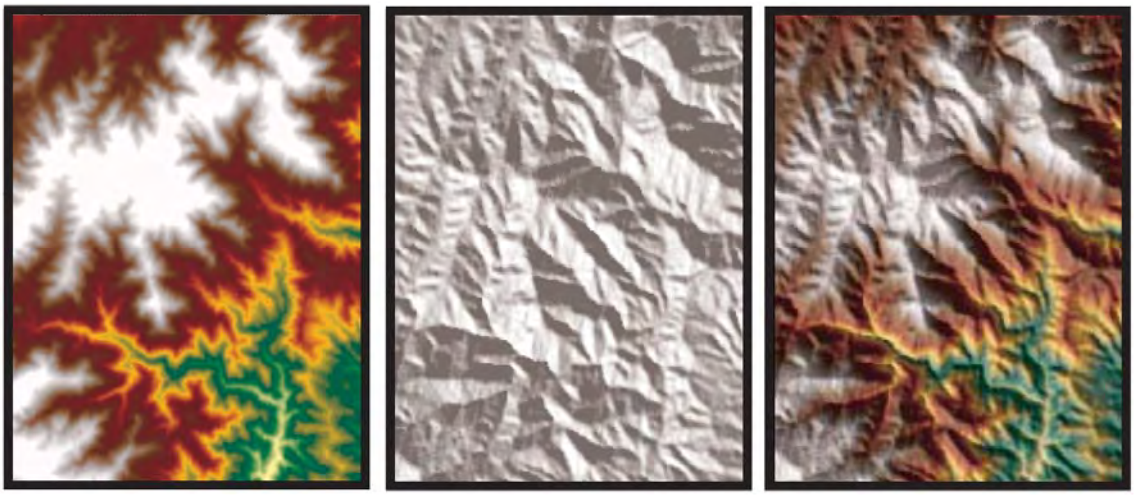

Figure (3-17) **2D DEM**, transparent hill-shade raster, and shaded relief map

On the other hand, **four main limitations** have been identified in the current **GIS** technologies:

- **First**, current **GIS** spatial analysis techniques are **static** and **weak** in handling dynamic representation of real phenomena (Longley & Batty, 2003).

- **Second**, to date the spatial representation in **GIS** has relied upon a limited map metaphor. Consequently, the representation schemes and analytical functions in **GIS** are **oriented toward map layers** and **geometric transformations**. The layer approach implicitly supports a segmentation of geographical features with irregular links and casual relationships rather than a system with dependent and independent variables and their attribute data (Wegener, 2000).

Figure (3-18) **3D** visualization in **GIS**

- **<u>Third</u>,** is the inability of **GIS** to perform **<u>complex numeric analysis</u>** and to process **<u>multi-dimensional spatio-temporal systems</u>**, especially when dealing with large scale data (Couclelis, 2002).

- **<u>Fourth</u>,** The absolute conceptualization of space in **GIS** describes the space and real world elements into a geometrically indexed representation scheme via planar representation.

  In contrast, embedded urban elements in various urban models are essentially a **<u>relative or relational</u>** conceptualization of space, as illustrate in various kinds of spatial structure and spatial organization of the current urban dynamics models, *(for more details about current urban dynamics models, see **chapter Four**, section 4-4).*

  This relative view of space is not compatible with the notion of space built into commercially available GIS packages.

Due to these limitations, therefore, GIS might not be an adequate tool for simulation and modelling real patterns and their spatial behavior. In addition, there is a complaint that, GIS is not flexible enough to adjust to user specific needs, while some of its operations and functions are <u>still weak</u> to support urban dynamics processes (Wagner, 1997).

b) Previous Studies and Researches Review

More recently, there are some attempts to develop dynamic spatial models within **GIS** environments, where **GIS** has been used as base for modelling and forecasting urban pattern, especially by adding more functionality and features. For example:

- **Meaille** and **Wald** (1990) have applied the **diffusion model** to study the urban growth of Marseilles *(France)*. They used satellite images and raster **GIS** data as inputs to predict the spatial distribution of urban population. This model, however, failed to produce realistic patterns of urban changes in Marseilles.

- **Batty** and **Xie** (1994) have linked a customized urban model with a popular **GIS** package **(ARC/INFO)** to develop an urban dynamics model by using raster **GIS** interface. They applied their proposed model to the city of **Buffalo** (USA). They found the **temporal and predictive capabilities were insufficient in this model and the analytical capacity of GIS package was also weak**.
  To improve the model results, **Batty and Xie** used external mathematical procedures to build the customized model. This can explain the limited capacity and functionality of **GIS packages** and their **macro-languages** to fully incorporate a time series spatial data analysis.
  The results obtained by Batty and Xie suggest that GIS by itself is not sufficient to develop a dynamic urban model, **therefore the proposed IHGM in this thesis**, **should use an external mathematical techniques (or tools) to build the dynamic model outside the GIS environment.**

- The First **C**alifornia **U**rban **F**utures **(CUF-1)** model, which developed by **John Landis** (1995), in the institute of urban and regional planning, university of California at Berkeley, combined **GIS** with **external expert systems** to predict the **location**, **pattern**, and **intensity** of urban growth of **San Francisco** over a **twenty year period**. The **CUF-1** had reasonable spatial and temporal dimensions. The predictive and simulation components of the **CUF-1** model were, however, **coarse** and **unreliable**.

This example shows that the combination of **spatial technologies** such as **GIS** with a **dynamic tool** such as **statistical or mathematical tools** could ultimately improve the results of urban growth models.

Thus, GIS alone does not have the capacity to produce a reasonable prediction of urban dynamics.

Many urban dynamics researchers have reported the **poor modelling and simulation capacity of GIS**. For example: **Longley** and **Batty** (1996, p.350) clearly stated that: **"GIS is not about modelling and simulation per se, nor it is about forecasting, design and prediction...[rather] it is an enabling technology…it is about representing digital data so that it can be stored, queried, and visualized in the most intelligent and relevant way"**

To achieve reasonable urban dynamics models, **GIS** technologies have to be combined with other mathematical tools. The literature suggests that some of the GIS **limitations to handle dynamics modeling and time-series prediction** can be overcome by incorporating other techniques, such as **Cellular Automata (CA)**, which have great advantages over **GIS** in performing dynamic simulations and time-series modeling (Couclelis, 2002).

(3-3-3) Approaches to Integrate GIS with Urban Dynamics Modelling

For almost **two** decades in the **1960s** and the **1970s**, **GIS** and urban modelling developed in parallel with **limited interactions**. The integration of **GIS** with urban modelling did not take place until the late **1990s**, as a part of the **GIS** community's many attempts to improve the analytical capabilities of **GIS** (Fischer *et al*. 1996).

Nowadays, GIS users and urban modelers have increasingly recognized the benefits of this integration, according to the preliminary successes of the past ten years. On the other hand, various urban modelling techniques have enabled **GIS** users to go beyond the data inventory and management stage to conduct sophisticated analysis and simulation.

The process of integration **GIS** with **urban dynamics modeling** will produce benefits for both the two technologies as follows:

- **For urban modelling**, **GIS** does a very good job of enabling us to **store**, **analyze**, **manipulate**, and **visualize current and past information**. Therefore, **GIS** will provide planners with new platforms for **data management** and **visualization**.

  The great importance of **GIS** in this society has the potential to make models **more transparent** and to enable the communication of their operations and results with a large group of users.

- **For GIS**, Models are used to **assist planners in looking to the future**. They allow building scenarios that can provide an important aid to future directed decision making. Also, **GIS does not in itself future directed tool**. Therefore, embedding **urban dynamics models** and **prediction techniques** into **GIS** will improve the analytical capabilities of **GIS** in the area of urban and regional planning.

Also, spatial information systems and databases are important components of the planning activities. Planning, however, is more than models and GIS.

Generally, there are **four** different approaches have been widely used to integrate **GIS with urban modelling**. Several recent research initiatives in North America and Europe focus on the improvement of **spatial analytical capabilities of GIS technology**, by integrating urban models and statistical analysis tools with **GIS packages**.

a) Embedding GIS functionalities into urban modelling packages

This approach aims to embed **GIS** functionalities in urban modelling packages, this concept has been adopted primarily by urban modellers and planners **who think of GIS essentially as a mapping tool**.

This approach usually gives the system developers **maximum freedom for system design**, and is capable of incorporating the latest urban modelling packages. In addition, the implementation is not constrained by any existing **GIS** data structures or requirements,

The weakness of this approach is that the data management and visualization capabilities of these urban modelling software are in no way comparable to those available in commercial **GIS** packages and the programming efforts also tend to be intensive and sometimes redundant.

In addition, we should recognize that **individual researchers** developed most urban modelling software packages, and these packages oriented to specific projects. Although they have common conceptual framework, these urban modelling packages use a **great variety of data structures**, **programming tools**, and **hardware platforms** that make this approach very difficult for non-technical users.

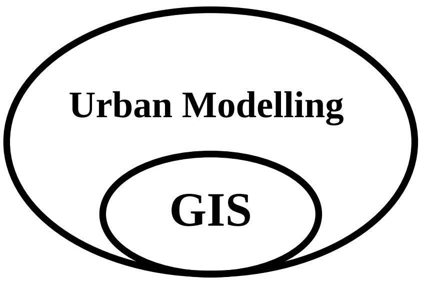

Figure (3-19) Embedding **GIS** into urban modelling

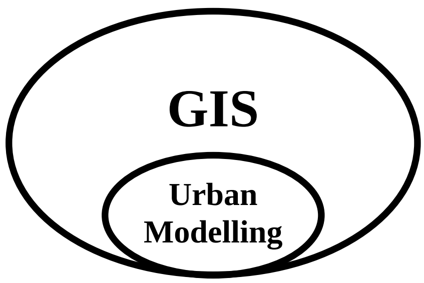

Figure (3-20) Embedding urban modelling into **GIS**

b) Embedding urban modelling into GIS by software vendors

A few leading **GIS** software vendors in recent years have made extra efforts to improve the analytical and modelling capabilities of their products, **several commercial software vendors have developed stand alone GIS software packages with functions that can be used for a variety of urban modelling needs** (Ferguson et al. 1992).

Certain urban modelling functions have been embedded in leading generic **GIS** software packages, such as **TRANUS** [(1)], **TransCAD**, and **ArcGIS** extensions *(Spatial and Network Analyst)*. However, these modelling capabilities are still simple and the calibration stage must take place outside of the **GIS** package.
Also the market for modelling capabilities is still much smaller than that for data management and mapping, **most GIS software vendors have unenthusiastic in integrating sophisticated modelling capabilities in their software products**.

c) Loose coupling

This approach usually incorporates a standard **GIS** package *(e.g., ArcGIS)* and an urban modelling program *(e.g., TransPlan or Trips)* or a statistical package *(e.g., SAS or SPSS).*
The advantage of this approach is that redundant programming can be avoided, but the data mixing and conversion between different packages can be tedious and error prone.
This approach may be the most realistic method for most planners, who use GIS to conduct and test new modelling efforts, **because computer programming is minimal**.

d) Tight coupling

This approach embeds certain urban models with a commercial **GIS** software package via either **GIS** macro or traditional programming techniques. Due to the users need to develop customized applications, **GIS** software vendors are providing **macro** and **script programming capabilities** so that, users can collect or gather a series of individual commands in a batch mode or develop a customized user interface for specific applications.

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(1) *more details about the **TRANUS** model will discuss in Chapter Four, section 4-4-5*

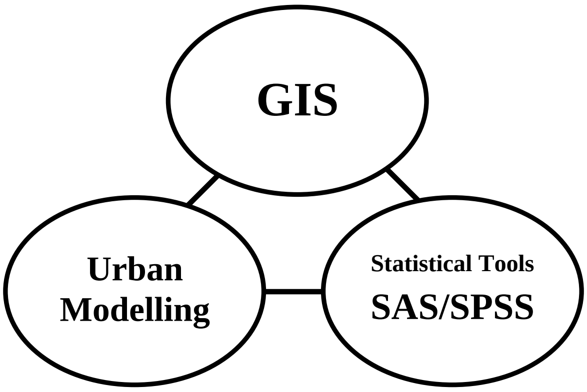


Figure (3-21) Loose coupling

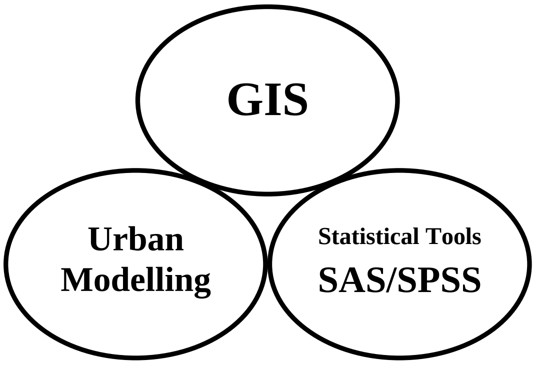


Figure (3-22) Tight coupling

Such languages are seldom powerful enough to implement sophisticated models; however, an alternative method is to incorporate user written routines into a **GIS**.
Several software packages have already developed mechanisms to allow **user-developed modelling libraries or routines** to be run within the normal **pull down** menu of a particular **GIS** package. This approach requires a **well-defined interface** to the data structures held by the **GIS**.

The future challenge will be to develop <u>new generic techniques</u> for all users to access spatial data without needing to know about the particular data structures used in the GIS (Daniel Z. Sui. 1998).

The first two approaches lend the integration effort to software developers; users have minimal involvement in the technical aspects of the integration, whereas **the third and fourth approaches** put the technical task of integration on the shoulders of the users.
Although **GIS** software vendors have increasingly recognized the importance of analytical and modelling capabilities, most of the recent **GIS-base urban modelling efforts are made via the <u>loose</u> or <u>tight</u> coupling approach** (Daniel Z. Sui. 1998).

(3-4) Cellular Automata and Urban Modelling

As shown in the previous section, the current **GIS** technologies do not have a dynamics modelling capabilities. To achieve the thesis aim, which intends to develop a **realistic urban dynamics model** that can model and predict the emergence and growth of **I**nformal **H**ousing, it will be useful to seek the contribution of other dynamic tools that will support the spatial capabilities of **GIS**.

Urban **Cellular Automata (CA)** have been developing rapidly for the simulation of **dynamic urban systems** since the late of **1980** , **C**ellular **A**utomata **(CA)** are becoming increasingly used as dynamic modelling tools, because they are **simple to build**, **flexible to formulate**, and **capable of generating complex patterns** that can emerge from historical evolution trends [(1)]. Also, **CA** models are **discrete dynamic systems** based on **transition rules** that are simpler than complex mathematical equations, and can produce more comprehensive results.

Cellular **A**utomata thus, appears to include a plausible additional conceptual framework able to complement the **GIS** tools to manage informal urban factors. Specifically, **CA** can assist in developing the **simulation and prediction component** of the proposed growth model, which can be incorporating and running within a current **GIS** framework.

This section will discuss **C**ellular **A**utomata **(CA)** from these points:

- Introduction to **C**ellular **A**utomata, including the history of **CA** and its theoretical formulation,
- Basic principles of **C**ellular **A**utomata,
- **C**ellular **A**utomata operation, *(The Game of Life)*
- Types of **C**ellular **U**rban **M**odels **(CUM)** and their calibration,
- Representing real cities using **CA** approach, through some examples and attempts to model real urban dynamics using **CA**,
- Limits and strengths of **C**ellular **A**utomata.

[(1)] http://www.geosimulation.org/geosim/cellular_automata.htm

(3-4-1) Introduction and History of Cellular Automata

The history of **C**ellular **A**utomata **(CA)** dates back to the **1930's**, when **Alan Turing** proposed a hypothetical machine with limited specifications and ranges of action. This machine was **capable of computing anything** that could be computed, **using simple rules** and given an **appropriate initial state**, this machine *(or **automaton**)*, could **evolve into a replica of itself** and have **the ability to produce additional copies**. Hypothetically, this "***Universal Turing Machine***" was the one **meta-machine** needed to build any complex system (Stephenson, 1999).

In **1940**, based on **Turing's** work, **Stanislas Ulam**[(1)], this mathematician was interested in the evolution of graphic constructions generated by simple rules. The base of his construction was a two-dimensional space divided into "***cells***". Each of these cells could have only two states: **ON** or **OFF**.

Starting from a given pattern, the cell state at next generation was determined according to:

- **The current cell state**,
- **The states of surrounding** *(or neighboring)* **cells**,
- **The defined local transitional rules**.

For example, if a cell was in contact with **two** "**ON**" cells, it would switch "**ON**" too; otherwise it would switch "**OFF**". **Ulam**, quickly noticed that this mechanism permitted to generate complex and graceful figures. These figures could, in some cases, *self-reproduce.* **Extremely simple rules permitted to build very complex patterns**.

After he discovered this mechanism, **Ulam** suggested **von Neumann**[(2)], to use what he named ***"cellular space"*** as a possible idealization of biological systems, to model his **self-reproductive machine**, (Von Neumann, 1966). They developed **C**ellular **A**utomata **(CA)** as a framework for investigating the logical rules and factors underpinning the life.

---

(1) **Stanislas Ulam**, worked on Monte Carlo simulation and the Manhattan Project atomic bomb.

(2) **John von Neumann**, *the founder of game theory and pioneer in set theory and quantum mechanics*, he was interested in the theory of **self-reproductive** automata and worked on the conception of a **self-reproductive** machine.

"They were interested in exploring whether the self-reproducing features of biological automata could be reduced to purely mathematical functions, whether the forces governing reproduction could be reduced to logical rules" (Torrens, 2000).

After that, they have been applied the concept of **Cellular Space** for a wide variety of purposes, and referred to by a variety of names, including "**tessellation automata**", "**homogeneous structures**", "**cellular structures**", "**tessellation structures**", and "**iterative arrays**".

Therefore, the concept of **C**ellular **A**utomata **S**pace **(CAS)**, were originally conceived in the **1940s** by **Ulam** *(who invent the cellular idea)* and **Von Neumann** (*who invent the automata idea*) to provide a framework for investigating the behavior of complex and extended systems (Schatten, 1999). [(1)]

Thus, a **cellular space** qualifies the basic component of the space, while an **automaton** is a self-organizing element that performs logical and continuous programmable instructions and rules.

> So, the following question was asked, **can these repetitive mechanisms** *(i.e. the state of any element depends on its own previous state and its neighborhood states)* **explain the complexity of the real world? And used to simulate urban emerge and sprawl through some logical conditions and transition rules**.

[(1)] This article available at: http://www.ifs.tuwien.ac.at/~aschatt/info/ca/ca_print.html.

(3-4-2) Basic Principles of Cellular Automata

Cellular **A**utomata **(CA)** in its original format can be understood as a mathematical idealization of physical and dynamic systems in which **space** and **time** are discrete, and physical quantities take on a finite set of discrete values (Semboloni, 1997). The basic idea behind **C**ellular **A**utomaton is not to try to describe a complex system by using difficult equations, but simulating the system by interaction between cells through pre-defined rules.

A **C**ellular **A**utomaton consists of **five** main elements as follows:

1) **A "cell space"** is a regular uniform and infinite "lattice" or "grid" with discrete variables at each cell, *(e.g., an urban space)*. Lattice space has ***(n)*** dimensions; **two-dimensional CA** is the most common in urban dynamics simulation, as shown in Figures (3-23 to 3-26). On the other hand, few urban studies have used **three-dimensional CA**.

   In mathematical terms, the cell space can be expressed as:

   $$\mathbf{L = \{ (\mathit{i,j}) \mid i , j \neq \infty,\ 0 \leq i < c ,\ 0 \leq j < r \}},$$

   Where: **L** is the lattice, ***(i)*** and ***(j)*** are the number of **columns** and **rows**, located in the lattice with the maximum number of columns ***(c)*** and rows ***(r)*** of cells.

2) **A "cell"** *(or a site)* is a single element in the entire lattice *(or space)*, in other words **a cell** is a **sub-unit** of a regular geometrical grid, which usually in a rectangular form, **a cell** can be formulated as an irregular polygon, hexagon or a link. During the simulation *(or the changing of state)*, cells react on the entire lattice, according to a set of transition rules. Although representing only **one state** at **the time**, a cell can encapsulates an infinite number of states variable, depending on its geographical location and attributes.

3) **A "state"** is a variable, which takes a different value at each **site** or **time**. It can be a property, a number or word **(0 or 1, urban or non-urban)**. It can vary from two to **29** states (Von Neumann, 1966). The variables at each site are updated synchronously.

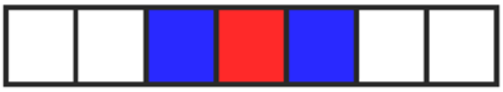


Figure (3-23) One dimensional **CA** grid with **three** neighbors on a lattice of **7** cells

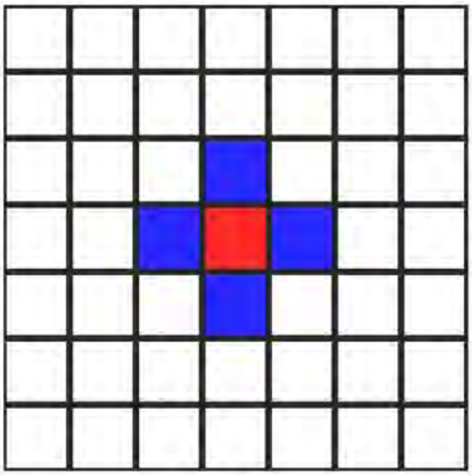


Figure (3-24) Two dimensional **Von Neumann (5)** neighbor possible cells

4) **<u>The "neighborhoods"</u>**, these are the cells physically closest to the central examined cell, which might influence its value at the next step.
During the simulation, the neighborhood cells act as zones of impact for the central cell. The neighborhood matrix includes the cell itself.

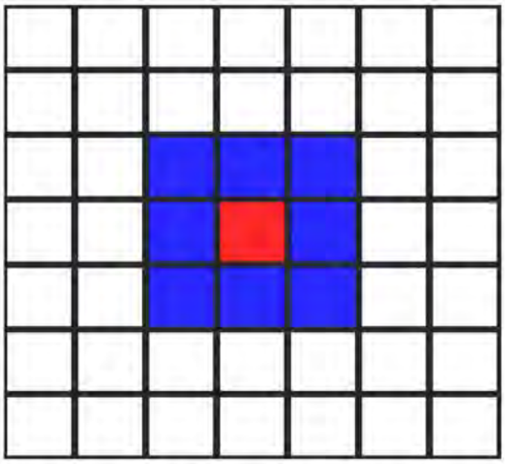


Figure (3-25) Two dimensional **Moore** neighborhood matrix, ***(r =1)***

Many types of neighborhoods can be identified, in the case of **two-dimensional raster based CA models**, the commonly used neighborhoods type are:

a) **Von Neumann** matrix with **<u>five</u>** neighbor possible cells, Figure (3-24),
b) **Moore** matrix with **<u>nine</u>** neighbor possible cells, Figure (3-25),
c) **Extended Moore** matrix with **<u>25</u>** neighbor possible cells, Figure (3-26).

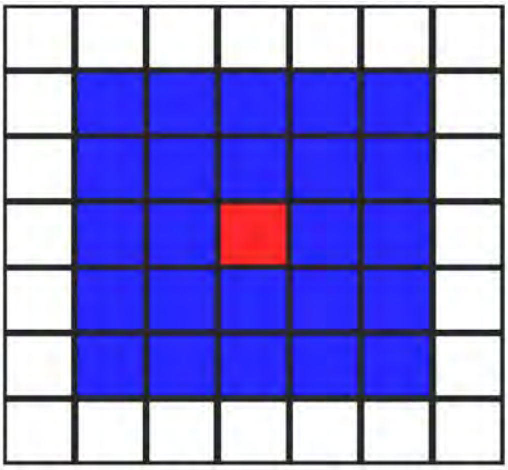


Figure (3-26) **Extended Moore** neighborhoods matrix, ***(r =2)***

In the literature, **there are many other neighborhood types,** applied to the **CA** models of urban growth**,** according to the **geometrical pattern of the cities**, the influenced urban area can be divided into two zones

Inner zone corresponds to the area where the urban growth is considered finished or slow dynamics of transformations.

Outer zone corresponds to the area where the urban growth is considered still ongoing or faster (Barredo et al., 2003).

According to this fractal structure, two zones are defined in a neighborhood type: **inner** and **outer** on which development of the cell depends.

Based on this structure, Figure (3-27 c, d) shows the **rectangular** neighborhood types, and Figure (3-27 e, f) shows the **circular** neighborhood types.

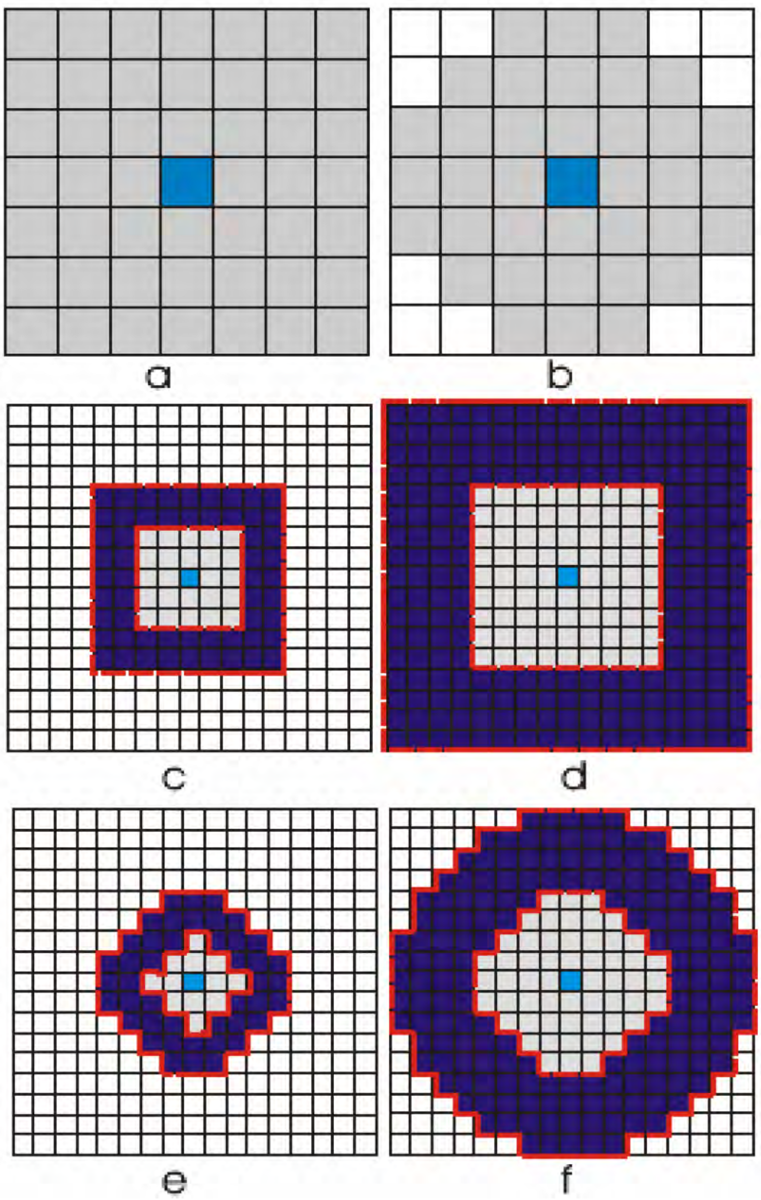


Figure (3-27) Sizes and types of neighborhood matrices

a) rectangular neighborhood;

b) circular neighborhood;

c) small rectangular neighborhood (inner: 2 cells, outer: 4 cells);

d) large rectangular neighborhood (inner: 4 cells, outer: 8 cells);

e) small circular neighborhood (inner: 2 cells, outer: 4 cells);

f) large circular neighborhood (inner: 4 cells, outer: 8 cells).

Two different sizes were specified to represent the size of **small** and **large** neighborhood matrix. The inner size of the **small** neighborhood matrix is **2** cells and of the **large** is **4** cells surrounding the central cell. The outer size is also defined to contain **4** and **8** cells for both **small** and **large** neighborhood matrix, respectively.

5) **Local or transitional "rules"** are a set of conditions or functions that define how each cell's state changes according to its current state and that of its neighbors. **The future state of any cell is determined by the transitional rules in a discrete time frame**. There are many different neighborhood models, of which **von Neumann** and **Moore** neighborhood is the most applied one. For example, the **Moore** neighborhood matrix is expressed as:

$$N_{ij} = \{(k,l) \in L \mid |k - i| \leq 1 \text{ and } |l - j| \leq 1\},$$

Where: **L** is the lattice, ***(i)*** and ***(j)*** are the number of **columns** and **rows**, located in the lattice with the maximum number of **columns *(l)*** and **rows *(k)*** of cells and the neighborhood search radius ***(r)*** = 1.

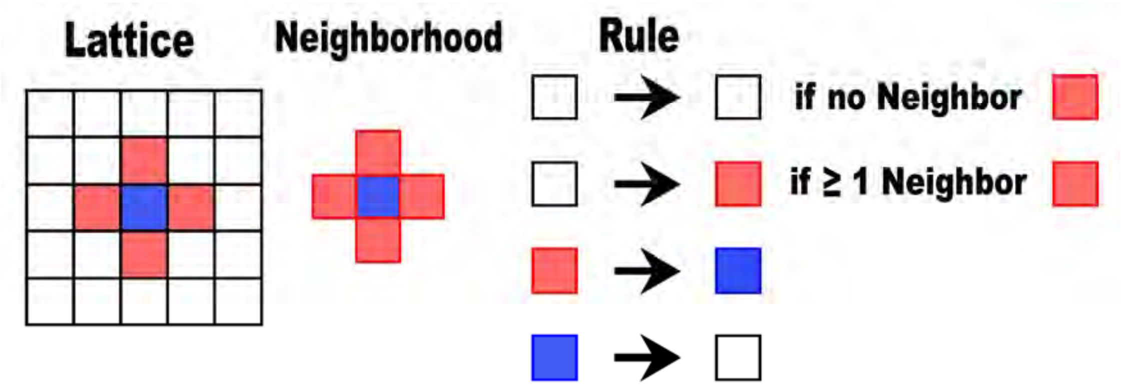


Figure (3-28) **C**ellular **A**utomata components: lattice, neighborhood, rules and states
(Source: freely adapted from Sietchiping, R. 2004)

*Other properties of **CA** include **animation** and **dynamic visualization**. **CA** behaves in accordance with the principle of **"think locally, act globally"**. That is, it can encapsulate specific and smaller details that define the bigger picture.*

In relation to urban modelling, **CA** can assist in developing a growth model to show the **interaction** and **contribution** of various growth factors that are influencing the future expansion of **informal housing**.

According to the **"bottom-up"** approach of **C**ellular **A**utomata, **CA** applications pay particular attention to detail and are spatially and temporally explicit. This capacity to integrate **spatial** *(geographic location)* and **temporal** *(time series)* dimensions makes **CA** very attractive technique for the development of powerful and reliable urban dynamics models.

The proposed urban dynamic model **(IHGM)** in this thesis has many reasons to use **CA** as a dynamic tool:

- **a)** With the aim to correct the weaknesses of traditional urban dynamics modelling,
- **b)** The potential for integrating **CA** with **spatial technologies**, such as **GIS**,
- **c)** Explore new possibilities to improve operational urban modelling, particularly with regard to the prediction of dynamic visualization of informal urban evolution and growth.

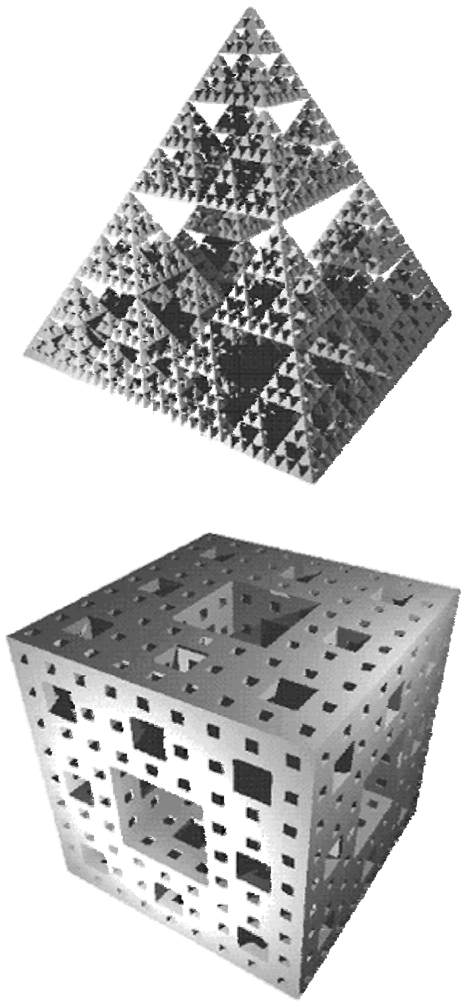


Figure (3-29) Examples of **three-dimensional CA** attempts

(3-4-3) Cellular Automata Operation *(The Game of Life)*

Originally, the **C**ellular **A**utomata operation is presented as a mathematical operation. Its description will allow us to materialize and better understand what **CA** are? Like **Ulam's** cellular spaces, the universe is limited to a rectangle of **5** by **3**. To make the explanation easier, we numbered the cells from 0 to 4 horizontally and from 0 to 2 vertically. Light cells are active ones, as shown in Figure (3-30).

In **CA** operation, any adjacent cell is considered as neighbor, including the diagonals of the examined cell. Figure (3-31) shows the neighborhood of cell **12**. In this case, **two** cells are active out of the **eight** neighbors.

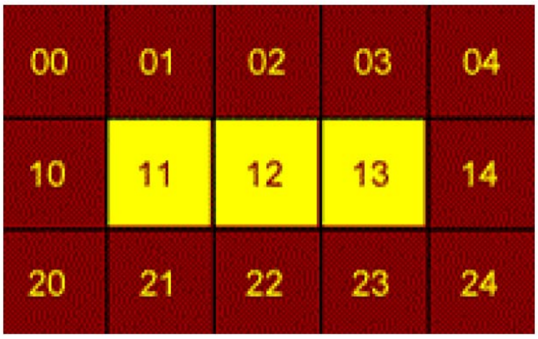


Figure (3-30) Example of a starting pattern

The transition rules are quite simple:

1- **If one inactive cell surrounded by three active cells, it becomes active** *"it's born"*;
2- **If one active cell surrounded by 2 or 3 active cells, it remains active**;
3- **In any other case, the cell** *"dies"* **or remains inactive**.

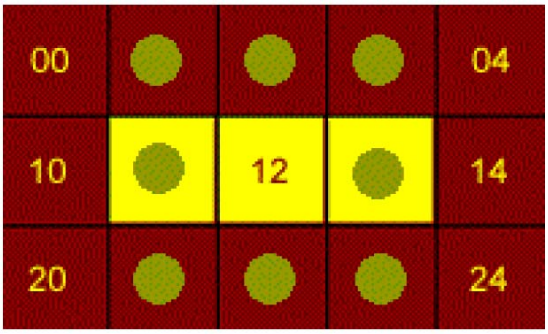


Figure (3-31) Determination of neighborhood

We can illustrate these rules by considering that a birth supposes a certain gathering of population, *(3 in this case)*, **that the cells cannot survive to a too wide isolation** *(less than two neighbors)* **and that a too strong concentration will kill them** *(more than three neighbors).*

CA work in a ***discrete*** manner. **That is to say, time goes step by step**. This means that in our case, for the generation, each cell examines its **environment** and **determines its future state**.

When all the cells have fulfill this computation, the transitions occur. We can illustrate this mechanism starting from the previous pattern, in Figure (3-32); the number of active neighbors is noted for each cell as follows:

1- The cells **00**, **04**, **10**, **14**, **20**, and **24** have got one active neighbor and then remain inactive.

2- The cells **01**, **03**, **21**, and **23** have got two active neighbors, and then do not change.

3- The two inactive remaining cells (**02** and **22**) have got three active neighbors, the rule **one** is applied: they are born.

4- The cells **11** and **13** have only one active neighbor, **so they die**.

5- Finally the cell **12** having two active neighbors, so it remains alive.

For the next generation, only the cells **<u>02, 12, and 22</u>** are then active, as shown in Figure (3-33).

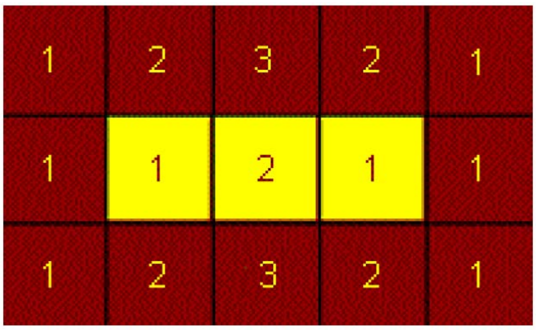


Figure (3-32) First generation

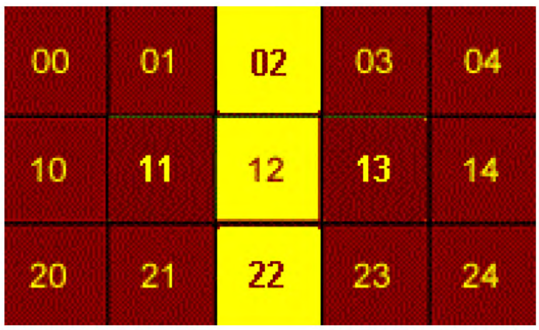


Figure (3-33) Second generation

<u>We can here observed **three** fundamental properties of **CA** concept:</u>

a) ***<u>Parallelism:</u>*** A system is said to be parallel when its elements evolve simultaneously and independently. So, the cells are updated independently of each other.

b) ***<u>Locality:</u>*** The new state of a cell only depends on its actual state and on the states of its neighbors.

c) ***<u>Homogeneity:</u>*** The rules are universal, that is to say the rules are common to the whole space of **CA**.

(3-4-4) Types of Cellular Urban Models and their Calibration

The **C**ellular **A**utomata **U**rban **M**odels **(CAUM)** can be classified into **three** main types as follows:

- **<u>The first type</u>** uses **CA** approach to generate results that can be explained by urban theories. These models are used to test urban ideas and assumptions for utopia cities. For example, **Webster and Wu** (1999) present an interesting **CA** model to implement urban theories concerning developers ***"profit seeking and communities"*** welfare-seeking behaviors.

- **<u>The second type</u>** uses **CA** models to simulate the real cities. **Clarke and Gaydos** (1998) apply **CA** model to simulate and predict urban development in the **San Francisco Bay region in California** and **the Washington Baltimore corridor in the Eastern United States**.

  Also, White et al. (1997) provides a realistic simulation of the land use pattern of **Cincinnati, Ohio.**
  In addition, **Li and Yeh** (2000) develop a constrained **CA** model to simulate urban expansion and agricultural land loss of **Dongguan in the Pearl River Delta**, a rapidly growing area in **southern China**.

- **<u>The third type</u>** uses **CA** models to develop **normative planning models** in orser to simulate different urban forms based on planning objectives. <u>For example</u>, **Yeh and Xie** (2001) have used **CA** macro to generate different urban forms, ranging from **mono-centric** to **poly-centric** urban development. These urban forms can be assessed to meet selected criteria for sustainable development through <u>minimizing agricultural land use in an effort to achieve compact development</u>.

Ward et al. (2000) also develop a constrained **CA** model which has been applied to an area in the **Gold Coast**, a rapidly urbanizing region of eastern **Australia**. They have demonstrated that how **CA** models can simulate **planned development** as well as **realistic development** by incorporating sustainable criteria in the simulation process.

The goal of urban models is to simulate some aspect of the urban system. If a model is developed for a specific city or region, its applicability to another location is likely to be impossible. In this case, **the model's use is quite limited**.
Conversely, if a model simulates characteristics that are general to the process of urbanization, such as edge growth, **in-filling urban gaps**, and considers the urbanization along transportation networks *(i.e., better accessibility to road network attracts more urbanization)* **then, the usefulness of the model is greatly increased**. Such **a general purpose model may be applied to multiple cities and can adapt for new application through the process of calibration.**

The objective of **model calibration** is to determine the numerical values of the model coefficient that can best fit the historical development and tend to guide the direction of future expansion. Unfortunately, there is no universal applicable method of calibration due to the complexity of nature. **Another reason** is that no general procedures have been well developed. On the other hand, there are very limited studies in addressing the calibration issues in **CA** models.
This is because the computational requirements of CA calibration are considerable while forecasts are generated relatively easily.

The model coefficients are initialized at some date in the past, then it used to **predict** land use change and future urban expansion. This methodology has been used successfully in several applications (Candau and Clarke, 2000), as follows:

- **Wu and Webster** (1998) used **M**ulti-**C**riteria **E**valuation **(MCE)** approach to define the values of parameters for **CA** simulation.
- **Clarke et al**. (1997) proposed **CA** model by using several spatial and statistical metrics to quantify how well simulated urban extent matched historical data gathered from maps and remotely sensed data for several periods in the past.
- **Clarke and Gaydos** (1998) suggested that calibration can be done by statistically testing the observed growth against the expected. These methods are very time-consuming because they need to compare all possible combinations of parameters. Another problem is that the combinations are infinite and an effective procedure is difficult to design.

(3-4-5) Review of Cellular Automata Urban Modelling Attempts

Since the **1970s**, **CA** has been regarded as a useful tool to simulate and model various urban systems and sub-systems such as **traffic**, **transportation**, **urbanization**, and **land use changes**. Although **CA** initial applications have been limited to test urban theories, hypothesis and generating the utopia, however the real applications have been rare.

From the **1990s**, **CA** operational urban models started to explore real patterns, some strict principles of **CA** have been reduced to achieving more realistic simulations (Almeida *et al.* 2002). In this section, we will review some examples of **C**ellular **A**utomata **U**rban **M**odelling **(CAUM)** applied to real world data, highlighting the <u>achievements</u> made but also pointing out some of these <u>models limitations</u>.

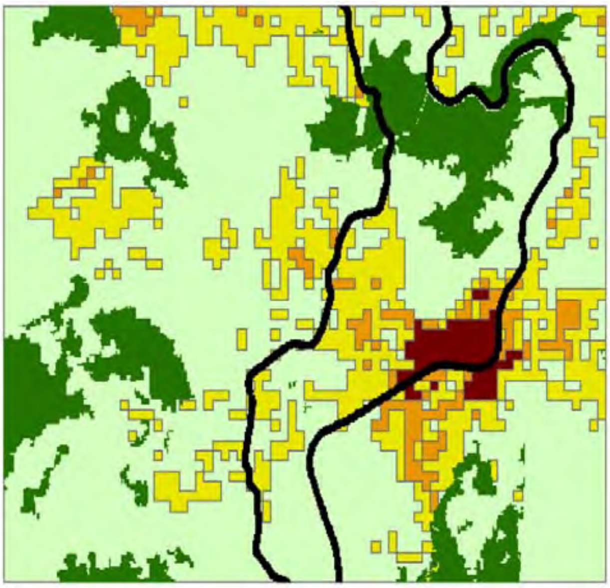


Figure (3-34) Representing various urban features with raster format

- **<u>First:</u> in the 1993s**, **White & Engelen** have used **CA** to explore the spatial structure and temporal dimension of urban land use pattern and to test general theories of urban evolution. **The cellular model generated patterns for each land use type**, then these patterns are compared with real data represents a set of **US cities**. <u>The results showed good representations of actual urban form, suggesting that **CA approaches** could used to achieve a high level of real spatial data representation.</u>

- **<u>Second:</u> in the 1997s**, **White & Engelen**, implemented **CA macro** to model and predict the **land use change** of the City of **Cincinnati in USA**. In fact the **first** and **second** models were **successful to model and cover a small area only**. But these models neglect the importance and size of some areas *(like **CBD**)* with compared to other parts of the city. Furthermore, these models only <u>deal with relatively little data</u> and <u>the prediction period was too short</u> to be realistic.

- **<u>Third:</u> in the 1999s, Batty *et al.*,** build urban dynamics hybrid software that combines the strengths of both **GIS** and **CA**. Their **D**ynamic **U**rban **E**volutionary **M**odelling, (**DUEM**) software is written in **C++** language and designed to achieve both hypothetical and realistic simulations. They recommend that, even in cases where **CA** has been extensively used as an urban simulator, the **real world** *(spatial)* data need to be incorporated with powerful ways.

- **<u>Fourth:</u> in the 2004s**, **Metin Senbil, *et al.***, have developed a cellular automata model for land use evolution to simulate the planning theories, which discussed the spread of urbanization along main roads and transportation axis.
  This model based on **<u>the choice of transition probabilities as cellular automaton rules</u>**. The model assume that, we have **<u>four</u>** time points of data collected about the land use types and related attributes on each cell.

The city is assumed to be one centered city at the first time period, and the only determinant of land use development is assumed to be the **transportation network**. **The transportation network develops at <u>four</u> periods as follows:**

- **<u>T1:</u>** A rail road is constructed, thus suburban communities emerged at distant areas formed small centers,
- **<u>T2:</u>** A roads are constructed parallel to the railroad,
- **<u>T3:</u>** Radiating roads from the center are constructed, as well an outer loop for the city connecting suburban centers has also been constructed,
- **<u>T4:</u>** An inner circular road is constructed around the city.

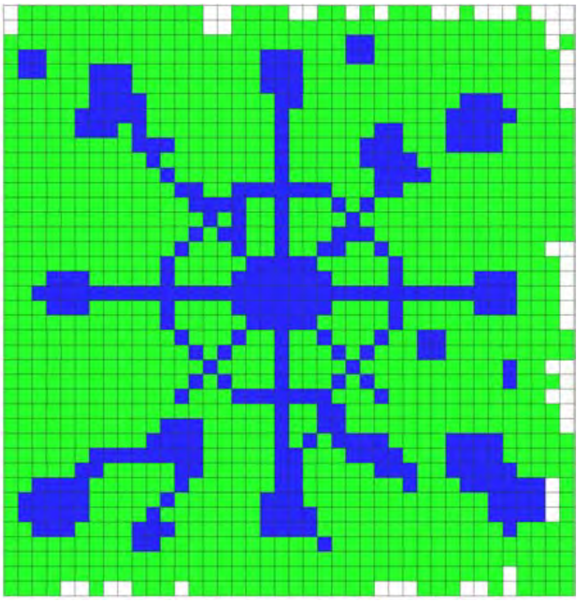


Figure (3-35) The resulted land use development after transportation investment on diagonals

The estimated model is used to predict the future land use patterns of the Mexico City, the following figures illustrate the model results:

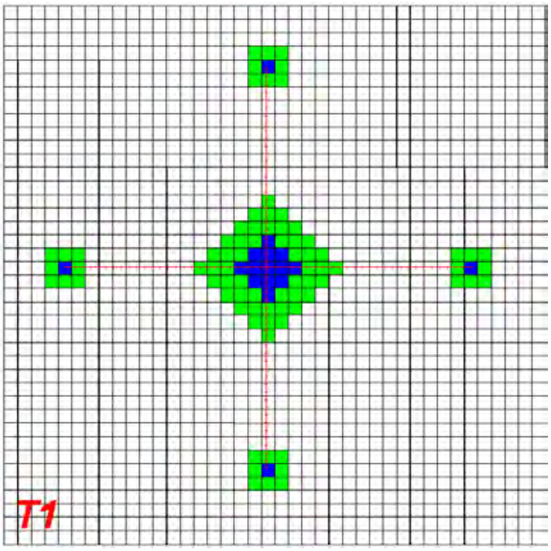


Figure (3-36/A) **Land use at the first period**

(Rail transit city with four suburban communities)

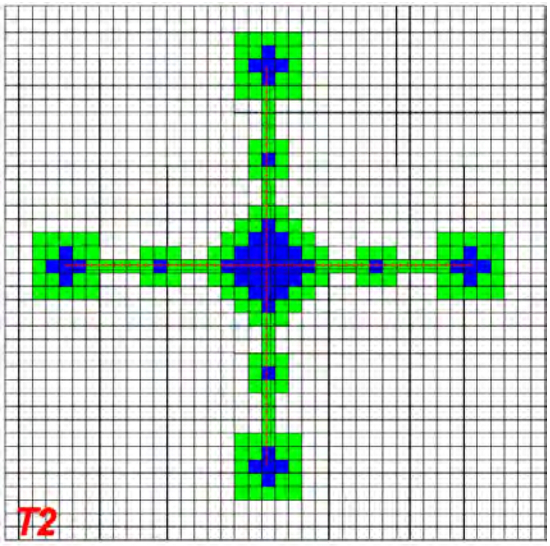


Figure (3-36/B) **Land use at the second period**

(Suburban communities are connected to the city by roads)

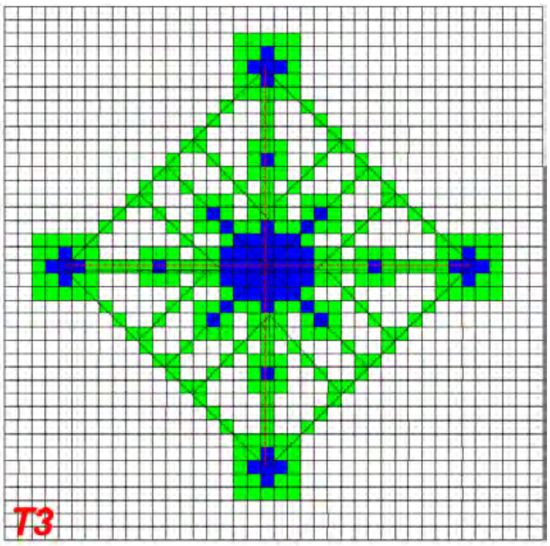


Figure (3-36/C) **Land use at the third period**

(New roads radiating from the city and an outer loop connecting suburban centers have been constructed)

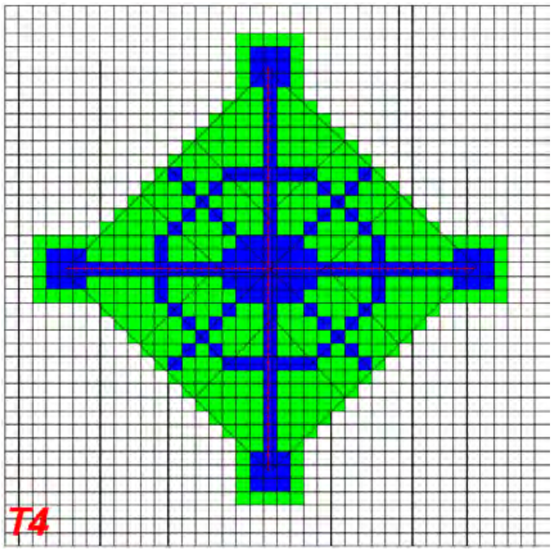
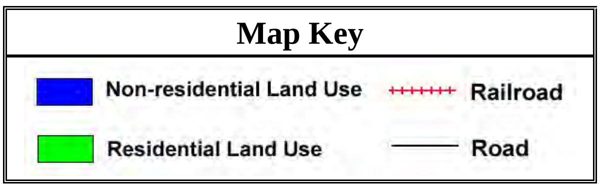


Figure (3-36/D) **Land use at the fourth period**

(A circular new road has been added)



On the other hand, some researchers explain that, while **CA** models can successfully simulate real urban dynamics, but the urban simulation attempts by means of **CA** are more relevant for **theoretical and educational investigation, rather than useful real world applications** (Almeida *et al*., 2002). Furthermore, many researchers in urban modelling suggest that **CA** should integrate with other **spatial techniques** to improve the **real world** representation (Batty & Xie; 1997; Xia & Yeh, 2001).

Many of the urban dynamics models implemented using only a CA approach, these attempts have performed poorly in generating realistic patterns. Some limitations can be related to the lack of input and output of attribute data into a **CA** framework, and the difficulty of capturing **top-down** approaches.

The trend is, however, to relax the initial principles and configurations of **CA**, by making them more **sensible** and **flexible** for realistic representation, **and to integrate CA with other spatial technologies such as GIS**.
In light of the **CA** capacities and in relation to its applications, the **GIS** contribution could assists in **data input**, **manipulation**, **visualization**, **data comparing**, and **output**, while **CA** could perform functions such as **calibration**, **transitional rules**, **parametric analysis** and other **modelling functions** beyond **GIS** capabilities.

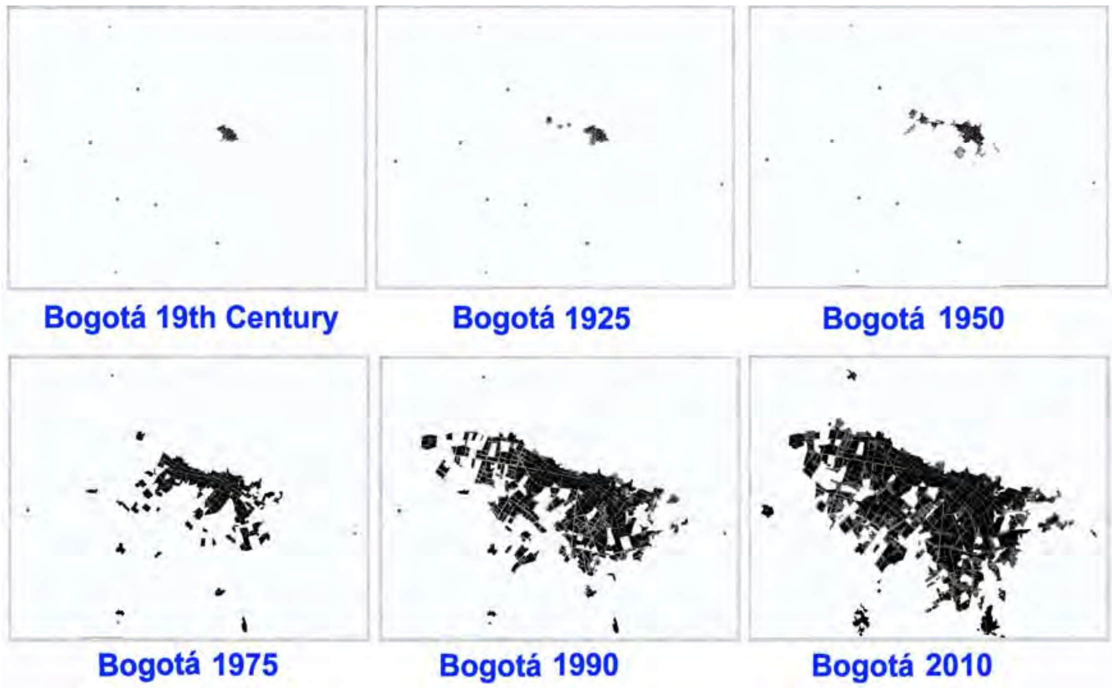


Figure (3-37) The expected urban growth for **Bogotá** the capital of Colombia (Jairo A. 2004)

(3-4-6) Limits and Strengths of Cellular Automata

Conceptually and theoretically, a **C**ellular **A**utomaton has some **limitations** and **advantages** with regard to the development of an urban dynamics framework. This section first discusses some of the **CA** limitations, and how they can be overcome, and then expands on **CA** strengths to improve **"real world"** simulation and modelling.

a) Cellular Automata Limitations:

1- The original framework of **CA** is not designed to inform and support realistic urban dynamics. For instance, the original structure of **CA** is reported to have been **too simplistic** and **limited** to apply in real urban applications. Specifically, the original concept of cells is considered **not suitable** for urban dynamics studies because not all spatial patterns have a regular grid form (Batty et al., 2001). (1)

2- The idea of an **infinite space plane** *(two-dimensional)* and **uniform regular space** is not reasonable to apply on the city because cities are not infinite, regular, or uniform.

3- The idea of studying the state of neighboring cells is **too coarse** and does not **take external factors** and distance decay actions into consideration.

4- The original framework of **CA** only takes a **bottom-up approach**, and **accounts for local entities** that ultimately define the overall representation of the space. Generally, All elements of urban systems, however, do not represent only **bottom-up behavior** *(e.g., planning decisions, national policies, macro-economy, etc….,)* (Sietchiping, R. 2004).

5- **CA is restricted to general rules and does not create its own dynamic**. In real urban contexts, not all changes in the systems are produced by the same force or mechanism. Also in some cases, urban elements can react differently to the defined transition rules.

However, **the previous limitations of the CA architecture can be progressively overcome to develop comprehensive urban dynamics models**, **especially when associated with other spatial tools**. **So applying the CA framework in urban dynamics studies requires a continuously improvements to generate**

(1) This article available at: http://www.cybergeo.presse.fr/ectqg12/batty/articlemb.htm.

a realistic urban patterns. The original **CA**, transition rules are universal and applied synchronically to all cells. **In real urban processes and forms, no single rule controls the behavior of the entire system**.

To solve the rigid **CA** transitional rules, the transition rules of urban dynamics **CA** models can be formulated by using **Boolean statements**, and **probabilistic expressions** such as **IF, THEN** and **ELSE**. **The flexibility thus gained in these expressions, simplifies the representation of more complex systems** (Sietchiping, R. 2004).

b) Cellular Automata Advantages :

Recently, **C**ellular **A**utomata represent a useful tool for understanding urban dynamics, **White and Engelen** (1993) have demonstrated a **C**ellular **A**utomata approach, that can lead to a better understanding for urban patterns, as well as representing realistic patterns, the advantages of **CA** can summarized as follows:

1- The **strengths** of **CA** lie in their capacity to perform dynamic spatial modelling over a discrete period and continuous **plane space**, *(two-dimensional space).*

2- **CA** has several features that make them seem natural tools for simulating urban dynamics. Cells can represent many of the elements that make up an urban system: **built pattern**, **parcels**, **topography**, **census units**, **automobiles**, **traffic analysis zones**, ...**etc**.,

3- The **cell states** may be assigned for the attributes of an urban area. A simple example is the binary attributes of **urban/non-urban**. Various other attributes can be used, such as **population density**, **transportation elements**, **land use types**, **land cover**, ...**etc**.,

4- The flexibility of transitional rules that can embedded into **CA** architecture favors a better **"control"** over the dynamic patterns that are generated. **The transition rules can be formulated to mirror how real urban systems operate, and then coded as algorithms "macro" within the simulation process** (Torrens, 2000).

Hence, by placing urban elements as attributed cells within a dynamic CA program, urban processes may be studied as an artificial system. Whereas, CA has the ability to exhibit clear spatio-temporal dynamics

Other work has shown how **CA** models can be integrated with other spatial techniques, to improve the representation of urban features. The important role of using complex systems such as **C**ellular **A**utomata to **discover**, **understand**, **and explain** how cities emerge and change is now well established (Portugali, 2000).

The following part will demonstrate the previous attempts and researches that show how **CA** can be used in urban dynamics modeling:

- **First:** **Hägerstrand** (1968) started to represent the **CA** in geography, as a diffusion models. In his representation of a society with a **"robotic life"**, Hägerstrand highlighted the major components of current **CA** architectures: **discrete time**, **current cell state**, **neighborhood matrix size and its cells states**, **uniform transitional rules** and **lattice**. The investigation of Hägerstrand was limited by the capacity of the simulation *(less than 200 cells)*, yet it was theoretically and conceptually well formulated.

- **Second:** **Tobler** (1970) started to develop a forecasting model based on urban growth. He called it a **"computer movie"** and the description was so close to the current **C**ellular **A**utomata. In fact, **Tobler's** study laid the theoretical and conceptual foundation of **C**ellular **A**utomata **(CA)** for future applications in geography.

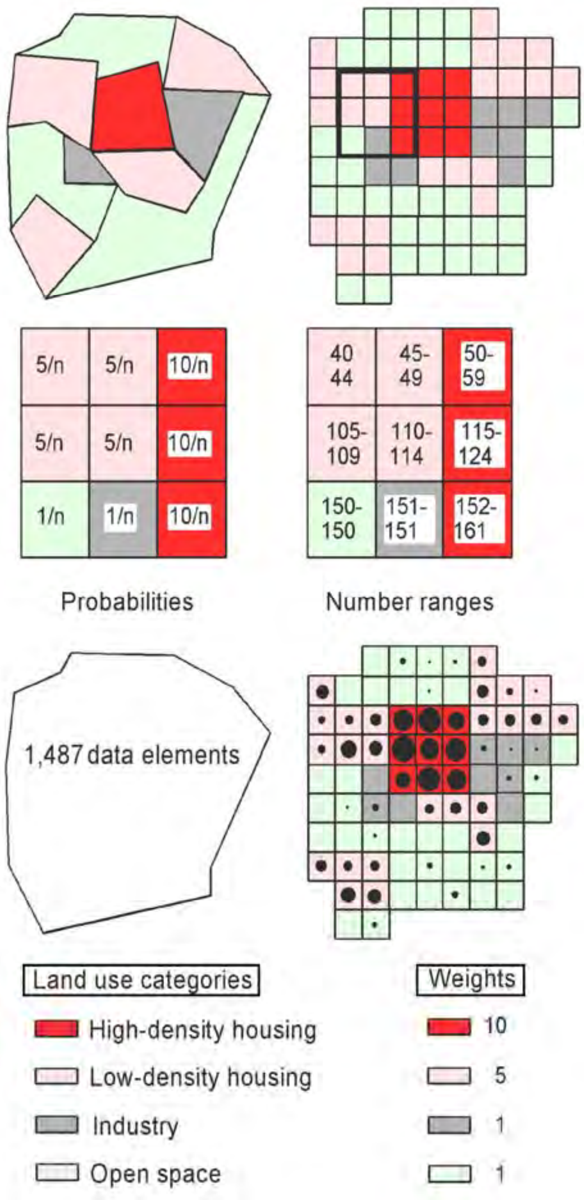


Figure (3-38) Dis-aggregation of zones to raster data

(Source: Spiekermann and Wegener, 2000)

In **1979**, he published a paper formalizing the concept of **CA**, and opening the way for geographers to use **CA** for planning applications, spatial modelling and simulation.

- **Third:** **Couclelis** (1989) in the same essence, demonstrated how **CA** might be used as a systematic approach *(or metaphor)* to study how different varieties of urban dynamics that might arise. **Couclelis claims that, although CA is not originally intended to produce realistic representations of urban dynamics, it can be reformulated and integrated with some spatial models to form better predictive models**.

(3-6) Conclusions

From this Chapter we have shown that, two main stages have emerged from the review of urban modelling research based on **CA**, **GIS** and their **integration**.

The first period *(from 1940 to 1990)* was the development of the conceptual and theoretical framework. **The second period** *(since the 1990)* can be described as the increasing interest oriented to the applications of dynamic approaches; **first** in the utopia's cities and **second** in real cities. In particular, this Chapter demonstrates that *(in the field of urban modelling),* there is an indication of growing awareness that **the concept of equilibrium is no longer sustainable,** and the theory of complex systems *(theory of dynamics)* is dominant.

This Chapter also confirms that **real urban dynamics models** should consider the equal representation of **space**, **time** and **other key attributes**, and this can only be successfully conducted by the integration of many spatial tools.

The second part of this Chapter illustrates how **the improvements in computing tools and GIS technologies for the last thirty years have helped the development in the field of urban dynamics modelling and simulation.**

In particular, this Chapter demonstrated that, **GIS** is suitable for urban modelling and simulation *(by using its spatial capabilities)* by integration with **CA** *(by using its computation and mathematical capabilities)*, this integration well suited the needs of **real world** data to generate useful simulations. The characteristics of **CA** and **GIS** respectively have been highlighted, as well as their potentialities for developing comprehensive real modelling.

Application of urban dynamics modelling has been presented using either **GIS** or **CA** alone or integrated **GIS & CA** models. From the application review it is apparent that, the **GIS & CA** integration models is the **way forward to gain better insight into the process and form of urban dynamics simulation and modelling**.

After presenting the framework to build real urban dynamic models, the next Chapter will review existing urban dynamics models to assess their suitability to be implemented in an **I**nformal **H**ousing (**IH**) growth in **LDC**, especially the case of **GCR** in **Egypt**.

Chapter 4

Towards a Methodology to Select an Appropriate Predictive Model

(4-1) Introduction

Operational urban dynamics models **aim to inform urban theory and to support urbanization**. Similarly, the incorporation of complexity theory and spatial dynamics methods is increasingly looking forward to the emergence of useful urban dynamics models; therefore a realistic simulation of urban growth is becoming more available.

As a result, urban dynamics models can improve our understanding of the processes that support urban evolution and **I**nformal **H**ousing **(IH)** growth, as well as, our ability to predict more accurately their spatial distribution.

Previous Chapter highlighted the role of computer technologies, **GIS** and complex systems theories in the development of current urban dynamics models. **It also demonstrated how GIS and Cellular Automata (CA), taken separately, would not be able to develop realistic urban dynamics models.** Also, Chapter two proved that the integration of **GIS** and dynamics models such as **CA** has emerged as an important path into the regeneration of urban dynamics fields.

This new approach is progressively embedding spatial and temporal factors, not only for academic or theoretical purposes, but also as part of a **Decision Support System (DSS).** There are many attempts have been made to develop **knowledge-based** urban dynamics models, programs and software packages.

This Chapter will present a methodology to select urban dynamics models that could assist for understanding urban and **IH** dynamics in **LDC**. In addition, this Chapter will define the criteria that must be considered in relation to urban expansion and **I**nformal **H**ousing modelling.

This Chapter consists of three main sections as follows:

- **Section one** will discuss the main classifications of urban dynamics models.
- **Section two** will discuss the criteria that should consider in selecting the suitable model for a specific application, especially the unplanned growth in **LDC**.
- **Section three** will presents a complete review and comparison of the existing operational urban models, and their transferability to the context of cities in **LDC**.

(4-2) Classifications of Operational Urban Dynamics Models

A model is a simplified representation of a real life system, by representing reality with only those variables that truly affect the behavior of the system, and by clarifying the relationships between those variables, the assumed **"real world"** is broken down into a **sub-systems** that can be analyzed (US. EPA, 2000). (1)

There are many kinds of models, which have been developed by a host of diverse professionals, such as, transportation engineers, economists, biologists, demographic statistics, **urban prediction** and **urban planning** … etc.,

Models can range from simple spreadsheets to highly complex simulations that require the use of a super computer. **Simple models** provide rapid estimates with minimal effort and required data input. On the other hand, **complex models** provide the greatest level of accuracy, but they are usually much more costly in terms of data needs, hardware, software demands, and required professional expertise.

In **2003** Timmermans classified the urban models into **three** main generations as follows:

- **First generation** models are based on aggregate data and the principles of gravity.
- **Second generation** models are based on the principle of utility maximization.
- **Recently models** have been developed based on micro-data and activity travel patterns.

Generally, the current operational urban dynamics models can be classified into four different types according to its objectives and areas of interest:

a) Land use models.

b) Urban transportation models.

c) Economic models.

d) Environmental impacts models.

(1) This article available at: http://www.mnrg.gov/meetings/2005cimpacts/pdf/EPAreview.pdf

(4-2-1) Land Use Models

Land use models often incorporate a variety of land use categories, general categories *(urban and non-urban),* detailed categories *(such as residential, commercial, industrial, services and agricultural)* and more detailed categories that represent subclasses *(like population density, residential density, type of industry and agricultural type …etc,).*

The **three** levels of Anderson et al.'s (1976) [(1)], land use classification are often used for modelling land use change in the cities of developed countries. **The higher the classification level, therefore the model can be more detailed, complex, realistic and prescriptive**.

Models such as **C**larke's **U**rban **G**rowth Model **(UGM or SLEUTH)**, the **L**and **T**ransformation **M**odel **(LTM)**, and the **L**and **U**se **C**hange **A**nalysis **S**ystems **(LUCAS)** use Anderson Level **I**, whereas the **C**alifornia **U**rban **F**uture **(CUF I)** model uses Anderson level **II**.

Many of the more **user-friendly** models are integrated with **GIS** to become spatially explicit **D**ecision **S**upport **S**ystems **(DSS)** with relational database technology.

(4-2-2) Urban Transportation Models

Urban transportation models use variables such as <u>traffic flow, number of daily trips, distance from origin to destination and accessibility to services.</u>

Modern transportation models such as **I**ntegrated **L**and **U**se and **T**ransport **P**lanning **S**ystem **(TRANUS)** use some variant of the **U**rban **T**ransportation **P**lanning **S**ystem **(UTPS)** models. Using the following **four steps**, transportation models answer questions about future travel patterns:

- **<u>Trip generation</u>**: How many trips will be made?
- **<u>Trip distribution</u>**: Where will the trips be?
- **<u>Mode split</u>**: Which modes *(automobile, transit, cycle, or on foot)* will be used?
- **<u>Traffic assignment</u>**: What routes will be used and at what time of day will the trips be taken? (US. EPA, 2000).

---

(1) See **Anderson** land use classification system for county or small city in **Appendix (A)**.

(4-2-3) Economic Models

Urban economic models project **employment**, **population**, **wage rates, rents, incomes**, and **prices**…etc., for different geographic areas. This modelling process relies on census data and different population projections to build the model data sets.

(4-2-4) Environmental Impact Models

Many different types of environmental models have been developed to assess the impacts of natural changes on the environment system. These models range from projecting the long-range transport of pesticides, to evaluating the impacts of vehicular exhaust on air quality.

More recently, current urban dynamics models, such as **L**and **Tr**ansformation **M**odel (**LTM**), **U**rban**S**im, and **S**mart **P**laces, have been developed to address the effects of land use changes on different aspects of the environment system including: **water and air quality, natural habitat, natural resources, energy, groundwater recharge and pollution, habitat fragmentation, and agriculture land loss. PCRaster** [(1)] for instance, is designed to investigate urban ecology, hydrology and geomorphology.

On the other hand, urban system models are **borrowing from each other** *(land use, economic, transportation and environmental impacts)* to achieve spatially and temporally explicit and improve urban decision support.

Considering that urban systems are complex and consist of various components *(physical, human, network, activities, etc.),* the ability of an urban model to incorporate an increasing number of urban systems variables with their appropriate relationships, **<u>is promising in terms of being able to better represent these urban complexities</u>.** Current urban dynamics models, such as **LUCAS**, **UrbanSim**, **and What if?** integrate **two** to **three** sub-models.

Due to the variety of urban dynamics models that developed from various areas of interest, therefore choosing the right model for a specific application is one of the most important issues to select the suitable urban predictive model.

[(1)] More information about **PCRaster** can be found at http://www.pcraster.nl (last accessed, 10/12/09)

(4-3) Steps towards Selecting the Best Urban Dynamics Model

(Selection criteria approach)

When faced with such situations *"either as the decision maker or one who seeks to inform or influence the decision making process"* it is worth considering the following **five-step** approach to selecting the best urban dynamics model *(package)* as illustrated in Figure (4-1), that could be used for a specific planning situation.

This approach begins by clearly defining the whole scenario involved in the decision making *(e.g., a proposal for a new development project)* and concludes with criteria for model selection.

The appropriate model will vary from scenario to scenario and from community to community. The model needed today may be completely different than the model needed for tomorrow's project. This variation between projects requires an understanding of the diversity of available models in order to determine which is the best model to use in a given situation.

The most critical component of an effective community decision making modelling tool is its ability to address specific analytical needs and to model alternative planning approaches.

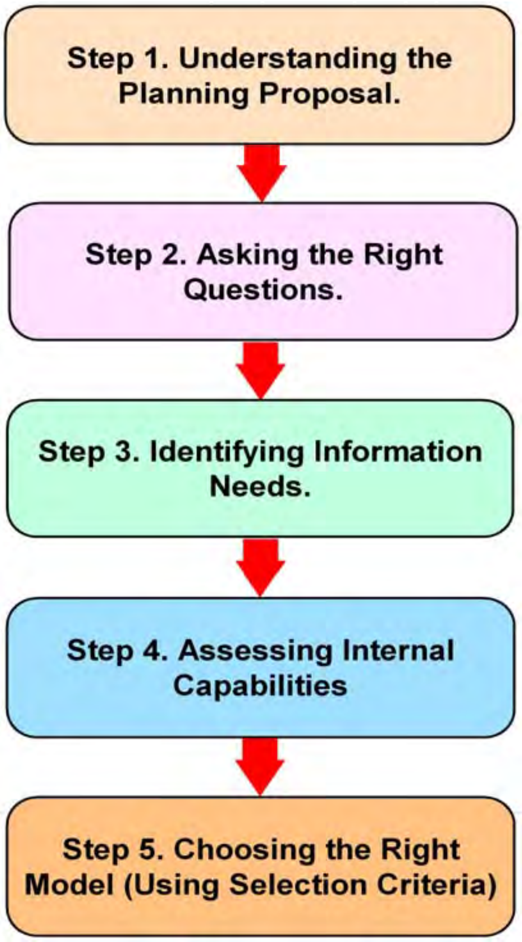


Figure (4-1) The **Five-Step** process for selecting the best urban dynamics model

Also, it is important to note that while **current land use change models** serve as powerful tools to assist municipalities in making their planning decisions, **many** are limited in their capabilities. **Few,** attempt to fully model all of the various factors affecting land development patterns, and **none** can account for all factors that affect land markets and land use change behavior (US. EPA, 2000).

Thus, no model can perfectly replicate reality. But, as technology continues to advance, more and better models will be developed to answer on the specific policy questions of citizens, land use planners, and decision makers.

(4-3-1) Step 1: Understanding the Planning Purpose

The first step in selecting the best suitable urban dynamics model is including the project's proposal. **The project proposal must be stated as succinctly**, **objectively, and as accurately as possible in order to begin the decision making process.**

There are many specific research questions related to urban dynamics in fast growing cities cab be asked, such as:

- **What are the impacts of expanding infrastructure to a new area?**
- **What are the consequences of a new tax strategy directed to IH?**
- **What is the desire to preserve environmental resources?**
- **What are the project's land boundaries?**
- **Also, it is important to determine the project's entire geographic scope.**

(4-3-2) Step 2: Asking the Right Questions

Once the planning proposal has been clearly defined, the **project scope** must be broken down into detailed pieces. At this point, essential questions must be asked in order to have a complete understanding of the full costs and benefits of the proposal. **Considering the direct and indirect, cooperative, and accumulative impacts which will the community gained from this project.**

(4-3-3) Step 3: Identifying Information Needs

The **availability** and **reliability** of the data for the study area must be verified. This was an important step because the quality of the data input determines the **accuracy of the output information** from the model. Also, access to modelling resources was then evaluated. In this step a determination should be made to know **what types of data are required to answer the decision maker questions.**

(4-3-4) <u>Step 4:</u> Assessing Internal Capabilities

This step requires a clear understanding of what internal capabilities can be accessed to **acquire** and **use** the model. This includes assessing the following:

- **Financial resources** - How much can be afforded?
- **Staff resources** - What is the needed staff experience to use the model?
  - Does additional help or consulting expertise need to be hired to use the model?
- **Computer resources** - Are the existing hardware, software, and computing power resources sufficient to run the models?

(4-3-5) <u>Step 5:</u> Choosing the Right Model *(Using Selection Criteria Approach)*

First, we must agree that there is not a ***"perfect"*** model; the proposed approach here aims to choose the model which has the capacity to produce realistic and informative representation of urban settlements, <u>because one of the problems with current dynamics models is that they do not take into account the various angles and aspects of the prediction for other urban contexts.</u>

It would also be important to select the model that could be **<u>flexible enough</u>** to consider incorporating more variables and **create the interactions between these variables and the model components, as well as <u>the feedback effect</u>**.
The "checklist approach" is the most suitable way to select the desired model. We believe that this is the best approach for model selection, each model **options**, **components** and **variables** should be completely analyzed against selection criteria. Then this criteria may be weighted, based on level of importance, to guide the decision making process.

The U.S. **E**nvironmental **P**rotection **A**gency **(EPA)** review of **twenty two** models is a useful starting point in selecting the most appropriate model (US. EPA, 2000) for urban and **Informal Housing** dynamics in **LDC**. The **EPA's** evaluate the selected urban dynamics models on the basis of their **ability to predict emergent patterns** and its ability to **predict new developments** using relevant variables with logical rules or conditions of change.

Specifically, the EPA found twelve points should be considered:

Item	Description
1) Relevancy	Does the model provide relevant information that meets the analytical needs of the community?
2) Resources	Are the model and the **computer requirements** *(hardware, software)* and staff needed to support the system within the community's budget and infrastructure?
3) Model Support	Do the model developers provide sufficient support needed to understand and implement the model *(e.g., model documentation, training, user discussion groups)*?
4) Technical Expertise	Does the community have the technical staff experience required to use, calibrate, and interpret the results of the model?
5) Data Requirements	Does the community have, (*or can they obtain)* the necessary data to run the model?
6) Accuracy	Are the projections generated by the model reliable to a degree that is useful to the community?
7) Resolution	What is the level of detail to reflect the reality of urban can be modeled?
8) Temporal Capabilities	Can the model project outcomes for multiple time periods?
9) Versatility	Can the model project outcomes for multiple variables *(e.g., land use, transportation, services, employment, housing, and environmental)*?
10) Linkage Potential	Can the model be linked to other models currently in use by, or of interest to, the community?
11) Public accessibility	Can the model be run in an interactive public environment and display the results in a manner that is comprehensible to the general public?
12) Transferability	Can the model be applied to locations other than the one(s) for which it was developed?

(4-3-6) Additional Selection Criteria to Fit IH Growth in LDC

Whilst the **EPA's** checklist was useful in the process of selection the best urban dynamics model, we believe that the **EPA's** selection criteria needed to develop to fit the **exceptional circumstances of IH in LDC**, because the **EPA** criteria were developed to support the planning agencies in **USA**, so many other criteria could be added to fit the context of cities in **LDC**.

Therefore, new set of selection criteria were suggested to fit the case of unplanned growth in **LDC**, These criteria include:

1) **Temporal and spatial resolutions of the required data**.
2) **Cost and accessibility of the model**.
3) **The model flexibility**.
4) **Accuracy and reliability of the required data**.

1) Temporal and spatial resolutions.	The ability of the model to handle both **temporal and spatial dimensions** was considered. *(dis-aggregation level)*

Level of dis-aggregation refers to the properties of the temporal and spatial input data files required to run the model.

<u>**The temporal resolution**</u> can vary from **1** day to **100** years and can have continuous or multiple time steps. A model that can be adapted to use in the case of unplanned or **IH** growth in **LDC should have a temporal resolution of 1 to 5 years**, because this is a reasonable period where changes can be noticed. Also the selected model must allow **continuous** and **multiple time steps** because **IH** expand continuously and could follow different stages.

<u>**The spatial resolution**</u> can vary from **1** km^2 **to 1 million** km^2. The recommended model should incorporate both **too coarse** and **too dis-aggregated** spatial data. This condition is critical for the selected growth model to fit the characteristics of unplanned growth in the context of **LDC**.

2) Cost and accessibility of the model.	Is the model accessible and can obtained free of charge?

Other important selection criteria are the **cost and accessibility** of a selected model. This is because the limitation of budget, so models that could be obtained free of charge were highly considered.

3) The model flexibility.	The ability to **access and modify the model source code** to adapt it with specific needs.

The **flexibility of the model** depends on the user ability to adapt the program with specific need (Agarwal *et al*., 2000). [(1)] That is, because some models still function as a ***"black box"*** [(2)] not allowing access to their source code, and not enabling the user to comprehend how the process operates. On the other hand, **open source urban modelling**, is useful, because it allow the user to observe the modelling procedure *(such as; calibration, probability, simulation and prediction)*, and to make the necessary adjustment to fit the project objectives.

Therefore, in the case of **IH** in **LDC** we need to consider models that are flexible in relation to their input datasets requirements, as well as, **the model structure and design** should be able to adapt with the common characteristics of **IH** among **LDC**.

4) Accuracy and reliability of the required data.	What are the accuracy and reliability of the required data to run the model?

Accuracy and reliability of the required input data will be assessed as important elements when selecting or designing operational urban dynamics models. This is because the input and output data of the desired **I**nformal **H**ousing **G**rowth **M**odel should be **sufficiently accurate, visually explicit, trusted, and can be easily available to inform planners and decision makers in LDC**.

Finally, each selected urban dynamics model will be discussed separately, in relation to the model's theory and structure, its flexibility, the cost of the program, access to internal code, level of dis-aggregation of input data, data requirements and real world application. These factors will also be considered for the overall evaluation of our proposed Informal Housing Growth Model (IHGM).

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(1) This article available at: http://caplter.asu.edu/biocom/Agarwal%20et%20al.pdf.

(2) In a ***"black box"*** model, the program is executed without any capacity to understand its internal structure, especially the source code of the executed program. This concept of a ***"black box"*** is opposite to a "***white box***" or **public domain software** where the potential user can access and modify the program assumptions.

(4-4) Review of the Operational Urban Dynamics Models Software

A variety of urban dynamics models have been developed with different levels of **complexity**, **structure**, and **purpose**. The purpose of this section is to use the selection criteria developed above, to evaluate the appropriateness of existing urban models to explore and simulate urban and **I**nformal **H**ousing **(IH)** dynamics in **LDC**.

This section will review **eight** selected urban dynamics models. Table (4-1) shows the model name, developer, and the initial purpose of each model.

Each model will be introduced through the following points:

- **Model overview.**
- **Model structure.**
- **Information provided by the model** *(Land use addressed, Questions answered).*
- **Information needed to run the model.**
- **Model strengths and limitations.**

Each model will evaluated and compared in regard to the previously developed selection criteria in sections (4-3-5) and (4-3-6). The model description highlights the relevance of the model to be used in the exploration of urban dynamics in **LDC** cities, as well as some of their advantages and limitations.

Model	Developer	Model Purpose
1- California **U**rban **F**utures Model (**CUF-1**)	John Landis, Institute of Urban and Regional Planning, University of California at Berkeley.	Provides a framework for simulating how growth and development policies might alter the **location**, **pattern**, and **intensity** of urban development.
2- Land **T**ransformation **M**odel **(LTM)**	Dr. Bryan C. Pijanowski, Michigan State University.	Integrates a variety of land use types and artificial neural networks to model land use changes, using the derived information from historical analysis.

Table (4-1) The operational urban dynamics models discussed in this Chapter

Model	Developer	Model Purpose
3- Land **U**se **C**hange **A**nalysis **S**ystem **(LUCAS)**	Michael W. Berry, et al., Department of Computer Sciences, University of Tennessee.	Examines the impact of **human activities** on land use and the subsequent impacts on environmental and natural resource sustainability.
4- SLEUTH (Clarke Urban Growth Model)	Keith C. Clarke, Department of Geography, University of California at Santa Barbara	Simulates the changes from **non-urban** to **urban** based on grid of cells to understand how urban areas extend to their surrounding land, and can includes the nature environmental impact.
5- TRANUS	Modelistica	Analyzes the effects of land use, transportation and policies on the location of various activities and the land market.
6- UPLAN	Robert Johnston, Dept. of Environmental Science and Policy, University of California at Davis	Creates alternative development patterns in response to changes in development and fiscal scenarios.
7- UrbanSim	Paul Waddell, Daniel J. Evans School of Public Affairs, University of Washington	Explores how the interactions between land use, transportation, and public policy on the community's shape development and affect the natural environment.
8- What if?	Dr. Richard E. Klosterman	Supports comprehensive community land use planning in regard to determining **land suitability** for development, projecting **future land use demand**, and providing the capability to **allocate the demand to the most suitable location**

Table (4-1) The operational urban dynamics models discussed in this Chapter (cont.)

(4-4-1) FIRST California Urban Futures Model (CUF -1)

John Landis and his colleagues at the University of California, Berkeley, [1] have developed two of the first **GIS-based urban models**. The two models are similar in their overall design but different enough in their details to serve separate objectives. The first model, **California Urban Futures Model I** (or ***CUF-1***), will be discussed in this section. The second model is **California Urban Futures Model II** (or ***CUF-2***). [2]

(4-4-1-1) Model Overview

The purpose of the **CUF-1** model is to provide a framework for simulating how growth and development policies applied to various levels of government *(e.g., state government, local government, and special districts),* might alter the **location**, **pattern**, and **intensity of urban growth**.

The **CUF-1** model was designed to be able to simulate the spatial growth of the **metropolitan area** as it actually occurs, site by site, parcel by parcel, block by block, and city by city. **County-level** and **zonal growth** totals, *(such as: those produced by regional forecasting models),* were considered to be too aggregate to provide a clear picture of the spatial processes of urban growth. The **CUF-1** model is able to simulate the specific locations ***where*** growth might occur and ***how much*** growth might occur.

Our insistence that the **CUF-1** model be spatially accurate magnified both **the complexity of the model, and the volume of data required to build it**. This requires the use of **GIS** to manage and access the huge of spatial data (John D. Landis, 1994).

The model is essentially different from other **traditional spatial interaction models**, and unlike most metropolitan forecasting models in several areas:

- **First,** in contrast to most other metropolitan forecasting models *(which project population growth at the regional level, and then allocate it downward),* the **CUF-1** model projects population growth at a **sub-area level** *(e.g., a city),* and then aggregate the projected growth to larger units *(e.g., county, regional level).*

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(1) The model and relevant materials can be obtained from: http://www-dcrp.ced.berkeley.edu. (last accessed, 5/1/2009). More information about **CUF-1** are available in **Appendix (A)**.

(2) Additional information about **CUF-2** are available in **Appendix (A)**.

- **<u>Second,</u>** instead of allocating the projected growth to zones, the **CUF-1** model allocates growth to individual sites according to each **site's potential profitability** if developed. Thus, the model recognizes the importance of land developers and home-builders as main actors in determining metropolitan development patterns.

- **<u>Third,</u>** most of urban simulation models rely on **relative transportation accessibility** as the primary factor of urban development patterns (US. EPA, 2000).
  CUF-1 uses the **spatial accessibility factor** *(measured as buffers around potential development sites rather than as network travel times)* as one of many variables that determine the location and density of new development locations.

- **<u>Fourth,</u>** the **CUF-1** model is the first metropolitan simulation model that takes advantage of the analytical power of **G**eographic **I**nformation **S**ystems **(GIS)** to **assemble**, **organize**, **manage**, and **display** the millions of available pieces of information describing land development potential.

- **<u>Fifth,</u>** also, the **CUF-1** model can explicitly incorporating **realistic development policies** *(pursued at various levels of government)* into the future forecasting process and allowing the results of different policy scenarios to be presented directly in map form at any level of detail

(4-4-1-2) Model Structure

The **CUF-1** model was originally developed to predict the **location**, **pattern**, and **density** of growth in the **fourteen-county Northern California Bay Region** through to the year **2010**, the model was designed on **two** primary units of analysis:

1) **Political jurisdictions** *(the basic unit of analysis incorporated cities or counties),*
2) **Developable Land Units [DLUs]** *(i.e., undeveloped or underdeveloped areas that may be developed or redeveloped in future).*

<u>Population growth</u>: represents the demand side of **CUF-1** model, is projected on the basis of city population growth trends.
<u>Development potential</u>: represents the supply side of **CUF-1** model, is calculated in terms of **DLUs**. **[DLUs]** are currently undeveloped or underdeveloped areas inside and

outside cities which are candidates for development or redevelopment. **[DLUs]** are polygons generated by the **GIS** component of the model and they are constructed by the geometric union and intersection of various features, such as: environmental, market, and policy attributes, *(e.g., [DLUs] attributes might be a currently undeveloped site with steep slopes, that is served by sewers, zoned for light industrial, and less than 500 meters from a major freeway).*

Table (4-2) shows the structure of **CUF-1** model that consists of four related sub-models, which are described briefly below.

Steps	Operation / Procedure
Step 1.	**Forecast basic employment growth by county** *(regression equation)*
Step 2.	**Bottom-up population growth sub-model** (1) Project city population in year **(t+5)**. (2) Project county population in year **(t+5)**. (3) Calculate unincorporated population growth as a residual.
Step 3.	**Spatial database** (1) Update map layers with new information. (2) **"Union"** map layers to update list of developable land units [DLUs].
Step 4.	**Spatial allocation sub-model** (1) Calculate profit potential for each [DLU] if residentially developed. (2) Within each city sphere of influence, sort [DLUs] in order of profit potential. (3) Eliminate inappropriate [DLUs] from allocation according to local, county, regional, or state policy considerations. (4) Within each city sphere of influence, begin allocating population growth to [DLUs] in order of profit potential. (5) Allocate the predicted growth (if any) consistent with local policies.
Step 5.	**Annexation / incorporation sub-model.** (1) Incorporate new cities. (2) Annex newly developed [DLUs] to cities as appropriate. (3) Update city boundaries.

Table (4-2) Outline the structure of the **C**alifornia **U**rban **F**utures Model **(CUF-1)**

CUF-1 was used in the **fourteen county of Northern California,** by allocating projected residential land use demands in each projection period to **[DLUs]** as a function of:

(1) The projected population growth in each city and county;

(2) The profitability potential of each [DLU] *(if developed)*;

(3) A series of user specified development regulations or rules.

<u>The following section will discusses and illustrates the **CUF-1** sub-models:</u>

(a) The Bottom-Up Population Growth Sub-Model

The bottom-up population growth sub-model is the **demand side** of the **CUF-1** model. It consists of two **regression equations** of population growth in the cities and counties of the **Northern California Bay Region**. These functions predict the levels of population growth *(the dependent variable)* as function of historical population levels.

Other independent variables are included to account for place-specific differences from the overall trend-line.

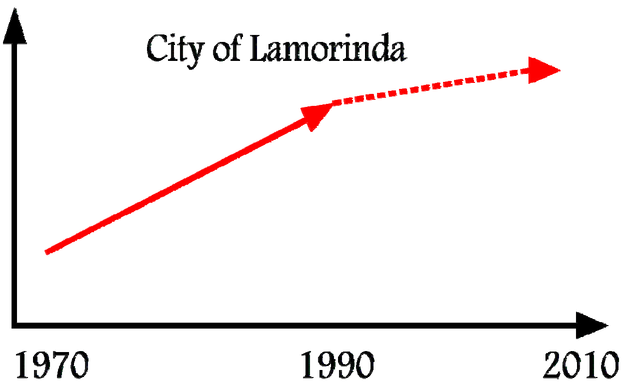


Figure (4-2) Projection of city residential growth as a function of historical trends, state growth, and local growth policies

<u>The first equation</u> is used to project city by city population growth levels at five-year increments for **112** incorporated cites in ten counties.

<u>The second equation</u> is used to project the county population growth at five-year increments.

These two equations were developed by ordinary **least squares regression** on a database which combines <u>cross-sectional</u> and <u>time-series data</u> *(cities and counties)* for **five year periods**. These two equations are project the population growth as a function of:

1) **An area's past population trends**.
2) **Variables that provide a <u>"brake"</u> on future population growth**.

In these equations, **three** variables were included in the model to provide a **"brake"** on population growth:

- **<u>Growth Control (t-5)</u>**, is a dummy variable indicating whether or not the city had adopted a population, housing, and development trend.
- **<u>Land-Lock (t-5)</u>**, indicates whether a city is land-locked *(or water-locked)* by neighboring communities, and thus prevented from expanding.
- **<u>Density (t-5)</u>**, is the gross population density of the city in the previous five year period, weighted by the population of the city in the previous period.

(b) CUF-1 Spatial Database

The spatial database consists of a series of map layers that describe the environmental, land use, zoning, current density, and accessibility characteristics of all sites in the fourteen county Northern County Bay Region. These various layers can be analyzed individually, or merged into a single layer which includes all the relevant attribute information for each resulting polygon. The spatial database is produced and managed through the use of **ARC/INFO**, **GIS** software, which incorporates a relational database and true map feature topology.

The spatial database functions are the **supply side** of the **CUF-1** model. It is a comprehensive list of the locations and attributes of currently undeveloped *(or underdeveloped)* sites that may be available to accommodate city and county forecast population growth. These sites are known as **[DLUs]**; the **[DLUs]** do not have regular shapes or sizes, **but are generated as the geometric union of different map features and their attributes.**

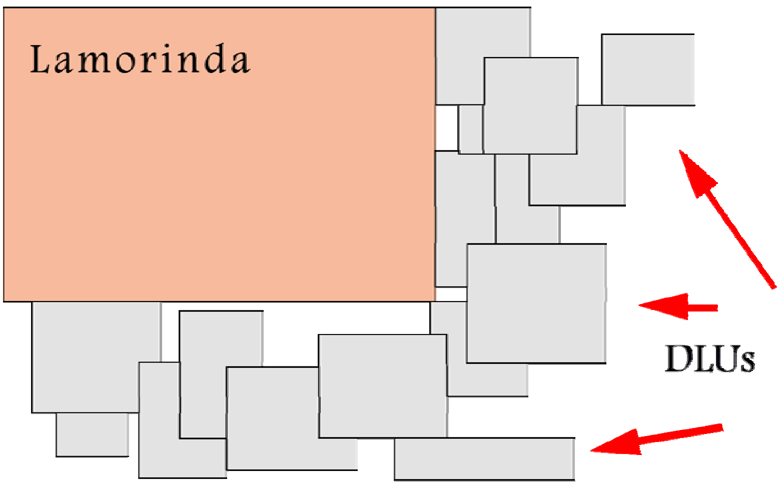


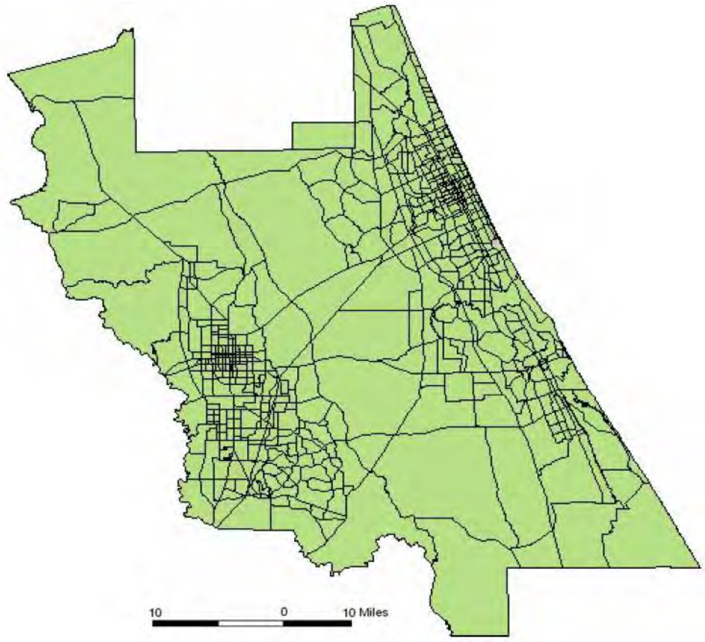
Figure (4-3) A schematic geometrically combine information from different layers to create map and database of **DLUs**

The spatial database currently includes the following map layers and information:

1) **Roads layer:** includes major roads and highways in all metropolitan areas. Also includes federal highways and roads, state highways, local arterials, and neighborhood serving roads.
2) **Census tracts layer:** includes the boundary lines of **1990** Census tracts. The boundaries were assembled into **census tracts** *(polygons)* using **ARC/INFO**.
3) **City boundary layer:** the boundary lines of counties and other local governments including all incorporated cities.
4) **Hydrology layer:** the locations of major streams and water bodies. These were imported into the spatial database in a separate layer.
5) **Other line features layer:** including railroads and airports.
6) **Spheres of influence layer:** spheres of influence were originally defined to demarcate each city's ultimate ***"build-out"*** and public service area, they are essential for analyzing possible limits to growth. The size and extent of spheres of influence vary widely by city and county. A map layer incorporating every city's sphere of influence was digitally encoded.
7) **Highway buffers layer:** To define **relative accessibility**, we generated **500** m, **1500** m, and **5000** m polygon buffers around major state and federal highways.
8) **Urban buffers layer:** Most new urban development occurs at the boundary of existing developments. This is because the cost of extending essential urban services to new undeveloped areas usually outweighs any land-cost savings. To capture this "*adjacency-preference*", we generated **1000** m and **2500** m polygon buffers around existing urbanized areas as a map layer.
9) **The agricultural lands layer:** Agricultural lands are classified into: prime agriculture, grazing, forest, state lands and private lands.
10) **Sewer and water utility service costs layer**.
11) **Slope Polygon layer**.
12) **Earthquake faults layer**.
13) **Marsh and wetland layer**.

Figure (4-4) Example of **D**evelopable **L**and **U**nits **[DLUs]**

(Source: FDOT Systems Planning Office). [1]



(c) The Spatial Allocation Sub-Model

The spatial allocation sub-model is a series of **user specified functions** and **decision rules** for allocating population growth to the most appropriate **[DLUs]** based on their potential profitability if developed. The allocation process includes the following steps:

- **<u>Step 1.</u>** All undeveloped **[DLUs]** in a county are scored according to their potential profitability if developed.

- **<u>Step 2.</u>** **[DLUs]** that are unsuitable for development due to environmental, ownership, or public policy reasons are **eliminated** from consideration. *Examples of [DLUs] that would not be considered for additional growth might include **publicly owned parks** and **open space**, or **steeply sloped [DLUs] having unstable soils.***

- **<u>Step 3.</u>** Within each city and its sphere of influence, the remaining **[DLUs]** *(those that could be developed)* are **stored** from **high** to **low** in order of their potential development profitability.

- **<u>Step 4.</u>** The projected population growth for each city is allocated to the **[DLUs]** within each city sphere of influence in order of **[DLU]** profit potential *(from high*

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[1] **F**lorida **D**epartment **O**f **T**ransportation **(FDOT)**, Systems Planning Office, 605 Suwannee Street, MS 19, Tallahassee.

to low); and at **population densities consistent with current market conditions, zoning, and general plan requirements.** After it has allocated as much population growth as will **"fit"** into the **[DLU]** with the highest profit potential, then the model moves to the next most profitable **[DLU]**, and so on.

- **Step 5.** A similar procedure is used to allocate the projected county population growth *(plus any unallocated potential growth from individual cities)* to unincorporated county **[DLUs]**.

The allocation process within a county is complete either when:

a. **All forecast and expected population growth is allocated,**

b. **When there is insufficient undeveloped land in the county to accommodate the projected population growth.**

Unallocated population growth, if any remains, is then accumulated for later reallocation to those counties with remaining developable [DLUs] sites.

Calculating [DLU] profitability potential

The core of the spatial allocation sub-model is a procedure for estimating the profit potential of each **[DLU]** if developed. Essentially, this procedure makes the computer as a developer, able to estimate the **profitability potential** of thousands of undeveloped **[DLUs]**.

The **profitability potential** of a **[DLU]** is the total profit that a home-builder would expect to realize on the construction of as many new homes as could be accommodated on that **[DLU]**. It is calculated as follows:

Per acre residential development profit *(i, j, k)* = new home sales price *(i, j, k)*

- **Raw land price *(j, k)***
- **Hard construction costs *(i, k)***
- **Site improvement costs *(i, j, k)***
- **Service extension costs *(j, k)***
- **Development, impact, service hookup, and planning fees *(k)***
- **Delay and holding costs *(k)***
- **Exceptional infrastructure capacity costs and impact mitigation costs *(j, k)*.**

Where, the index *(i)* denotes the size and quality level of the typical new home in each community. **The index *(j)*** denotes the slope, environmental characteristics and specific location of the home site or [DLU]. **The index *(k)*** denotes the jurisdiction in which the home is located.

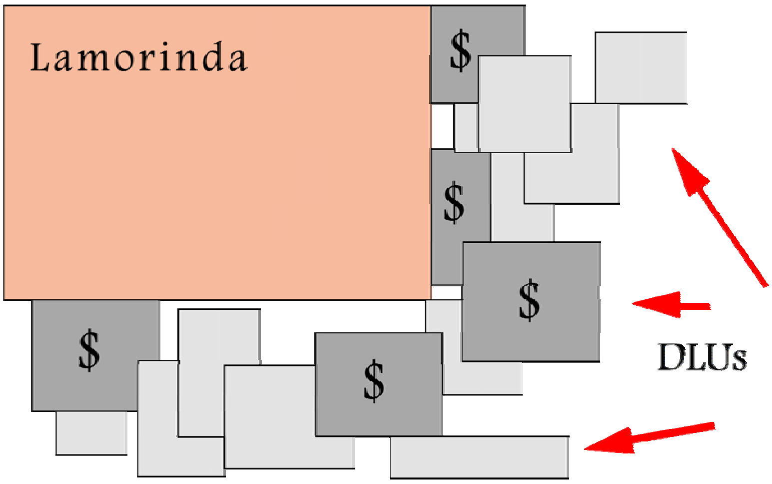


Figure (4-5) Allocate projected residential growth to the most profitable **[DLUs]** consistent with policies being simulated

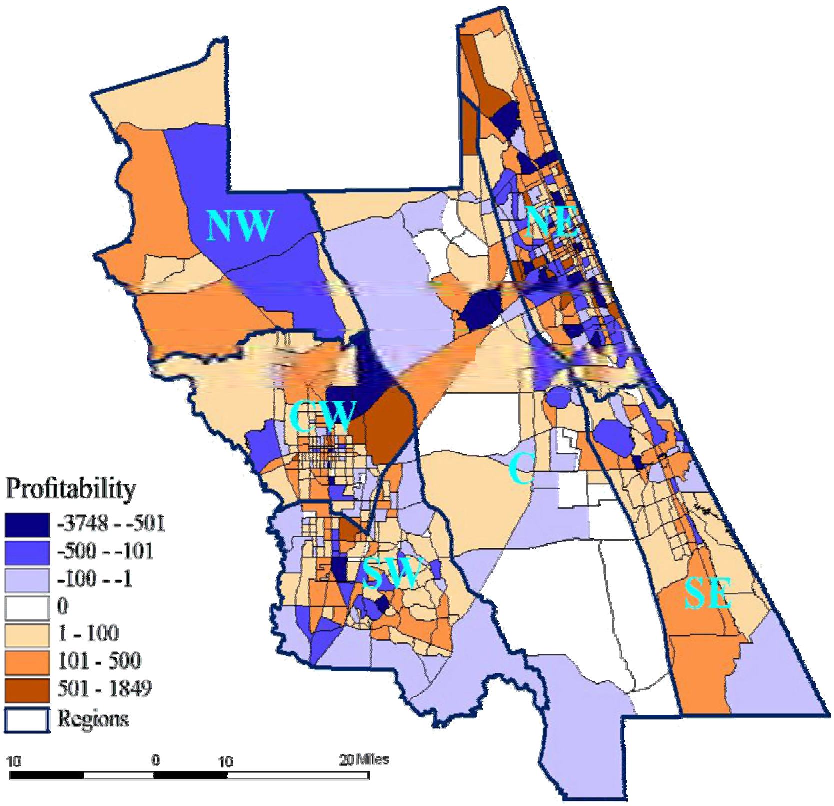


Figure (4-6) Calculating **[DLU]** profitability potential for the **Volusia** County (Source: FDOT Systems Planning Office)

(d) The Annexation / Incorporation Sub-Model

This sub-model consists of a **simple regression model** comparing 1980-1990 annexation activity by city according to city population, density, location, and growth policy.

Because city boundaries *(and spheres of influence)* are so essential a part of the **CUF-1** model, the updating process must necessarily include a procedure for determining which newly developed **[DLUs]** are to be annexed to existing cities and which are to be part of newly incorporating cities. Making such determinations is the purpose of the annexation/ incorporation sub-model.

<u>This component of the model determines whether newly developed **[DLUs]** will be :</u>

1) **Annexed into existing cities,**
2) **Part of newly incorporating cities,**
3) **Remain as they are.**

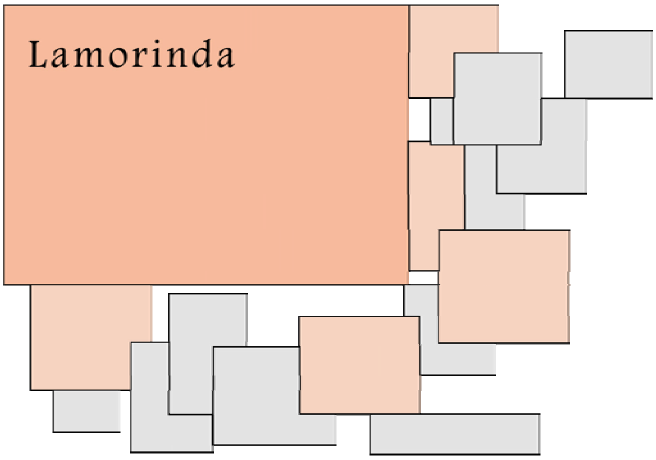


Figure (4-7) Annex / Incorporate **[DLUs]** as appropriate

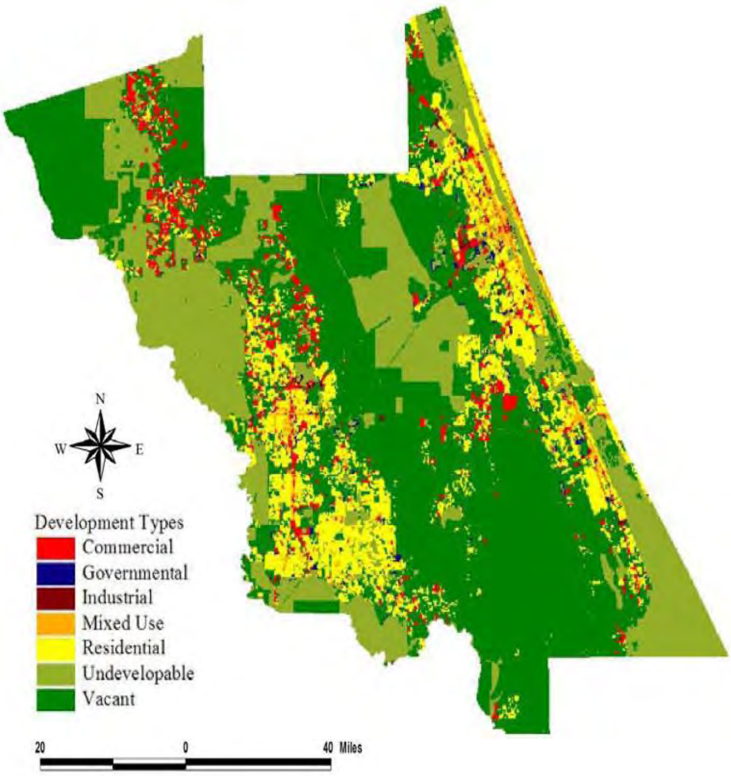


Figure (4-8) Distribution of development **[DLU]** for the **Volusia** County
(Source: FDOT Systems Planning Office)

(4-4-1-3) Information Provided by the Model

(a) Land Uses Addressed

The land use categories addressed by **CUF-1** are user defined and, therefore, could include any land use category as appropriate for the study area.

Four major land use categories were used for the application of **CUF-1** model on San Francisco Bay and Sacramento areas simulation: **agricultural land type**, **general plan use category**, **current land use and wetland** (US. EPA, 2000).

Land Use Categories		Yes?	No?
Urban	Residential	√	
	Commercial		
	Mixed-Use		
	Industrial		
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	

Table (4-3) Land use categories addressed by **CUF-1**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-4).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-4).

Community Action / Characteristic		Yes?	No?
Action	Transportation Infrastructure		√
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)		√
Characteristic	Travel Demand	√ [1]	
	Local Government Fiscal Conditions	√ [1]	
	Availability of Open Space	√ [1]	
	Environmental Quality	√ [2]	
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions		√

Table (4-4) Community actions and characteristics addressed by **CUF-1**

1) Only with some modifications or additions.
2) For water quality, **"yes"** with some modifications, but for air quality, **"no."**

(4-4-1-4) Model Strengths and Limitations

(a) Strengths

1) **Easy to use and visual:** The **CUF-1** model allows users to prepare and evaluate alternative policy scenarios quickly *(a typical simulation can be completed in a matter of hours)* and in **easy to read the simulation results in map form** at almost any level of detail.
2) **Expandable:** The **CUF-1** model is designed as a modular system of related independent sub-models that can be updated to include new information and theories.
3) **Policy approach:** The **CUF-1** model simulates the development of future alternatives based on specific policy changes.

(b) Limitations

A second generation of the **CUF** model **"CUF-2"** has been developed to handle several of the limitations discovered in the original **CUF-1** model.

1) **Availability:** The **CUF-1** model is currently unavailable as a product that can be purchased "off the shelf ".
2) **Singular land use:** The **CUF-1** model is limited to **residential development** and does not include methods for projecting and/or allocating future industrial, commercial, and public activities. Therefore, the most profitable sites to develop are reserved for residential development only.
3) **Lack of "infill" development and urban redevelopment:** The **CUF-1** model assumes that almost all population growth will occur at the urban edge.
4) **Allocation of population growth depends on the potential profitability of [DLUs]:** The **CUF-1** model may be insensitive to other factors that impact growth patterns and locations *(e.g., impacts of new infrastructure investments).*
5) **Lack of integration with historical experiences:** The **CUF-1** model's rules for allocating future development were not calibrated with regard to the derived Information from historical analysis.

(4-4-2) Land Transformation Model (LTM)

Other names: **LTM-ANN** (Artificial Neural Network); **LTM-MCE** (Multi-Criteria Evaluation); and **LTM-LR** (Logistic Regression).

(4-4-2-1) Model Overview

Development of the **L**and **T**ransformation **M**odel **(LTM)** [(1)] began in 1995 and is ongoing until now. The **LTM** combines **G**eographic **I**nformation **S**ystems **(GIS)**, **A**rtificial **N**eural **N**etworks **(ANN)**, geo-statistical and **R**emote **S**ensing **(RS)** technologies to simulate and forecast land use change in a variety of locations around the world.

The **LTM** uses population growth, transportation factors, proximity or density of important landscape features *(such as: rivers, lakes, recreational sites and high-quality vantage points)* as inputs to model land use change. Information derived from the historical analysis of land use change can be used to conduct forecasting studies (Pijanowski et al. 2002).

LTM is a **cell-based** simulation model of land use change induced by ecological processes (Pijankowski et al., 1997). The **LTM** uses **GIS** to simulate ecological changes. Changes are derived from transitional weighted probabilities obtained from:

- **Environment behavior:** such as, drainage and topography.
- **Socio-economic trends:** such as, population and employment.
- **Policy fluctuations:** such as, taxes and property rights.

(4-4-2-2) Model Structure

Technically, the **LTM** contains **six** interacting modules:

1) **Policy framework.**
2) **Driving variables.**
3) **Land transformation.**
4) **Intensity of use.**
5) **Processes and distributions.**
6) **Assessment endpoints.**

---

(1) The **LTM** relevant materials can be obtained from: http://www.ncgia.ucsb.edu/conf/landuse97. (last accessed, 2/3/2009). More information about **LTM** are available in **Appendix (A)**.

The main feature of the **LTM** is that the simulation can be executed from a parcel scale *(30m x 30m)* to a local level *(1km x 1km)* to forecast up to **50 years** of land transformation with **5 to 10 year time increments**.

The model also uses variables such as employment location, land use map *(Anderson level I land use classification)*, population distribution, topography (**D**igital **E**levation **M**odel, **DEM**), and transportation data.

The **L**and **T**ransformation **M**odel is more appropriate and often used for hydrology applications, as well as urban dynamics modelling.

The pilot model was developed for Michigan's Saginaw Bay Watershed and contains only two of the six LTM modules; driving variables and land transformation.

The pilot model integrates a variety of land use change driving variables, such as:

- **Population growth**,
- **Agricultural sustainability**,
- **Transportation**,
- **Farm land preservation policies for the watershed**.

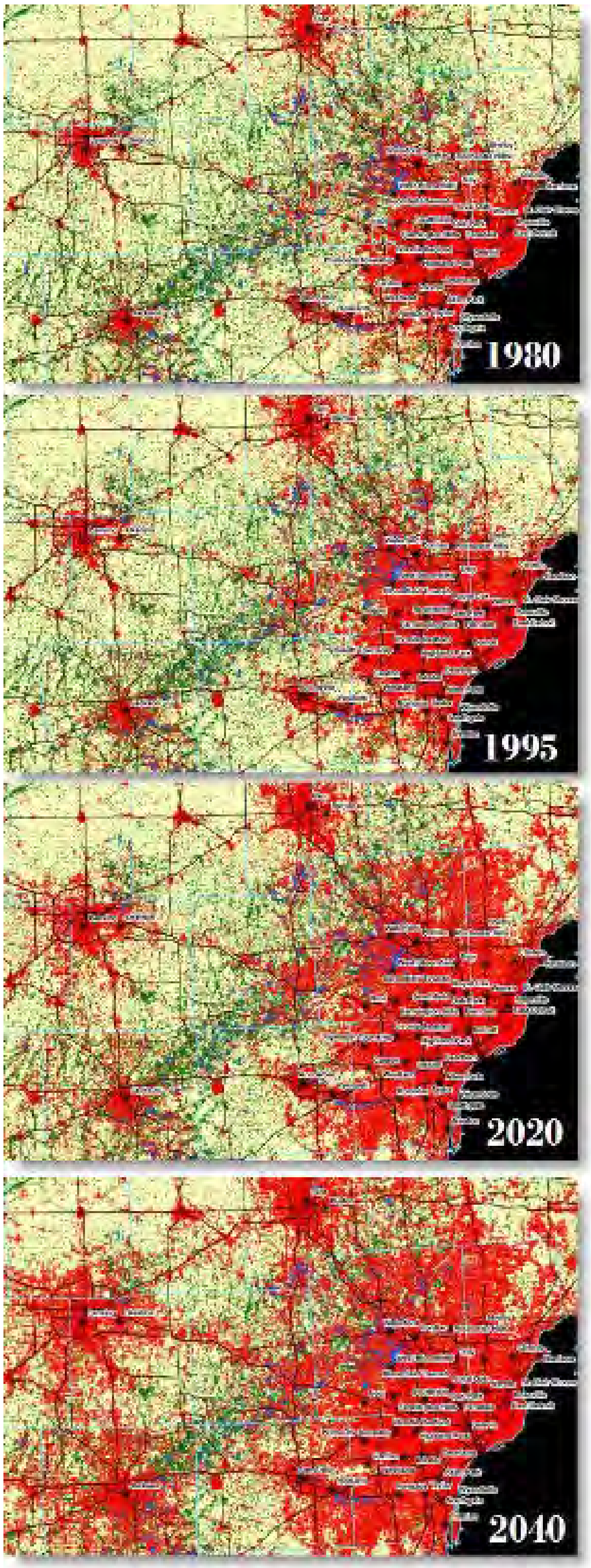


Figure (4-9) Urban expansion for the Detroit Metropolitan Area
(Source: The **S**outh **E**ast **M**ichigan **C**ouncil **O**f **G**overnments, **SEMCOG**)

(4-4-2-3) Information Provided by the Model

(a) Land Uses Addressed

The **LTM** can address up to **eight** different land use types**,** as shown in Table (4-5).

	Land Use Categories	Yes?	No?
Urban	Residential	√	
	Commercial		√
	Mixed-Use		√
	Industrial		√
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation		√
	Park Land	√	

Table (4-5) Land use categories addressed by **LTM**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-6).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-6).

	Community Action / Characteristic	Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning		√
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)		√
Characteristic	Travel Demand		√
	Local Government Fiscal Conditions		√
	Availability of Open Space		√
	Environmental Quality	√	
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions		√

Table (4-6) Community actions and characteristics addressed by **LTM**

(c) Information Needed to Run the Model

To operate the model, a community must have a **GIS** data base that contains basic land use information. At a minimum, the following input data are needed

Input	Format
Previous land use	ArcInfo GRID
Roads, highways, streets	ArcInfo Lines
Surface water (rivers, lakes, etc.)	ArcInfo lines or polygons
Elevation Map **(DEM)**	ArcInfo GRID
Public lands	ArcInfo GRID
Population	ArcInfo GRID
Per capita use requirements	ArcInfo GRID

Table (4-7) Types and formats of **GIS** data needed to run the **LTM** model

(4-4-2-4) Model Strengths and Limitations

(a) Strengths

1) **GIS** outputs provide stakeholders and resource managers with easy to understand results.
2) **LTM** allows users to explore various inputs of data types that are classified and ranked using the **GIS** environment.
3) **LTM** combined with a neural network software package that learns how historical changes in land use are driven by various social, political and environmental factors.

(b) Limitations

1) The **LTM** model **"drivers"** are not dynamic *(static)*; projective ability is around **35%** for **(100 x 100 m)** cell size.
2) **LTM** uses many large **C programs** to couple the **GIS** and neural network simulation software.
3) Environmental process models that are included in **LTM** require large amounts of memory, *(around 2 GB of RAM for a 5 to 7 county area).*
4) The model requires training and experience to run. It is not a commercial product. It was developed to be used by a researcher working with resource managers.

(4-4-3) Land Use Change Analysis System (LUCAS)

(4-4-3-1) Model Overview

Land Use Change Analysis Systems (LUCAS)[(1)] was developed in 1994 to examine the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability.

Land Use Change Analysis Systems (LUCAS) is a raster-based land use model aiming to identify the suitable areas for new development (Berry et al., 1996).

LUCAS stores, displays and analyzes map layers derived from remotely sensed images, census and ownership maps, topographical maps, and the outputs from econometric models using the **G**eographic **R**esources **A**nalysis **S**upport **S**ystem **(GRASS)**, as public-domain **GIS**.

Simulations using **LUCAS** generate new maps of land cover representing the amount of land-cover change. Issues such as: biodiversity conservation, conservation goals, long-term landscape integrity, changes in real estate costs, species abundance, and land-ownership characteristics can be addressed by **LUCAS** model.

(4-4-3-2) Model Structure

The structure adopted for **LUCAS** consists of **three** main modules linked by a common database as shown in Figure (4-10). The model uses input data such as: land cover maps, topographic maps namely a **D**igital **E**levation **M**odel **(DEM)**, socio-economic data, population density, and transportation networks.

The model uses **(90 m x 90 m)** grid cells to predict future development for up to **100** years with **5** year increments.

(a) First Module

The first **LUCAS** module contains the **socio-economic models** that are used to calculate the transition probabilities associated with changes in land cover. These probabilities are computed as a function of **socio-economic** driving variables including:

---

(1) The **LUCAS** relevant materials can be obtained from: http://www.cs.utk.edu/~lucas/ (last accessed, 12/5/2009). More information about **LUCAS** are available in **Appendix (A)**.

1) **Transportation networks,** *(access and transportation costs)*

2) **Slope and elevation,** *(indicators of land use potential)*

3) **Ownership,** *(land holder characteristics)*

4) **Land cover,** *(vegetation)*

5) **Population density.**

The result of studying the effects of these driving variables on the urban pattern is stored in a Transition Probability Matrix (TPM).

The **TPM** is a data structure which contains the information used to calculate the probability that any data pixel with a given land use type will change to another land use type based on the pre-defined scenario. The **TPM** contains the **independent variable** coefficients which are used in an equation along with the land use condition value for the pixel to calculate the probability of change.

The **TPM** contains the **independent variable coefficients** which are used in an equation with land use weights to calculate the probability of change for each data pixel. The **independent variable coefficients** were empirically derived by studying land use change as it relates to **social** and **economic** factors, the driving variables mentioned in the above list.

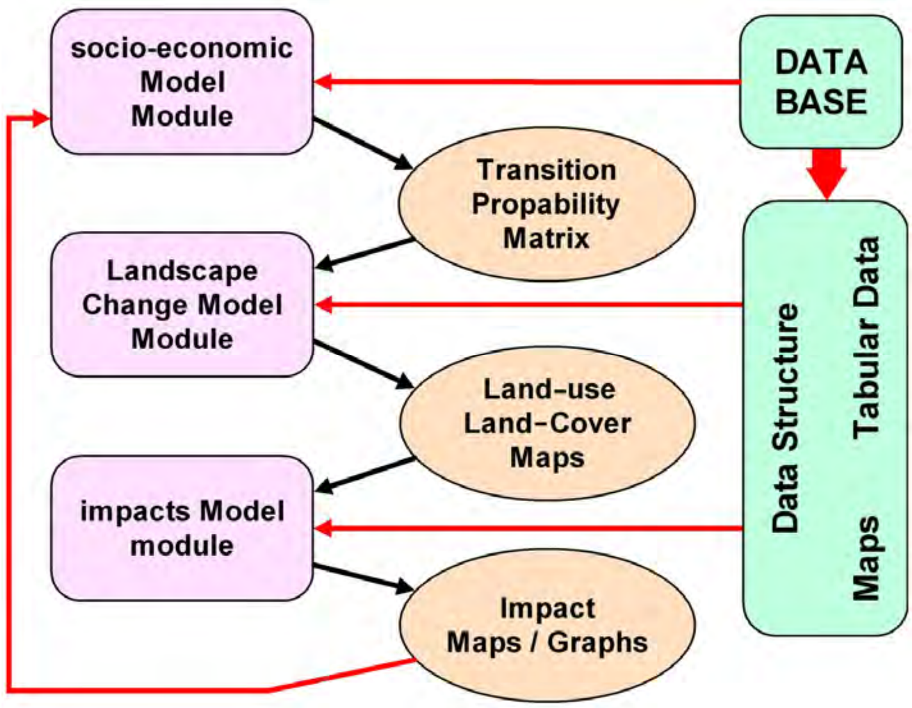


Figure (4-10) **LUCAS** model structure

(b) Second Module

The second **LUCAS** module is **land-cover** *(or land use)* **change model**; this module receives its input from the **TPM** produced in the **socio-economic model** *(Module 1)* and accesses the same spatial database of driving variables. A single iteration of the land-cover change model produces a predicted land-cover map that reflects **socio-economic** motivations behind **human land use** decision making, *(represented in the transition probability matrix).*

The user chooses a number of **time-steps and a number of replicates** from the model **G**raphical **U**ser **I**nterface **(GUI)**. The **GUI** passes this information to the underlying analysis code. The analysis code generates one map for each time-step in each simulation period.
Thus, if the user chooses **4** time-steps and **10** replicates, then **40** maps will be generated during the simulation. Each time-step map is based on the previous time-step map.

(c) Third Module

The third **LUCAS** module is the **impact models**, this module use the land-cover maps produced by the **land-cover change module** *(Module 2)* to evaluate the effects of these changes on selected environmental and resource supply variables.

These environmental variables include the amount and spatial arrangement of habitat for selected species and changes in water quality caused by human land use. Potential resource supply variables include timber yields and real estate values.

The resultant simulation maps stored in the temporary disk area are used as input to the impact models. The user chooses one of the impact models that he/she is interested in from the model **GUI**. This information is passed to the underlying analysis code through the use of **UNIX** environment variables. Graphs of the results and land-cover analysis are available after the simulation has completed. **The impact module and land-cover analysis results are stored in a file which is updated throughout the simulation.**

(4-4-3-3) Information Provided by the Model

(a) Land Uses Addressed

In **LUCAS**, land use is modeled as a multi-variate function of land cover change. This is an spatially explicit modelling approach.

LUCAS can address many different land use types, as shown in Table (4-8).

	Land Use Categories	Yes?	No?
Urban	Residential	√	
	Commercial	√	
	Mixed-Use		√
	Industrial		√
	Other		√
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	
	Park Land	√	

Table (4-8) Land use categories addressed by **LUCAS**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-9).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-9).

	Community Action / Characteristic	Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)		√
Characteristic	Travel Demand		√
	Local Government Fiscal Conditions		√
	Availability of Open Space	√	
	Environmental Quality	√	
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions		√

Table (4-9) Community actions and characteristics addressed by **LUCAS**

(4-4-3-4) Model Strengths and Limitations

(a) Strengths

1) **LUCAS** provides a **G**raphical **U**ser **I**nterface **(GUI)** that is intuitive and easily understood by users with a wide range of technical abilities and experience.
2) The system provides a flexible and interactive computing environment.

(b) Limitations

1) The temporal dimension is not explicit and consists of **five year** increments. The **Time-Series modelling approach** is important for the proposed urban and **IH** growth model in **LDC**, because it should encapsulate the actual spatial changes over time.
2) The spatial resolution is **too coarse** *(up to 90 m^2 grid cells)*, which is too large to capture the spatial distribution of **IH** patterns in most **LDC**.
3) **LUCAS** model uses **GRASS** as **GIS** environment, which still **non-commercial GIS** package, many bugs still exist in the **GRASS** software. In addition, some of the features of **GRASS** are not well documented.
4) The model requires training and experience to learn how to calibrate calculate the probability of the driving variables.
5) **LUCAS** lacks a feedback loop effect.

As stated in the introduction section, these features are important because the selected model should be able to produce a <u>realistic simulation</u> and display <u>dynamic representation</u> of urban and IH changes in the context of LDC.

(4-4-4) SLEUTH (Clarke Urban Growth Model)

SLEUTH is a coupled **GIS** and **CA** program to model urban and land cover changes, it originally innovated by **Keith C. Clarke**, 1997. **SLEUTH v3.0** is the most recent version of the program. **SLEUTH** growth coefficients are calibrated using **historical urban**, **transportation network** and **land cover** maps that aid in calculating an ideal numerical values of growth coefficients for **forecasting future urban change**. **SLEUTH** initially intended to model the urban expansion of American cities has so far been successfully tested in several American urban regions, such as New York, Chicago, Washington D.C., and San Francisco Bay (Candau, 2002).

(4-4-4-1) Model Overview

The **SLEUTH** [(1)] *(**S**lope, **L**and use, **E**xclusion, **U**rban, **T**ransportation, **H**illshading)* model is commonly known as the **C**larke **C**ellular **A**utomata **U**rban **G**rowth **M**odel or **C**larke **U**rban **G**rowth **M**odel **(UGM)**. The model is intended to simulate the changes from **non urban land cover** *(such as: agricultural, forest, wetlands, desert, Preservation, park land)* to **urban use** *(such as: residential, commercial, industrial, mixed use, and other land uses)* based on a grid of cells ***(Cellular Automaton)*** to understand how urban areas extend to their surrounding land and the environmental impact brought by this extension on the local environment (Clarke et al. 1996).

The model is defined as a **GIS** and **CA** based model that is scale independent, **The GIS part** of the model mainly contributes to the preparation and feeding of raster spatial data into the model, whereas **The CA part** is used to define functions such as **growth rule, simulation and prediction**. **GIS** and **CA** are loosely coupled to predict urban expansion and land use change based on historical trends.

The model assumes that historical growth trends will continue, and the future may be projected based on these trends.

Under this assumption, all **vacant cells** are updated synchronously in discrete time steps (*one year)*; the state of each cell depends on the previous state of its

(1) **SLEUTH** source codes and relevant materials can obtained free of charge from **http//:www.ncgia.ucsb.edu/ projects/gig/,** (last accessed, 15/02/2010). More information about **SLEUTH** program are available in **Appendix (A)**.

surrounding neighbors. In **SLUETH**, each cell is used to calibrate the growth coefficients, and the land use state of each cell is predicted based on **local factors** *(e.g., existing urban areas, roads, and topography),* **temporal factors, and random factors**.

(4-4-4-2) Model Structure

The Model Process includes **three main phases**:

- **Calibration of growth coefficients,**
- **Growth types,**
- **Testing.**

(a) Calibration of Growth Coefficients

SLEUTH simulates four types of urban land use change: **spontaneous growth, new spreading center growth, edge growth and road-influenced growth.** These four growth types are applied sequentially during each growth cycle *(or year)* and are controlled by five growth coefficients: **dispersion, breed, spread, road gravity and slope** (Clarke et al. 1997). The weight of each coefficient is determined by running four rigorous calibration phases: **coarse**, **fine**, **final**, **and averaging best results** *(All coefficients range from 0 to 100).*

The weighted probabilities of each coefficient are then used as input into the prediction phase. The **SLEUTH** growth coefficients can be described as follows:

- **The dispersion (or diffusion) coefficient** controls the number of times to randomly select vacant cells for possible urbanization at the next iteration.
- **The breed coefficient** determines the **<u>probability</u>** of an urbanized pixel by dispersion becoming a new growth center for the spread of urbanization.
- **The spread coefficient** calculates the probability of a vacant pixel at the edge of urban cluster *(>= 3 pixels)* to be urbanized.
- **The slope resistance coefficient** determines the effect of **slope** *(topographic constraint)* on the probability of a vacant pixel being urbanized.
- **The road gravity coefficient** determines the **<u>attractiveness</u>** of new urban cells along the existing transportation networks *(e.g., road, railway)* if they fall within a given distance of road (Clarke et al. 1998).

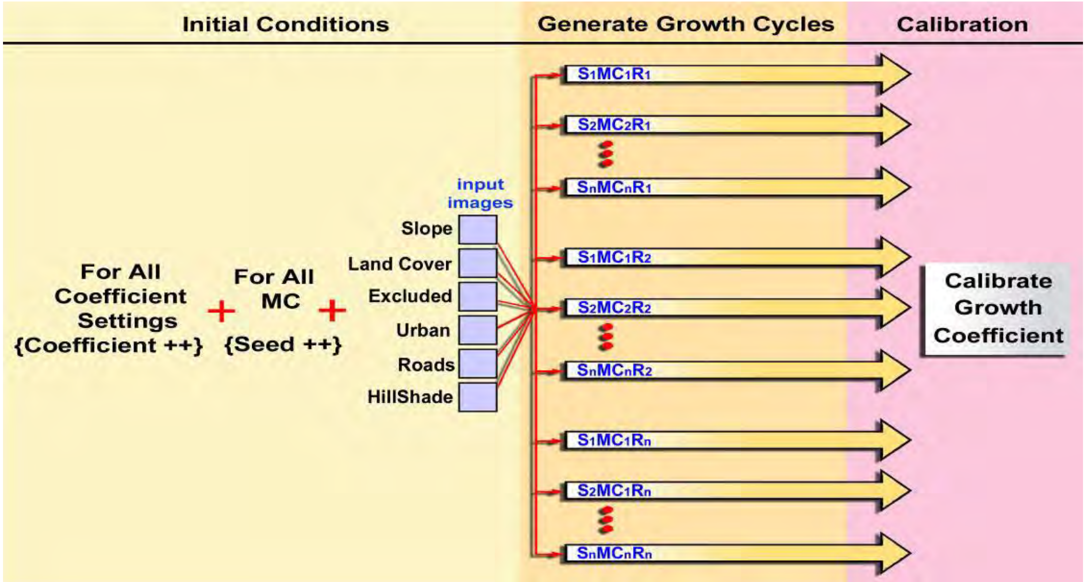


Figure (4-11) Growth coefficients calibration Work-Flow diagram

(Source: Yuanhong Zhu, Rick Day, 2002)

(b) Growth Types

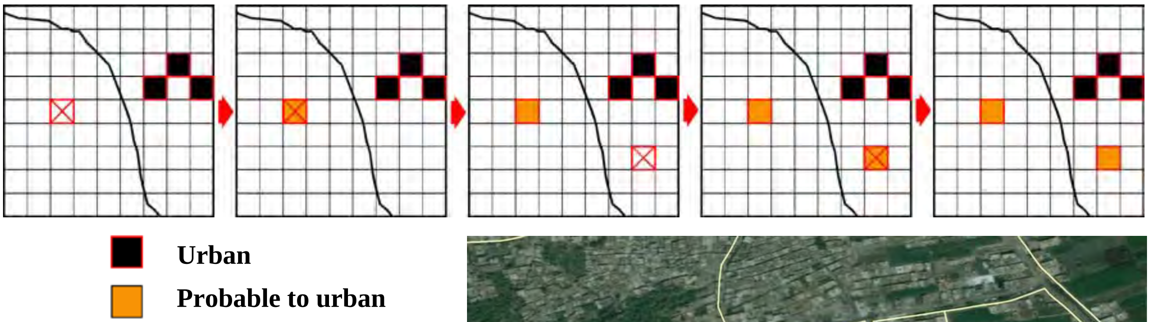
SLEUTH begins with a set of **initial conditions** which represents the existing urban. A set of **decision or growth rules** is then applied to the data to simulate urban and land cover change. When the calibration is running, all the **five** growth control coefficients are then weighted by probabilities that **encourage** or **slow** the growth cycle, according to **four growth types**, that can be summarized as in Table (4-10).

Growth cycle order	Growth type	Controlling coefficients	Summary descriptions
1	Spontaneous	Dispersion	Randomly selects potential new growth cells.
2	New Spreading Center	Breed	Growing urban centers from spontaneous growth.
3	Edge	Spread	Old or new urban centers spawn additional growth.
4	Road-Influenced	Road-Gravity, Dispersion, Breed	Newly urbanized cell produce growth along transportation network.
5 Throughout	Slope Resistance	Slope	Effect of slope on reducing probability of urbanization.
6 Throughout	Excluded Layer	User-Defined	User specifies areas resistant or excluded to development.

Table (4-10) Summary of growth types simulated by the **SLEUTH** model

- **<u>Spontaneous growth</u>** *(or Dispersion growth)*, occurs when a given <u>non-urbanized cell falls in the adjacent neighborhood of an already urbanized cell.</u> This then affects the urbanization of the surrounding cells. **Spontaneous growth function** expresses the probability of the random formation of new urban areas.

  Defined as cellular automata, **this function means that any non-urbanized cell in the lattice has a chance to be urbanized at the next iteration,** and its probability updated at each time step due to a self modification factor.



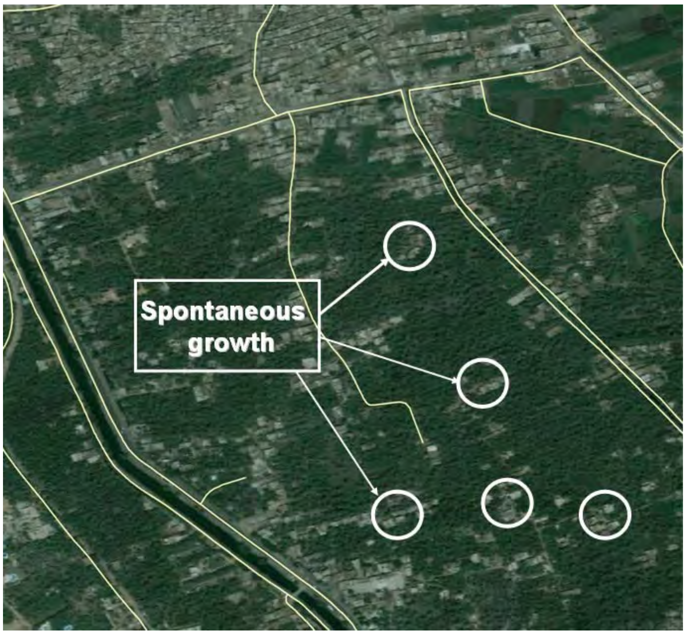
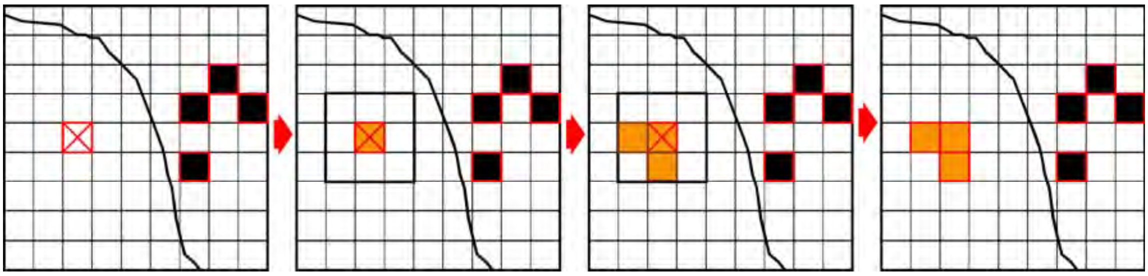


Figure (4-12) Tendency to urbanization due to **Spontaneous growth**

- **<u>New spreading center growth</u>** *(or Diffusion growth)* expects the emergence of urban cells in areas that are likely to become urban, even if urban cells do not surround them. Also known as <u>edge growth</u>, diffusion reproduces growth on the edge of an existing urban or on the new urban centers generated by spontaneous growth. Basically, if a **non-urban** cell has at least **three** urbanized neighboring cells *(>= 3 cells)*, then it may be urbanized at the next time step, depending on **slope and spread coefficients**.

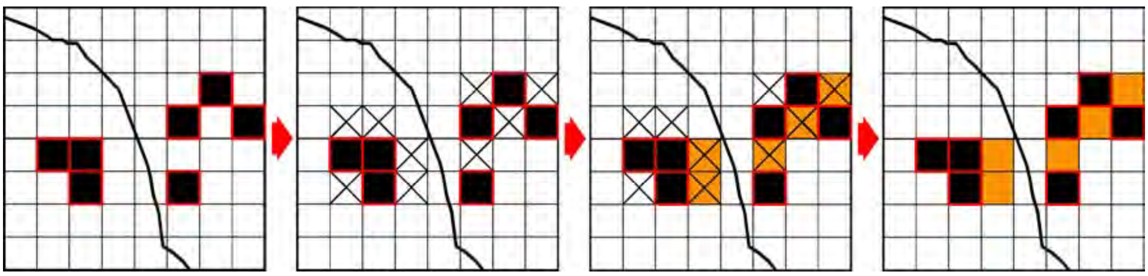


Urban

Probable to urban

Figure (4-13) Tendency to urbanization due to **New Spreading Center growth**

- **Edge growth** *(Organic growth)* expresses the tendency of the city to spread from the edge of existing urban to the **non-urban** and **non-excluded** areas of the lattice. This also refers to the probability that a new spontaneous growth cell will become a new growth centre.



Urban

Probable to urban

Figure (4-14) Tendency to urbanization due to **Edge growth**

- **Road gravity growth** factor estimates the probability of urbanization along the transportation and infrastructure networks, taking into account connectivity and accessibility. The probability of a cell being affected by road gravity growth is weighted by three coefficients: **breed**, **road gravity**, and **dispersion**.

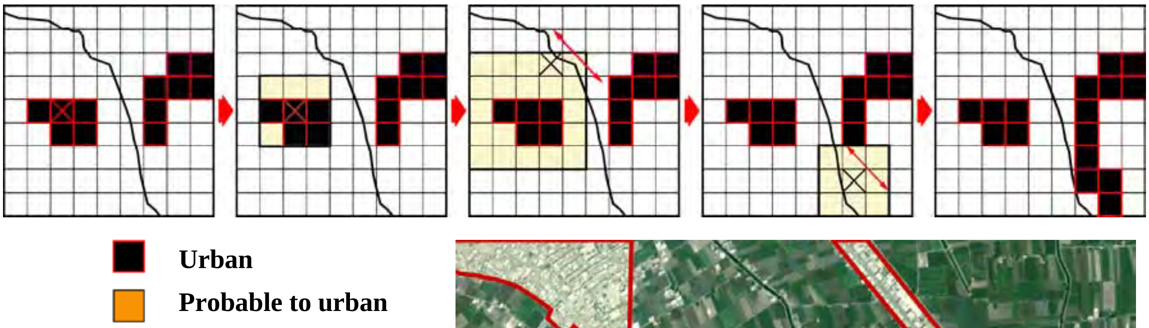


Figure (4-15) Tendency to urbanization due to **Road gravity growth**

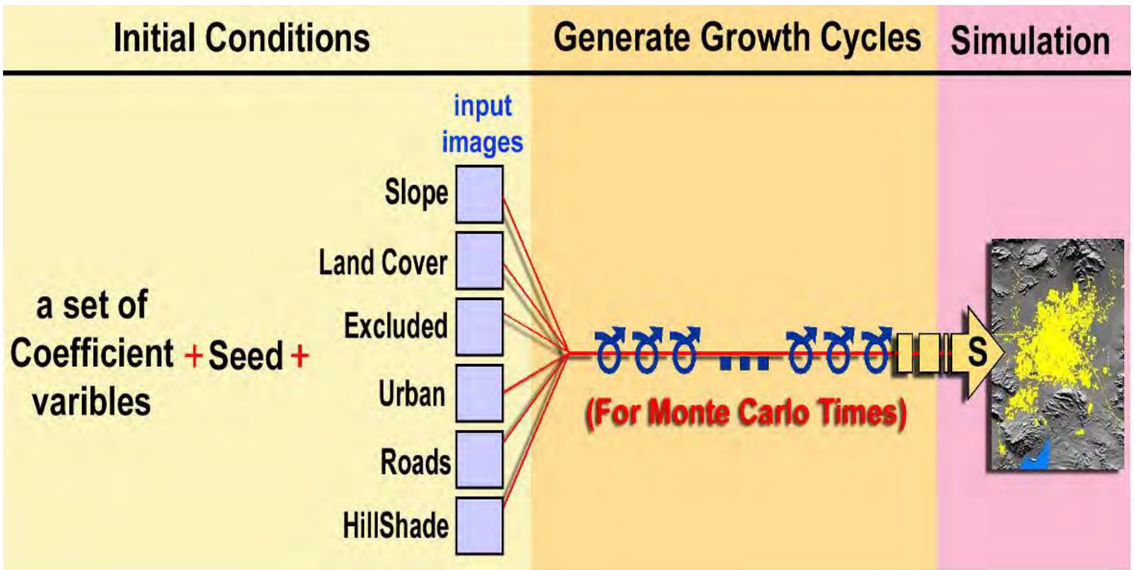


Figure (4-16) **SLEUTH** prediction Work-Flow diagram
(Source: Yuanhong Zhu, Rick Day, 2002)

(c) Information Needed to Run the Model

The model accepts two types of input files:

- **<u>Images folder</u>** consists of **six** categories of *(*.gif)* files that are fitted into the model. At least **three urban maps** and **two road maps** are acceptable, but only **one slope map**, **one excluded map** *(where urbanization can not occur)* and **one hillshade map** are required. **Land use maps** are optional

- **<u>Schedule folder</u>** contains **two** types of files. **First,** the dates of all the urban and road maps. **Second,** the spatial resolution of input files that can range from (100 m X 100 m) during coarse calibration to (30 m X 30 m) at the simulation stage.

The model provides outputs as a set of **GIF** image files that may be merged into an animation or brought into a **GIS** as data layers. Resolution of output images depends on the resolution of the input data. The model provides many outputs such as:

- The cumulative image that produced from multiple runs and shows the probability of urbanization in a particular year,
- The final coefficient values and the standard deviations of the average actual values,
- A set of best fit values between modeled and real data for calibrating the model,
- The start and stop times for an entire model execution (U.S. EPA 2000).

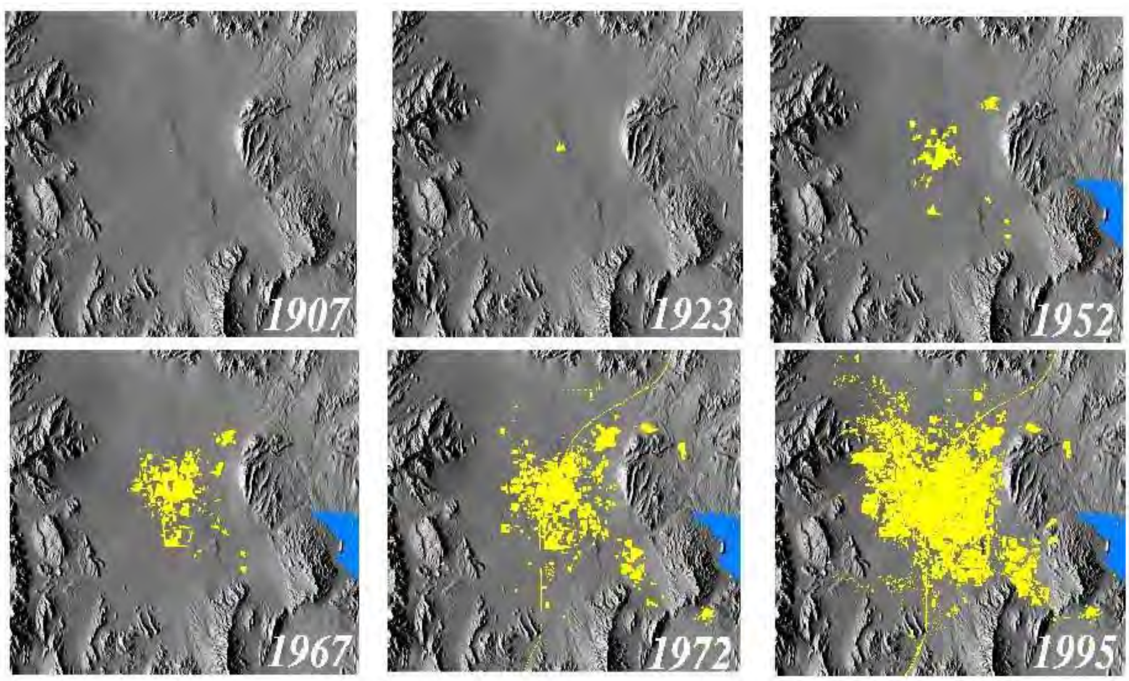


Figure (4-17) The growth of **Las Vegas** from **1907** to **1995**

(4-4-4-3) Information Provided by the Model

(a) Land Uses Addressed

The **SLEUTH** model assumes two land use maps and a set of predefined land use categories with names assigned by the user *(e.g., a numeric value, such as 6, in the land cover file to represent forest or non-urban land uses).*

The model handles any combination of user-defined **urban** or **non-urban** land use categories, including those represented in Table (4-11).

Land Use Categories		Yes?	No?
Urban	Residential	√	
	Commercial	√	
	Mixed-Use	√	
	Industrial	√	
	Other	√	
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	
	Park Land	√	

Table (4-11) Land use categories addressed by **SLEUTH**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-12).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-12).

Community Action / Characteristic		Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes,)	√	
Characteristic	Travel Demand		√
	Local Government Fiscal Conditions	√ [1]	
	Availability of Open Space	√	
	Environmental Quality	√ [1]	
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions		√

Table (4-12) Community actions and characteristics addressed by **SLEUTH**

1) Any fiscal or environmental impact which can be estimated as a function of urbanization could be developed for the output of this model.

(4-4-4-4) Model Strengths and Limitations

(a) Strengths

1) **SLEUTH** concurrently simulates **four** types of growth *(spontaneous, diffusive, organic, and road gravity).*
2) **SLEUTH provides** both graphical and statistical outputs.
3) The model allows for relatively simple alternative scenario projection.

(b) Limitations

1) **SLEUTH** does not explicitly deal with **population**, **policies** and **economic impacts** on land use change, <u>except in terms of growth around roads</u>.
2) **SLEUTH** relies on the historical behavior of physical and spatial factors and ignores other non-spatial factors that affect on the urban systems *(e.g., economic and land regulation, employment، population growth, urban growth policies and socio-cultural influences).*
3) Although the model successfully handles spatial temporal urban dynamics, it only models two states, **urban** and **non-urban space**, and does not simulate urban land use changes.
4) **SLEUTH** has a rigid number of input variables, which makes it difficult to adapt to the context of **IH** emergence and growth in **LDC**.
5) Using **SLEUTH** model requires a general understanding of **C** programming language, particularly if there is a need to modify the model source code**.**

(4-4-5) Integrated Land Use and Transport Modeling System (TRANUS)

The **TRANUS** [1] is the abbreviation of **I**ntegrated **L**and **U**se and **T**ransport **P**lanning **S**ystem. The **TRANUS** model simulates the location of activities in space, **land use**, **the real estate market** and **the transportation system**. It may be applied to **urban**, **regional** and **national** scales.

TRANUS uses **discrete choice** and **random utility** theories. The program has been used since **1982** and now runs on a **P**ersonal **C**omputer **(PC)** with a **GIS** interface. The **TRANUS** system may be applied to: **Detailed urban areas**, **Metropolitan areas**, **Metropolitan regions**, **states or provinces**, and **National level**.

(4-4-5-1) Model Overview

TRANUS is intended to assist transportation and land use planners to **simulate** and **evaluate transportation**, **economics** and **environmental policies**, the required data includes:

- **Population,**
- **Employment,**
- **Land use status and price,**
- **Transportation network information,** *(such as: network capacity, distance, links, speed limits, and traffic cost).*

The aim of the software can be summarized in **two** main points:

Firstly, **TRANUS** is intended to simulate **possible impacts** of applying particular **land use, transport policies and projects** of different kinds in cities and regions.

Secondly, **TRANUS** is used to evaluate these impacts on **social, economic, financial, and environmental** points of view.

The most worthy characteristic of the **TRANUS** system is the way in which all components of the urban or regional system are closely integrated, *such as the location of activities, land use and the transport system*. These elements are related to each other in an explicit way, according to a theory that was developed for this purpose.

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[1] The **TRANUS** relevant materials can be obtained from: http://www.modelistica.com/tranusenglish.htm, (last accessed, 12/4/2009). More information about **TRANUS** are available in **Appendix (A)**.

In this way, the movements of **people** or freight are explained as the results of **the economic and spatial interactions between activities, the transport system and the real estate market**. In turn, the accessibility that results from the transport system influences the location and interaction between activities, also affecting land rent.

The system may be used also as a stand-alone transport model, especially to evaluate the short-term effects of transport projects.

(4-4-5-2) Model Structure

The main components of the **I**ntegrated **L**and **U**se and **T**ransport **M**odel **(TRANUS)** are:

- **Activities location and land use module**,
- **The transport system module**,
- **The activities-transport interface module**,
- **The evaluation procedure**.

The **two** main subsystems of the model are: **activities** *(land use)* and **transport**. Within each subsystem a distinction is made between **demand** and **supply** elements that interact to generate a state of equilibrium, as shown in Figure (4-18).

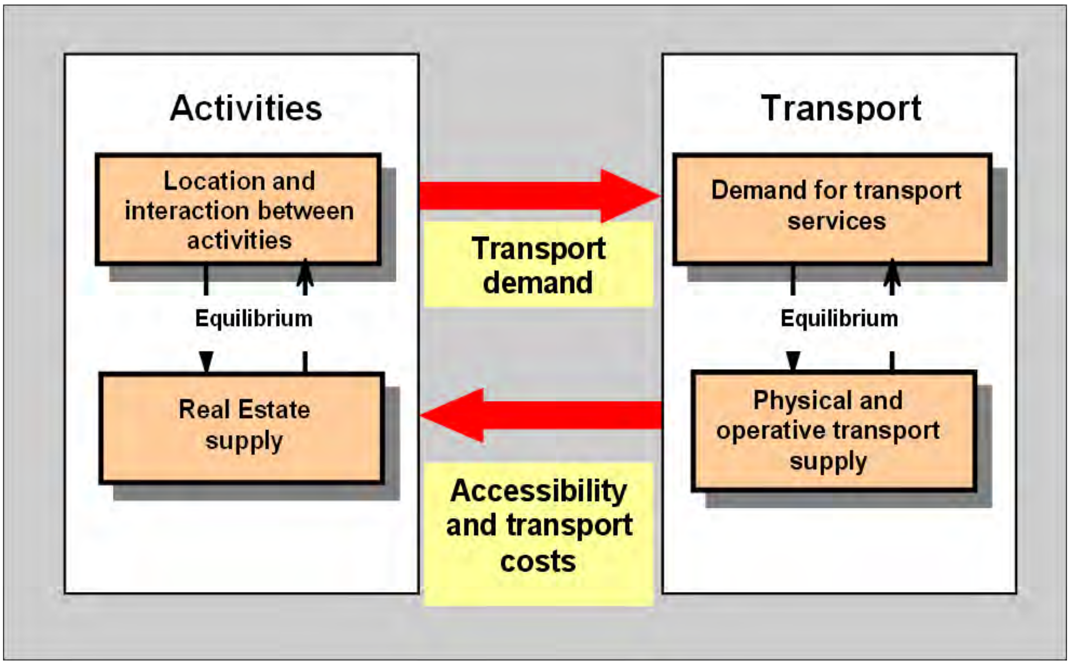

Figure (4-18) Main elements of the **land use transport system**

(a) Activities Location and Land Use Module

The purpose of the **activities location module** is to simulate a **spatial economic system**. Given a region or city divided into zones, the model estimates the activities that locate in each zone and the interactions that they generate.

The location and interaction of activities represent the **demand side** in the activities location subsystem. **Activities** such as: industries or households locate in specific places and interact with other activities to perform their functions.

Activities also require land and floor-space in order to perform their functions. Such spaces are provided by developers in the real estate market, thus representing the **supply side**. The interaction between these two elements must lead to a state of equilibrium.

If demand for land is greater than supply in a specific place, land rent will increase to reduce demand.

Consequently, **land rents** and **real estate prices** are the variable elements that lead the system to a state of equilibrium.

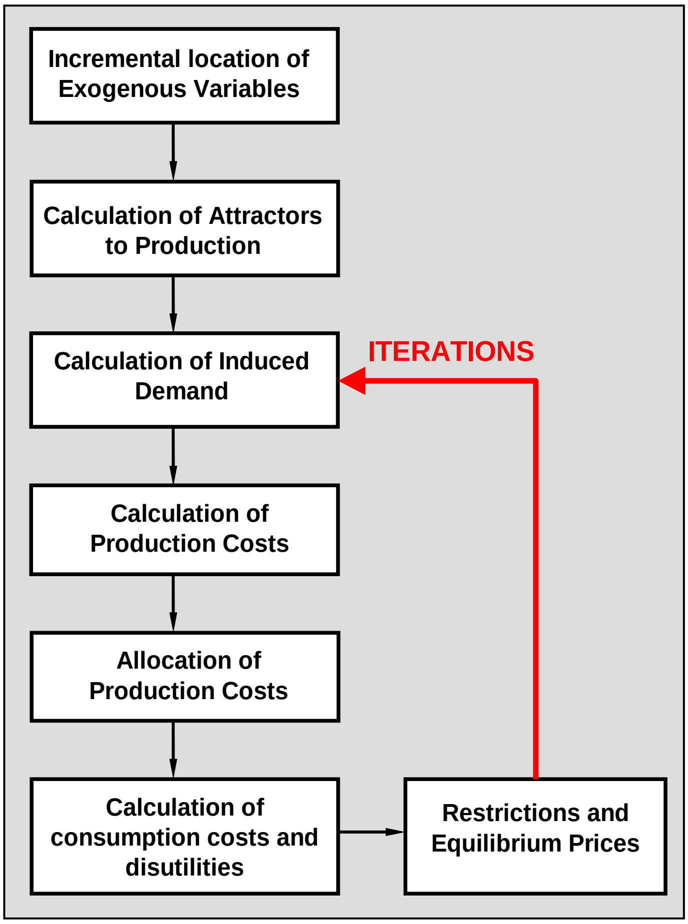

Figure (4-19) Structure of the **activity location module**

(b) The Transport System Module

The main purpose of the **transport module** is to estimate **travel demand** and assign it to **transport supply**. The demand is represented by the need for travel according to the interaction between activities that may take the form of people traveling to their places of work or services, or goods that are produced in one place and consumed in another. A distinction must be made between the **physical supply** and the **operative supply**.

- **The physical supply :** is represented by roads, railways, maritime routes or any other relevant transport component.
- **The operative supply :** is made of a set of transport operators that supply **transport services**, such as bus companies, truck companies, airlines, or even automobiles and pedestrians, **The operative supply uses the physical supply to perform its functions.**

Demand/supply equilibrium in the transport subsystem is achieved in two ways: prices and time. If demand becomes greater than supply for a particular service, the price of the service may increase, but it is mainly the travel time that increases to achieve equilibrium.

For instance, *if the number of passengers for a bus service is greater than the spare capacity of the service, waiting time will increase. Similarly, if the number of vehicles along a road gets close to the capacity of the road, congestion is generated, thus increasing travel times.*

In other words, time is an important component in the demand/supply equilibrium in the transport system.

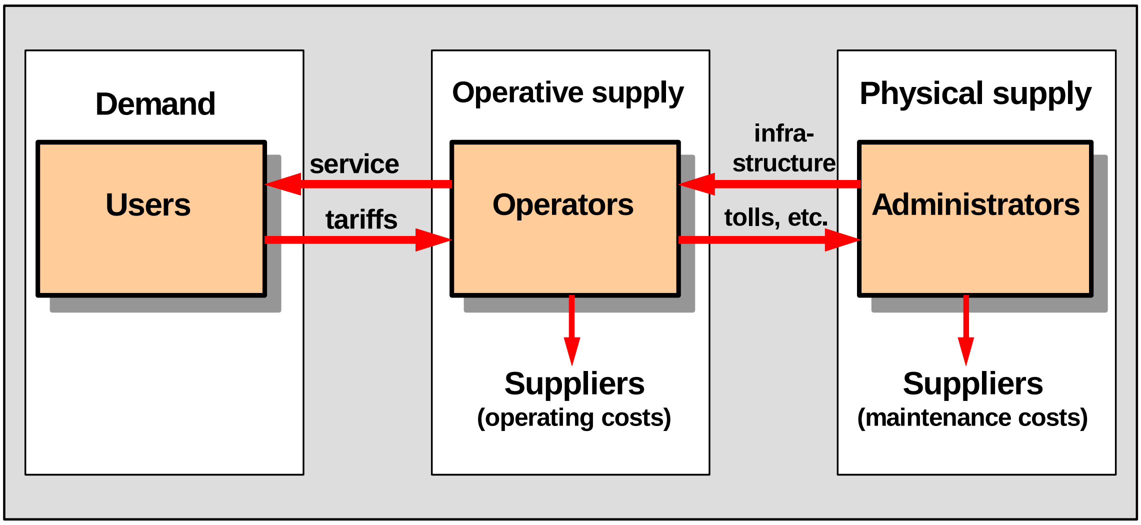

Figure (4-20) Elements of the **transportation subsystem**

(c) The Activities-Transport Interface Module

The **activities-transport interface module** performs other transformations to make compatible the units of **time, magnitude and direction of the flows** between the land use and transport model. The following transformations are possible:

- **Formation of transport categories from economic flows**,
- **Time factor**,
- **Volume / value factor**,
- **Direction of flows**.

(d) The Evaluation Procedure

The model also allows for the definition of any number of *"scenarios"* with corresponding policies and projects to simulate.

A **base case scenario** is used to compare results and obtain the probable effects of applying particular policies and projects. The model calculates many indicators to evaluate these effects, from social, economic, financial and environmental points of view.

(4-4-5-3) Information Provided by the Model

(a) Land Uses Addressed

There are no fixed categories to **TRANUS**. Any number of land use categories may be defined, limited only by available information and the objectives of the project. The model is flexible to be set with the categories normally used in the planning offices or master plans of the study area.

TRANUS is an **Activity Location**, **Land use**, and **Transport** model. Not only land use categories need to be defined, but also activities like **population** *(by income groups or household size)* **employment** *(by type)*, **education** *(employment and students)* and any other relevant activity in the study area**.**

Land Use Categories		Yes?	No?
Urban	Residential	√	
	Commercial	√	
	Mixed-Use	√	
	Industrial	√	
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	
	Park Land	√	

Table (4-13) Land use categories addressed by **TRANUS**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-14).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-14).

Community Action / Characteristic		Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)	√	
Characteristic	Travel Demand	√	
	Local Government Fiscal Conditions	√	
	Availability of Open Space	√	
	Environmental Quality	√	
	School Quality	√	
	Crime	√	
	Other Quality-of-Life Conditions	√	

Table (4-14) Community actions and characteristics addressed by **TRANUS**

(c) Information Needed to Run the Model

The **TRANUS** model requires the following user input:

- Network nodes, links and routes *(comma delimited text files generated by any **GIS** program can be imported to **TRANUS**)*. Alternatively, small networks can be interactively created in the graphic window of **TRANUS** with the mouse.
- Transport variables *(introduced in the database with the Windows-like menus and commands provided by the **TRANUS** User Shell).*
- Activity location and land use data by zone *(copied from any worksheet or **GIS** and pasted to the **TRANUS** database).*
- Activity location and land use variables *(introduced in the database with the Windows like menus and commands provided by the **TRANUS** User Shell or copy-and-paste from spreadsheet).*

(4-4-5-4) Model Strengths and Limitations

(a) Strengths

1) **TRANUS** is one of the very few integrated **land use and transport models** commercially available, backed by a sound history of practical applications in many countries.
2) **TRANUS** is extremely **user-friendly**, with a powerful graphical **Windows-based interface. The interface is supported by a dynamic object-oriented database, with GIS** interface capabilities. From the beginning, the model was developed for use on personal computers.
3) The model can be applied to a large variety of case studies, ranging from very simple urban or regional models to highly sophisticate national or regional models.
4) **TRANUS** is backed by a continuous research and development process. Every year a new version of **TRANUS** is released, with many upgrades based on the experience of applications and suggestions or users requests.

(b) Limitations

1) **TRANUS is not a traffic model yet**, the model was designed for planning, for strategic decisions about main policies: **railroads**, **metro systems**, **new highways**, **master plans**, and so on. After many years of development and applications, **Modelistica** expanded the model to cope with detailed urban applications, including a sophisticated representation of transit systems. However **TRANUS** does not cover all aspects of traffic models, such as calculating signal times or intersection movements (US. EPA, 2000).
2) **TRANUS** input data needed to run the model are too disaggregated and may not always be easily available for many cities in **LDC**.
3) **TRANUS** package is **expensive** and requires reliable socio-economic statistics, such as speed limits, which are not critical for the exploration and simulation of urban and **IH** growth in **LDC** cities (Sietchiping, R. 2004).
4) **TRANUS** not only relies heavily on transportation models, it is not flexible enough to allow the modification or addition of input parameter (US. EPA, 2000).

(4-4-6) UPLAN

The Urban Growth Model **(UPLAN)** [1] is a **raster-based urban simulation package**؛ it was developed to allow users to project future land use patterns. The model can used to generate development scenarios according to a set of decision policy rules. The first version of **UPLAN** *(V 1.2)* was designed by the **University of California, Davis,** in cooperation with the **M**erced **C**ounty **A**ssociation of **G**overnments **(MCAG)**, it was written in *Arc-View Avenue* scripting language. The new version *(V 2.04)* is fully programmed in *Visual Basic Application (VBA)* and runs in *ArcGIS (V9.0).*
This software displays the simulation result on the web using *Arc-View Map Object*.

(4-4-6-1) Model Overview

UPLAN provides a land use evaluation and change analysis based on **general land use plans, population and employment projections, characteristics of housing, and other user-defined conditions**.

UPLAN is integrated package that enable users to: Conduct a land suitability analysis, Project future land use demand. **UPLAN** helps communities to create alternative visions for their area's future by mapping alternative development patterns determined by local land development policies.
UPLAN uses input layers such as urban land use *(residential, commercial and industrial)*, population density, **DEM**, socio-economic data, transportation, agricultural land, and protected areas to derive the suitability of urban growth (Sietchiping, R. 2004).

UPLAN address some of the policies and decisions include:

- **Establishing various criteria to "weight" the suitability of different locations for a particular land use,**
- **Incorporating various land use planning, zoning considerations and other allocation scenarios,**
- **Defining various growth scenarios** (US. EPA, 2000).
- **Also, the model can used to determine various environmental and social constraints to growth by modifying their criteria and the associated weights.**

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[1] The **UPLAN** relevant materials can be obtained by contact the model developer. More information about **UPLAN** are available in **Appendix (A)**.

(4-4-6-2) Model Structure

The objective of building **UPLAN** model was to create a model that projects urban growth by using several land uses. Generally, at least **three residential densities** must be represented, in addition to **industrial and two densities of commercial land.** The model does not need to calibrate with historical data, because its intended use is for long-range scenario testing.

Many objectives have guided the design of the model such as: the **allocation rules** must simulate land markets and the model must be applicable to counties, metropolitan regions. These criteria make the model easy to use and informative for planners and citizen groups.

The UPLAN model was developed based on the following assumptions:

- The **population growth** can be converted into **demand for land use** by applying conversion factors to employment and households.
- The proposed **urban expansion** will conform to city and county general plans.
- Cells have **different attraction weights** because of **accessibility** to transportation and infrastructure.
- Some cells will not be developed, *such as: lakes and streams*. Other cells, such as sensitive habitats and flood-plains, will prevent new development.

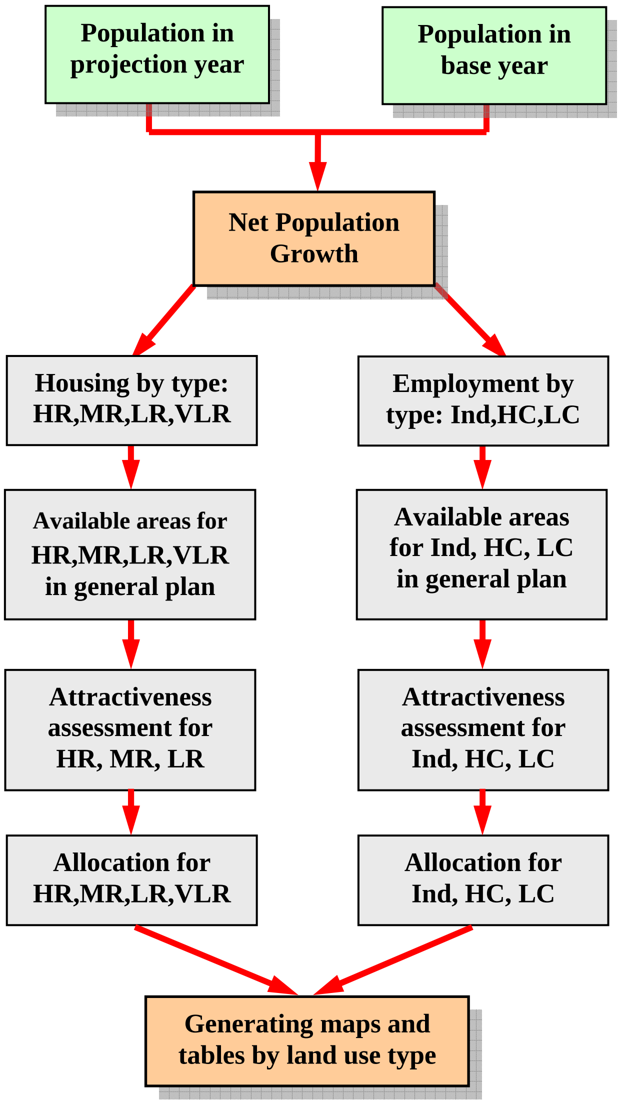

Figure (4-21) **UPLAN** model Flow-Chart

HC: High Commercial.

LC: Low Commercial.

HR: High Residential Density.

MR: Medium Residential Density.

LR: low Residential Density.

VLR: Very Low Residential Density.

The **UPLAN** model allows the user to develop specific parameters in the form of grids that are used to model future land uses. The user can generate **four** main categories of input grid layers including:

- **Attractive grids,** which represent the locations for future development *(i.e., near to roads, infrastructure, existing urban, etc.)*;
- **Exclusion grids,** which define the locations where development should not occur *(i.e. parks, excluded areas, waterways, etc.)*;
- **General plan grid,** which contain a composite grid of the general plan land use maps from the users region;
- **Existing urban grid,** which provides the current land use conditions.

UPLAN *(Urban Growth Model)* consists of **three** sub-models. The user will be asked in the first user interface to choose a sub-model to run.

The first sub-model is a *cluster **UPLAN** model* and designed to test the impacts of improvement of regional transportation infrastructure and land use policies. It treats the counties that have planning cooperation and strong economic interactions as a cluster. **Within the cluster sub-model, there are no constraints on the allocations of total residential and employment among the counties.** In other words, the impact of land use polices in one county may cross the county border and influence the land use patterns in other counties. *(A significant improvement in transportation infrastructure, such as the high speed road, may also cause a significant shift of residential and employment from one county to its adjacent counties).*

The second sub-model is a *county **UPLAN** model*. This sub-model is designed to project the spatial allocation of **residential** and **employment growth** according to the attractiveness of the grid cells, allocates the population growth and employment growth within the county to the land use types that are designated in the county general plan. **The areas with higher attractiveness values will have more growth of residential and employment than those with lower attractiveness values, given the same amount of available land.** Therefore, the cities with higher attractiveness and big amount of available land will have higher shares of population and employment growth.

<u>The third sub-model</u> is a *county sub-area model*. It is a **share-shift** model, and is designed to <u>project the spatial allocation of residential and employment at county sub-area level.</u> The total population for each county sub-area is controlled by its share in the total population growth of the county. Each sub-area is allowed to have its own input parameters. The share of population growth for each sub-area is pre-determined before the model is run.

The **employment growth** for each county sub-area is independent of its population growth. The spatial competition of employment growth is allowed among the sub-areas. However, the model reserves the flexibility to allocate the **employment growth** in the same way as the **population growth** is allocated.

(4-4-6-3) Information Provided by the Model

(a) Land Uses Addressed

UPLAN can accommodate up to **six** different types of land uses, as is, *(industry; high and low density for commercial; and high, medium, and low density for residential)* and can be modified to accommodate any number of land use categories.

Because **UPLAN** can be customized to accommodate the user's own data, so the number and type of land use categories can vary from application to application.

UPLAN is <u>policy-oriented</u> land use change projective tool. It shows the likely impacts of different user supplied assumptions concerning land use demands, land suitability.
Market mechanisms, such as subsidies and taxes can be coded *(or weighted)* **as sub areas with positive or negative values.**

Land Use Categories		Yes?	No?
Urban	Residential	√	
	Commercial	√	
	Mixed-Use	√	
	Industrial	√	
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	
	Park Land	√	

Table (4-15) Land use categories addressed by **UPLAN**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-16).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-16).

Community Action / Characteristic		Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)	√	
Characteristic	Travel Demand	√	
	Local Government Fiscal Conditions	√	
	Availability of Open Space	√	
	Environmental Quality	√	
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions		√

Table (4-16) Community actions and characteristics addressed by **UPLAN**

(c) Information Needed to Run the Model

The inputs listed below are **desired**, but not **required** for **UPLAN** since the model can be run with default values. The more **detailed specific inputs** the user provides, the more **accurate the analysis**. The desired inputs include:

- Demographic and land use factors, population projections, persons per households, assumed housing densities, average parcel size for each density class, employment by type, assumed employment density. *(Must be entered by system user).*
- Regional general plans, and incorporated city areas provided by Local Planning Organization users. *(Must be entered by system user).*
- All roadway and intersection. Data must be entered for each development scenario. Also major infrastructure locations, such as: airports, railway station. *(Must be entered by system user, digitized data)*
- Major waterways, lakes, and rivers. *(Must be entered by system user).*
- Existing urban lands for the base year, general land use plans, containing major land use types *(e.g., housing , commercial, and rail station locations),* and slope.

(4-4-6-4) Model Strengths and Limitations

(a) Strengths

1) **Easy to use: UPLAN** allows users to prepare and evaluate alternative suitability, growth, and allocation scenarios by specific commands generated by the program.
2) **Customizable to different areas: UPLAN** incorporates information provided by the users to currently available **GIS** and **non-GIS** data, allowing the system to be customized to many different geographic areas and conditions.
3) **Integrated system: UPLAN** provides an integrated software package that incorporates user provided **GIS** and other data as a foundation and applies various evaluation/decision-tools *(e.g., land use projection)* to the underlying data.

   UPLAN uses currently available GIS data to prepare maps and reports showing the outcomes of alternative development scenarios on future land use patterns.
4) **Input land uses:** The default **six** land use types *(industrial; commercial high and low density; and three residential densities)* permit the evaluation of the impacts of the future land use pattern on water pollution, habitats, and land costs.
5) **Data grid size:** Data grids can be a small as the data permit, generally **25 m** grid cells.

(b) Limitations

1) **Lack of sophisticated modelling: UPLAN** does not provide the sophisticated modelling capability and/or theoretical basis to examine the correlated factors of urban growth, and other planning decisions that affect on the amount and type of future development and land use change that will occur.
2) **UPLAN described as "black box" model:** The framework of **UPLAN** is rigid and can be regarded as a **"black box"**. The user is unable to make any changes in the program source code, *(such a: simulation period, number of variables and incorporate new rules).*
3) **User limitation:** The user can only enter the attraction weights for parameters that already set, limiting the capacity to introduce new growth parameter.
4) **Applications limitation: UPLAN** is in its early stages and like **CUF**; applications are customized to the **California** region.

(4-4-7) UrbanSim (Urban Simulation)

UrbanSim [(1)] *(Urban Simulation)* is not a single model. It might be better described as an urban simulation system, designed as a tool for urban planners, policymakers, and other community decision maker to help formulate and evaluate combinations of **land use, transportation and environmental policies**.

(4-4-7-1) Model Overview

UrbanSim consists of a family of models, such as the economic and demographic transition models, are aggregate**, non-spatial models** that deal with the interface to external **macro-economic changes**. Other components such as location choice are **discrete choice models** *(a household, for example)* making choices about alternative locations, taking a **top-down view** of the metropolitan area.

UrbanSim is currently being extended to address environmental impacts of development by simulating land cover, pollution, and water demnad. Specifically, the model:

- Simulates **urban development as a dynamic process over time and space.**
- Simulates **the key decision makers and choices impacting urban development**; in particular, the mobility and location choices of households and businesses.
- Simulates **the land market** as the interaction between **demand** *(location of businesses and households)* and **supply** *(existing vacant space and redevelopment locations)*, with prices adjusting in response to short-term imbalances between supply and demand.
- **Incorporates governmental policy assumptions explicitly**, and evaluates policy impacts by modelling market response (US. EPA, 2000).

Running the **UrbanSim** model requires exogenous input information derived from:

a) **The population and employment estimates.**
b) **Regional economic forecasts.**
c) **Transportation system plans.**
d) **Base year and future land use plans.**
e) **Land development policies**, *(e.g., density constraints, environmental constraints, development impact fees, incentive taxes and fees)*.

(1) **UrbanSim** is a public domain program and can be downloaded free of charge at http://www.urbansim.org/ (last accessed, 23/04/2009). More information about **UrbanSim** are available in **Appendix (A)**.

UrbanSim uses **GIS** to prepare the required input layers. The **GIS vector layers** are mostly produced from **parcel subdivisions**, **city boundaries**, **slope**, and **traffic zones**, whereas **GIS raster layers** are composed of aggregated parcels of **(150 m x 150 m)** grid cells. After preparing, the simulation process is derived from the following four steps:

- **Scenario assumptions,**
- **Runtime parameters,**
- **The model configuration,**
- **Event changes** *(policy, employment, environmental constraints and development).*

UrbanSim then generates **urban growth scenarios** (based on the information provided) with optional user-defined temporal increments of **1 to 10** years and a projection period scale between **5 to 100** years (Waddell, 2001). **UrbanSim** can simulate situations such as changes in <u>land use, number of new constructions, location of businesses, evolution of real-estate prices and the location of new development.</u>

(4-4-7-2) Model Structure

The **UrbanSim** model has two key components: **Demographic transition module and Economic transition module** that predict changes in the distribution of households and business by type (*e.g. age, income, businesses by industry)* at the regional level, consistent with exogenous aggregate forecasts of population and employment. Then **UrbanSim** model can predict:

a) The location of businesses and households,

b) The location, type, and quantity of new construction and redevelopment areas,

c) Estimates the prices of new development land and new buildings.

<u>In the household mobility and location module</u>, the **UrbanSim** model simulates household decisions about whether to move or remain in their current location, and if they choose to move, the model expects their selection of the housing type and zone (Waddell, P. 1998).

<u>In the business mobility and location module</u>, businesses make similar choices regarding mobility, building type and location choice. Household and business characteristics influence choices, as do spatial attributes such as accessibility and prices.

In the land development component module, the model simulates developer choices to convert **vacant** or **developed land to urban uses**, including the type of improvements and density, based on their profitability expectations and subject to constraints imposed by governmental policies such as: **zoning**, **services**, and **infrastructure availability** (Waddell, P. 1998).

As shown in Figure (4-22) UrbanSim has eight core models, which can be summarized as follows:

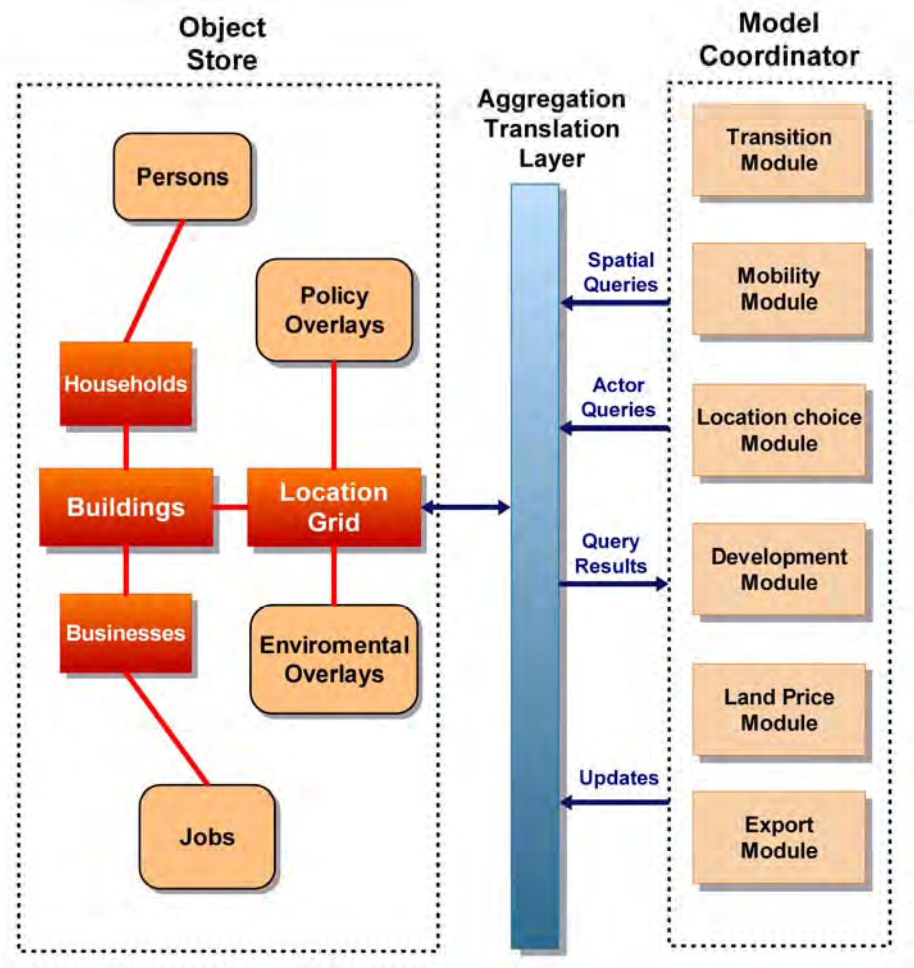

Figure (4-22) **UrbanSim** architecture

(a) The Demographic Transition Model simulates **births** and **deaths** in the population to determine the overall target population values. This enables the concept of shifting population distribution over time.

Iterative proportional fitting technique (Waddell, P. 2002) is used to determine how many households of each type are to be created or deleted. Newly created households are added to the household list but without an assignment to a specific housing geographic zone *(placed in geographic area)*, to be placed later in housing by the ***Household Location Choice Model***.

<u>(b) The Economic Transition Model</u> is responsible for modelling **job creation and loss**. Employment control totals are determine employment targets, and can be specified by distribution of business sector.

<u>(c) The Household Mobility Model</u> simulates households deciding whether to move. Movement probabilities are based on **historical data**. Once a household has chosen to move, it is placed in <u>transition stage</u> to indicate it has no current available location, and the space it formerly occupied is made available.

<u>(d) The Employment Mobility Model</u> determines which jobs will move from their current locations during a particular year using a similar approach to the Household Mobility Model.

<u>(e) The Household Location Choice Model</u> chooses a location for each household that has no current location. For each such household, a sample of locations with vacant housing units is randomly selected from the set of all vacant housing units.
Each alternative in the sample is evaluated for its desirability to the household, through a **multinomial logit model calibrated using the historical observed data**. The household is assigned to its most desired location among those available. The variables used in the **household location model** include:

- **Attributes of the housing in the grid cell** *(price, density, age,… etc.,)*
- **Neighborhood characteristics** *(land use mix, density, average property values, local accessibility to roads and commercial areas).*
- **Regional accessibility to jobs.**

<u>(f) The Employment Location Choice Model</u> is responsible for determining a location for each job that has no location. For each such job, a sample of locations with empty square feet, or space in housing units, is randomly selected from the set of all possible alternatives. Variables in the employment location model include:

- **Real estate characteristics in the grid cell** *(price, type of space, density, and age).*
- **Neighborhood characteristics** *(average land values, land use mix, employment in each other sector).*
- **Regional accessibility to population.**

(g) The Real Estate Development Model simulates the developer choices about what kind of construction to **undertake and where**, including both new development and redevelopment of existing urban areas.

Each year, the model iterates over all grid cells on which development is allowed and creates a list of possible transition alternatives *(representing different development types)*, including the alternative of not developing.

The probability for each alternative being chosen is calculated in a **multinomial logit model**. Variables included in the developer model include:

- **Characteristics of the grid cell** *(current development, policy constraints, and land improvement value).*
- **Characteristics of the site location** *(proximity to highways, arterials, existing development, and recent development).*
- **Regional accessibility to population.**

(h) The Land Price Model simulates **land prices** of each grid cell as the characteristics of locations change over time. It is based on **urban economic theory**, which states that the value of location is capitalized into the price of land.

The model is calibrated from historical data using the regression analysis to include the effect of site, neighborhood, accessibility, and policy effects on land prices.

Finally, the user is allowed to create **"scenarios"** as input to **UrbanSim** by specifying alternative forecasts of population and employment, land use policy assumptions, transportation infrastructure assumptions, ….etc.,.

The model then provides output regarding, future year distributions including:

- **Population, households by type** *(e.g. income, household size, presence of children, and housing type).*
- **Units of housing by type.**
- **Businesses by type** *(e.g., industry and number of employees).*
- **Land use by type** *(user-specified).*
- **Densities of development land use by type,**
- **Land prices and improvements by land use type** (UrbanSim final report, 2001) [(1)]

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(1) This article available at: http://www.urbansim.org/ --- (last accessed, 23/04/2009)

(4-4-7-3) Information Provided by the Model

(a) Land Uses Addressed

UrbanSim allows the user to define the land uses types, typically **10** or more urban categories, but there is no internal limit on the number of urban or non-urban categories, as shown in Table (4-17).

	Land Use Categories	Yes?	No?
Urban	Residential	√	
	Commercial	√	
	Mixed-Use	√	
	Industrial	√	
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	
	Park Land	√	

Table (4-17) Land use categories addressed by **UrbanSim**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-18).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-18).

	Community Action / Characteristic	Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)	√	
Characteristic	Travel Demand	√[1]	
	Local Government Fiscal Conditions	√	
	Availability of Open Space		√
	Environmental Quality	√	
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions	√	

Table (4-18) Community actions and characteristics addressed by **UrbanSim**

1) Included through the interaction with travel models.

(4-4-7-4) Model Strengths and Limitations

(a) Strengths

1) **Dynamic behavioral foundation** is used that makes the model more transparent and explainable to users and decision makers;
2) **Reflects real-world processes:** that make the model easier to evolve and to interface to other process models such as environmental and transportation models.
3) **High degree of spatial resolution:** Currently uses spatial grid of **150** meters for interface with environmental models *(such as: land-cover).*
4) **Model and source code are entirely open source:** They are freely **available for use and modification**, and can be downloaded from the web site. This is intended to facilitate collaborative use and further development.

(b) Limitations

1) **High data requirements: UrbanSim** uses a **high level of dis-aggregation** for each of the **five** parameters used *(household, job, land use, real-estate value, and policy constraints)*. For instance, land use categories have **twenty-five** designed classes. As a result of required detailed land use categories and data structured, this makes the model more appropriate only for cities in developed countries.
2) **The model is structured for a sample project:** The model has been recently developed, so experience is limited to current applications in Hawaii, Oregon, Utah and Washington. Also the required input data is difficult to compile for other applications such as unplanned areas in **LDC**.
3) **The dynamic visualization of UrbanSim simulation is poor** (Waddell, 2002).

Despite these reasons, the model is not suitable to simulate and predict urban and informal housing growth in the context of LDC.

(4-4-8) What If? Planning Support System (P.S.S)

What if? [1], is a scenario-based, policy-oriented **P**lanning **S**upport **S**ystem **(PSS)** that uses the increasingly available **G**eographic **I**nformation **S**ystem **(GIS)** data to support community-based processes of **collaborative planning** and **collective decision making**.

As its name suggests, **What if?** does not attempt to predict future conditions exactly. Instead, it is an explicitly **policy-oriented planning tool** that can be used to determine ***(what)*** would happen (***if)*** clearly defined policy choices are made and assumptions concerning the future prove to be correct. **What if?** provides an integrated package of modules that enable users to: **conduct a land suitability analysis** *(Suitability Module)*, **project future land use demand** *(Growth Module)*, and **allocate the projected demand to the most suitable location** *(Allocation Module)*.

(4-4-8-1) Model Overview

What if? was developed in 1997 to support communities in many aspects of the **land use planning process.** It helps communities to create many alternatives visions for their area's future by mapping alternative development patterns determined by **local land development policies**.

The **What if?** model address some policies and decisions include :

- Establishing various criteria to **weigh** the suitability of different locations for a particular land use.
- Incorporating various land use planning and zoning considerations, as well as, other allocation scenarios.
- Defining various growth scenarios.

What if? is a *"bottom-up"* model which begins with homogeneous land units or **U**niform **A**nalysis **Z**ones called **(UAZs)** [2], applies alternative policy choices to these units, allocates projected land use demands to them, and then derives regional conditions

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(1) **What if?** Trial version and relevant materials can be obtained by contact the model developer. More information about **What if?** model are available in **Appendix (A)**.

(2) The term "**U**niform **A**nalysis **Z**one" **(UAZ)** is used instead of Landis's (1994) comparable concept of "**D**evelopable **L**and **U**nit" **[DLU]** because these spatial units may, or may not, be **"developable"**, depending on a particular set of scenario assumptions.

(e.g., population and employment growth trends) by aggregating the values for these land units. The **(UAZs)** are **GIS-generated polygons** which are homogeneous in all aspects considered in the model. Hence, all points within a **(UAZ)** have the same characteristics, *such as have the same slope, are located in the same municipality, have the same zoning, have the same availability of sewer and water service, are within the same distance of an existing or proposed highway, and so on.*

The **(UAZs)** are created by using **GIS overlay functions** to combine all the relevant layers of information on natural and man made features to define the **(UAZs)** that are used in a study area. The map layers can contain information on :

- **Natural conditions** *(e.g., slopes, soils, and scenic vistas).*
- **Existing and proposed infrastructure** *(e.g., the proximity to infrastructure, major roads and the availability of sewer and water service).*
- **Land use controls** *(e.g., zoning districts and planned land uses).*

The **What if?** model is most appropriate for areas that are :

- **Facing rapid urbanization** and the associated problems of traffic congestion, inadequate public infrastructure, and the loss of agricultural and open space.
- **Areas that are currently undeveloped** and will remain so in the future have few impacts and policy options to consider.
- **Currently developed areas** face complex issues of redevelopment and re-use that are extremely difficult to capture in a computer model.
- **Areas on urban boundary, that suffering rapid** and uncontrolled urbanization and industrialization face difficult and complex issues of managing growth.

As a result, **What if? is particularly useful in promoting public dialogue and collective decision making in these rapidly changing areas.** It is a unique in providing a portable system which can be adapted to any community's **GIS** data and policy issues. **What if?** was developed **with Microsoft's Visual Basic and ESRI's MapObjects software**. It incorporates many of the design concepts in the first **C**alifornia **U**rban **F**utures **(CUF-1)** model (Landis, 1995) and similar models. (1)

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(1) Similar models such as the San Diego Association of Governments **So**phisticated **A**llocation **P**rocess **(SOAP)** model, (San Diego Association of Governments 1994).

(4-4-8-2) Model Structure

The **What if?** model is built to projects future land use patterns by balancing the **supply** of, and **demand** for, land suitable for different uses at different locations. **What if?** provides **three** major components **Suitability**, **Growth**, and **Allocation** which include the main three aspects of the land use planning and development process.

1) **Suitability Module:** Used to consider the **supply of land** *(i.e., the characteristics and location of land that is available for accommodating future land use demand).*

2) **Growth Module:** Used to consider the **demand for land** *(i.e., the amount of land that will be required to accommodate future population and business growth).*

3) **Allocation Module:** Jointly considers supply and demand by **allocating the projected demand** *(as determined by the Allocation component)* **to the most suitable locations** *(as determined by the Suitability component)* **to project future land use patterns**.

On the other hand, alternative visions for an area's future can be explored by defining many **alternative scenarios** for <u>suitability, growth, and allocation modules</u>. For example:

- **<u>A "Future Trend" scenario</u>** could determine the effects of continuing current development policies.
- **<u>An "Environmental Protection" scenario</u>** might consider the impact of policies that severely limit growth in scenic areas and on land that is most suitable for agriculture.
- **<u>A "Build out" scenario</u>** would reveal the implications of allowing growth to continue until it reached permitted density levels for all developable parcels in the study area.

The assumptions underlying these and other scenarios can be easily modified to incorporate the full range of alternative visions for an area's future.

1) Suitability Module.

What if? suitability module is the first stage in the **what if?** analysis process, determining land use suitability, incorporates standard **"weighting and rating"** procedures in a **quick** and **easy** computer-based process.

The suitability analysis process begins by using on-screen forms to modify a previously defined suitability scenario or to create a new one.

As shown in Figure (4-23), the **suitability assumptions form** contains **four** tabbed sheets, which correspond to the **four** steps of the suitability analysis process:

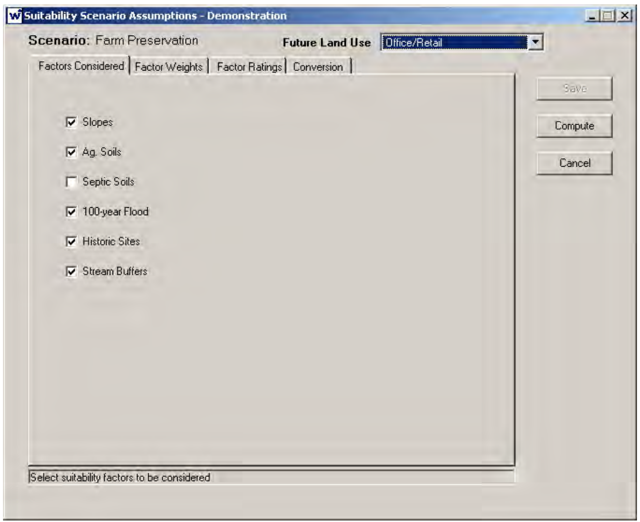

Figure (4-23) Specifying suitability scenario assumptions

a) **Identifying the suitability factors,**
b) **Specifying the suitability factor weights,**
c) **Specifying the suitability factor ratings,**
d) **Specifying the permissible land use conversions.**

These **four** steps are described briefly below.

a) Identifying Suitability Factors

The **first** sheet, labeled **"Factors Considered"** as shown in Figure (4-23), contains a series of check boxes that are used to specify the factors which the user feels should be considered in determining the suitability of different locations for a particular land use, *(e.g., slopes, soils, and hazardous areas).*

Different factors may be selected for different land uses; *for instance, good septic soils* **may be assumed to be important for locating residential uses but not important for locating commercial and administrative uses.**

b) Specifying Factor Weights

The **second** sheet, labeled **“Factor Weight”** contains a series of text boxes that are used to specify the suitability factor weights *(i.e., the numerical scores indicating the relative importance of different factors for determining the relative suitability of different locations for a particular land use).*

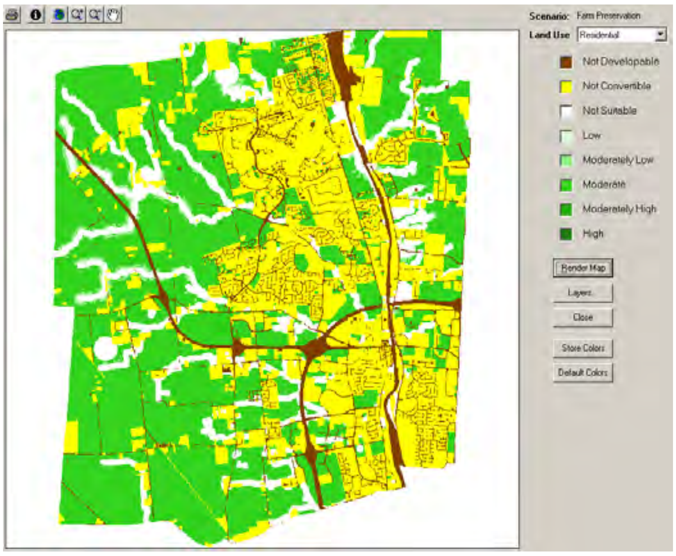

Figure (4-24) Residential suitability map

c) Specifying Factor Ratings

The **third** sheet, labeled **“Factor Rating”** contains a series of text boxes that are used to specify ratings for the different types within a particular suitability factor *(e.g., the different slope types: < 5%، 5% - 10%, and so on).* **“Factor ratings”** are numerical values <u>which indicate the relative suitability of locations with a particular factor type for locating a specified land use.</u>

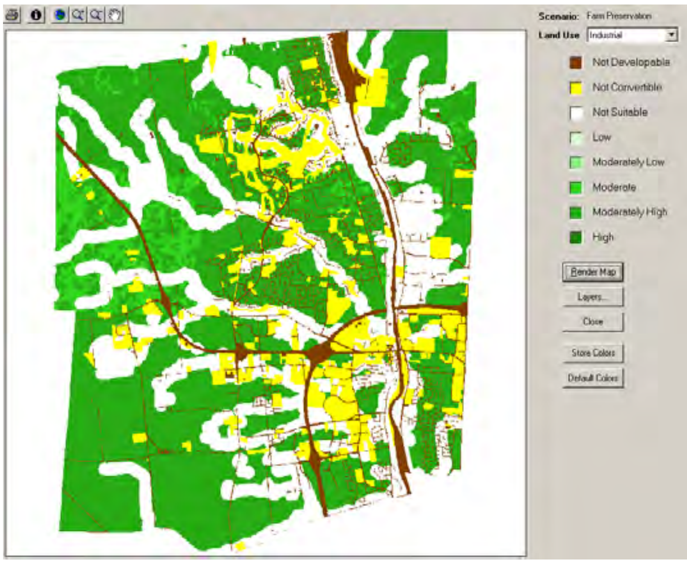

Figure (4-25) Industrial suitability map

d) Specifying Land Use Conversions

The **fourth** suitability assumption sheet, labeled **“Conversion”** contains a series of check boxes that are used to specify land uses that may be converted from their current use *(e.g., agriculture)* to another use *(e.g., low-density residential)* as a result of the projection process.

If no land uses are identified as conversion candidates, only currently undeveloped land will be available for satisfying the projected land use demands.

After all of the required information has been entered for all land uses, the model computes the **factor scores** for each **UAZ** by multiplying the user-specified factor **<u>weights</u>** by the corresponding user-defined factor **<u>rating</u>** and summing these values. The resulting suitability scores indicate the relative suitability of each **UAZ** for each land use when all of the suitability factors have been considered.

The model then generates a series of maps showing the **relative suitability** of different locations for each land use, as shown in Figures (4-24) and (4-25). It also generates **two** reports. **<u>The first report</u>** identifies the number of acres within each suitability class for all land uses. **<u>The second report</u>** lists the assumptions that underlie a specified suitability scenario.

(2) Demand Module

What if? considers the demand for land by converting the **five** main categories of land use demand *(residential, industrial, commercial, preservation, and locally-oriented uses)* into the equivalent future land use demands.

The demands are computed for **three** projection periods, allowing the system to incorporate **a staged development process** in which future development patterns are based on the <u>previous development patterns</u> and <u>expected infrastructure improvements</u>.

The process of projecting land use demands begins by selecting a growth scenario to create, view, or modify. The user is then presented with the **Growth Assumptions form**, as shown in Figure (4-26); **the Growth Assumptions form** contains **five** tabbed sheets. These sheets used to specify the assumptions to define the demand for different land use types:

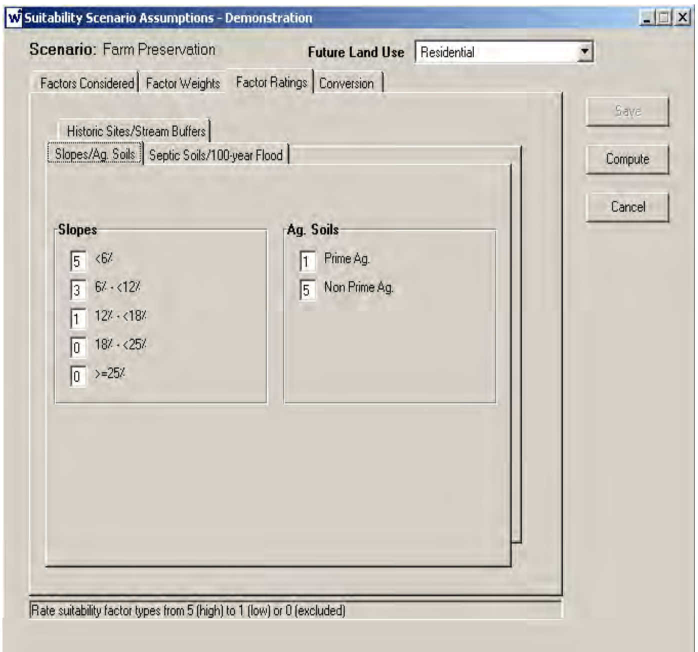

Figure (4-26) Specifying residential demand assumptions

a) **Computing Residential Demand,**
b) **Computing Industrial Demand,**
c) **Computing Regional Commercial Demand,**
d) **Computing Preservation Demand,**
e) **Computing Local Demands.**

For example, **the Residential sheet** contains **two** tabbed sheets.

- The **first** sheet allows the user to select up to **five** independently prepared projections for the total number of households in the context region *(e.g., county)* and the study area's share of the region's households. These two values are multiplied to compute the projected number of households in the study area in each projection period.
- The **second** sheet is used to specify the assumptions about new residential units, including:
  i. **The breakdown by housing type for new residential construction.**
  ii. **The housing density for each housing type.**
  iii. **The average household size for each housing type.**
  iv. **The residential vacancy rates.**
  v. **The proportion of existing housing units that will be lost to demolition during each projection period.**

The model uses the specified values on the two residential sheets to compute the projected demand for residential land in each projection period. In the same manner you can calculate the projected demand for each land use type in each projection year.

(3) Allocation Module

What if? projects future land use by allocating the projected land use demands *(derived from the user-selected growth scenario)* to different locations on the basis of their relative suitability, as defined by the assumptions of a user-selected suitability scenario. *(For instance, the projected demand for residential land is assigned **first** to the most suitable sites, then to the **second** most suitable sites, and so on until all of the residential demand in a projection year has been satisfied).*

If desired, the growth allocation can be controlled by user-selected land use controls *(land use plans and zoning restrictions)* **and infrastructure plans.**

The user is notified if not enough land is available to satisfy the projected demand. If this occurs, the user must **modify the suitability, growth, or allocation scenario assumptions** *(e.g., relax the land suitability requirements, allow more land uses to be converted to other uses, or increase future densities)* to make them consistent.

The growth allocation process begins by selecting the suitability and growth scenarios that will be used for a given allocation scenario. The user is then presented with the **Allocation Assumptions form**, as shown in Figure (4-27).

The form contains **five** tabbed sheets which are used to specify the assumptions that underlie a growth allocation scenario, these allocation assumptions are:

a) **Allocation Priority Order**.
b) **Infrastructure Control**.
c) **Land use Control**.
d) **UAZ Minimum Size**.
e) **Growth Pattern**.

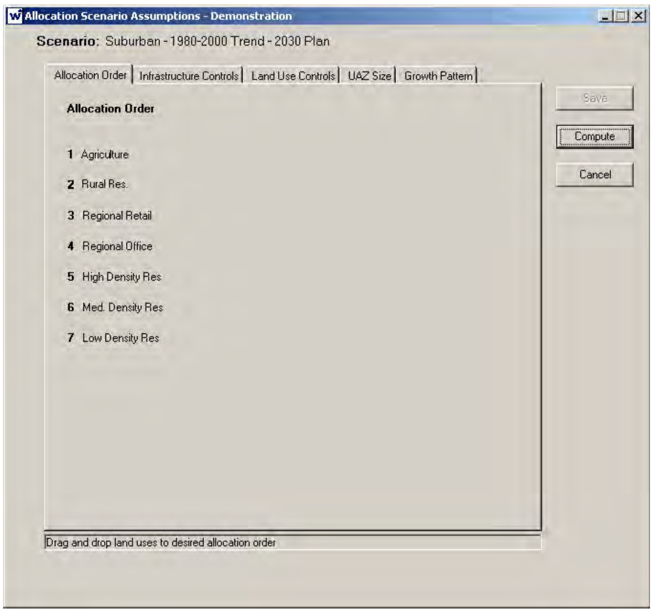

Figure (4-27) Specifying allocation scenario assumptions

For example, **the first sheet, labeled "Allocation Priority"** is used to specify the order in which projected land use demands are to be allocated in each projection year *(i.e., the land use demand to be satisfied first, which to be satisfied second, and so on).*

The allocation priority list can be revised by selecting a land use label and dragging it to its preferred location in the list. For example, the user has the ability to specify that the **Agriculture demand** should be satisfied first; the **Rural Residential** demand should be satisfied second; and so on, as shown in Figure (4-27).

The system projects future land use patterns by allocating the projected land use demands to the most suitable sites, subject to any land use controls or infrastructure plans selected by the user.

The resulting land use projections for each projection year can be viewed in map or report form. Figure (4-28) shows the projected land use patterns for a **"Farm Preservation"** scenario in which growth is prohibited from areas that have prime agricultural soils.

Also Figure (4-29) shows the projected land use patterns for a **"No Farm Preservation"** scenario that incorporates the same land use demand assumptions but does not impose any restrictions on where growth can occur.

These two examples illustrate the power of **What if?** for graphically represent the implications of alternative policy choices.

The system also generates reports which record the projected land use quantities for the study area and each political subdivision in each projection year, as well as the assumptions that underlie a scenario.

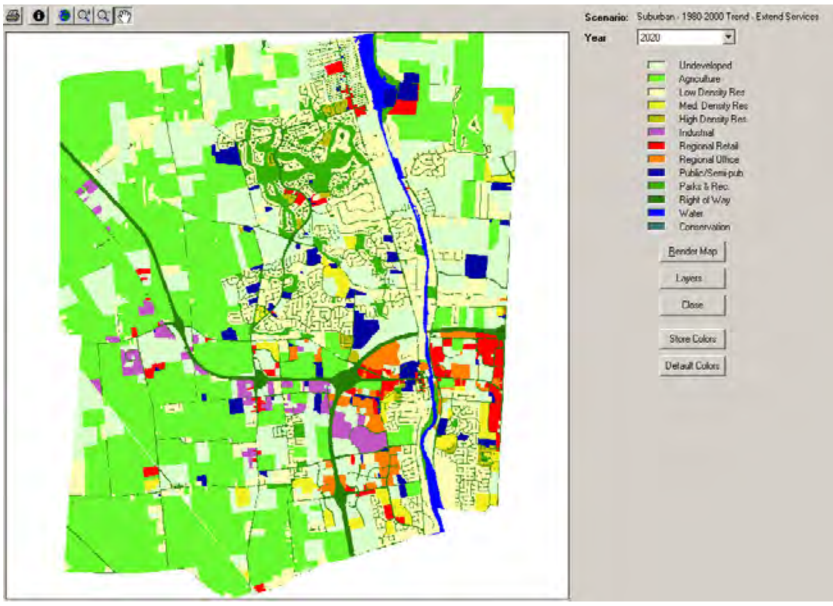

Figure (4-28) **Farm Preservation** scenario map for **2020**

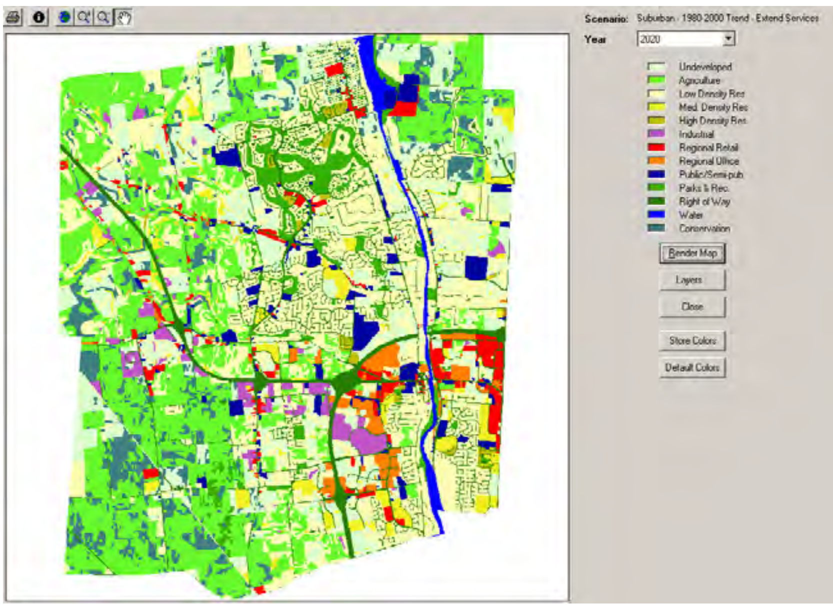

Figure (4-29) **No Farm Preservation** scenario map for **2020**

(4-4-8-3) Information Provided by the Model

(a) Land Uses Addressed

What if? is capable of including any kinds of land use data available from the community.

The only GIS layer that is absolutely essential for using What if? is the existing land uses. A variety of additional layers can be added, depending on the available **GIS** data

Land Use Categories		Yes?	No?
Urban	Residential	√	
	Commercial	√	
	Mixed-Use	√	
	Industrial	√	
	Other	√	
Non-Urban	Agricultural	√	
	Forest	√	
	Wetlands	√	
	Water	√	
	Preservation	√	
	Park Land	√	

Table (4-19) Land use categories addressed by **What if?**

(b) Questions Answered

1) The model is capable to address many **community actions** that affects on the changing of land use patterns, as shown in Table (4-20).

2) The model is capable to address many **community characteristics** that affects on the changing of land use patterns, as shown in Table (4-20).

Community Action / Characteristic		Yes?	No?
Action	Transportation Infrastructure	√	
	Local Zoning	√	
	City/County Master Plans	√	
	Local Fiscal Policies (e.g., fees, taxes, and incentives)		√
Characteristic	Travel Demand		√
	Local Government Fiscal Conditions		√
	Availability of Open Space	√	
	Environmental Quality		√
	School Quality		√
	Crime		√
	Other Quality-of-Life Conditions		√

Table (4-20) Community actions and characteristics addressed by **What if?**

(4-4-8-4) Model Strengths and Limitations

(a) Strengths

1) **Easy to use: What if?** allows users to prepare and evaluate suitability, growth, and allocation scenarios by using only Windows standard buttons, check boxes, and text boxes.
2) **Customizable: What if?** incorporates information provided by the users and applies its decision tools to currently available **GIS** and **non-GIS** data, allowing the system to be customized to many different geographic areas and conditions.
3) **Integrated system: What if?** provides an integrated software package that incorporates user-provided **GIS** and other data as a foundation and applies various evaluation/decision tools to the hidden data.
4) **Self-contained system: What if?** is self-contained and no requires any additional **GIS** or **non-GIS** software, although the user can be able to prepare and incorporate **GIS** layers *(e.g., ESRI shapefiles)* as input to the system. If desired, **What if?** inputs and outputs can be used with **ArcView** software and any other package that works with **ESRI** shapefiles.

(b) Limitations

1) **Lack of sophisticated modelling: What if?** users must provide the scenarios to the system as inputs. **What if?** does not provide the sophisticated modelling capability and/or theoretical basis to examine the correlated factors of urban growth, fiscal policies, and other planning decisions on the amount and type of **future development** and **land-use changes** that occur.
2) **What if? does not employ random utility or discrete choice theory** to explain and project the behavior of various urban actors.
3) **What if? does not explicitly model the behavior of actors** such as households, businesses, and developers like "**O**bject-**O**riented **M**odels".

(4-5) Comparison of Urban Dynamics Models

After reviewing the previous selected **eight** urban dynamics models software, This section will discuss and illustrates the results of comparison between these models, Based on the developed criteria at the beginning of this Chapter, it also follows that the choice of the most suitable model to be used to simulate urban and informal housing growth in **LDC**.

The desired model must have some characteristics, such as, **provide realistic representation, reasonable spatial and temporal resolution, flexible and sensitive to changes, freely accessible, handle complexity by integrating a vast range of data.**

Table (4-21) provides a comparative matrix of the different models, based on some attributes and criteria including:

- Whether the model integrates land use and transportation factors;
- Ease of use;
- Availability of a graphic user interface;
- **GIS** capability;
- Whether the model is based on an economic theories;
- Modelling of demographic change;
- Modelling of market mechanism;
- Consideration of income;
- Learning curve;
- Proprietary software *(as opposed to public domain software)*;
- Availability of technical support;
- Continued update.

Table (4-22) gives basic information about each model: **aim**, **spatial resolution**, **dynamic visualization**, **real applications**, **level of data dis-aggregation**, **freely accessible**, **and technical support** *(websites availability and additional information).* Table (4-23) also provides a summary of the **model type**, **thematic scope**, **implemented methodologies**, and **model output**.

Model	Integration	Ease of Use	Graphic Interface	GIS Capability	Economic Theory Base	Demographic Change	Market Mechanism	Income	Learning Curve	Proprietary	Technical Support	Continued Update
CUF-1	N	Y	N	N	Y	N	Y	N	N	C	N	Y
CUF-2	N	Y	Y	Y	Y	N	Y	N	N	C	N	Y
LTM	N	N	N	Y	Y	Y	N	N	N	C	N	N
LUCAS	N	N	Y	Y	N	N	Y	N	Y	N	N	N
SLEUTH	N	N	Y	N	N	N	N	N	Y	N	N	Y
TRANUS	Y	N	Y	Y	Y	N	Y	Y	N	Y	Y	Y
UPLAN	N	Y	Y	Y	N	Y	N	N	Y	N	N	Y
UrbanSim	N	N	Y	N	Y	Y	Y	Y	Y	N	Y	Y
What if?	N	Y	Y	Y	N	N	N	N	N	Y	Y	Y

Notes:

Y – Yes
N – No
C – Contact developer

Table (4-21) Summary of features of selected urban dynamics models

Model	Aim	Spatial Resolution	Temporal Resolution	Dynamic Visualization	Real Applications	Data Dis-aggregation	Free	More info. (Ref & Web)
CUF-1	Modelling urban policy and urban growth	**GIS** Vector layers	Annual fixed timeframe **5 - 10** years.	**NO**	**YES**	**- Household** **- Parcel**	**YES**	Landis and Zhang, 1998
CUF-2	Modelling urban policy and urban growth	Raster GIS **(100 x 100)** m Bottom-up	Annual fixed timeframe **5 - 10** years dynamic	**NO**	**YES**	**- Household** **- Parcel**	**YES**	Landis and Zhang, 1998
LTM	Simulate land use change and physical impacts	Raster cell **(CA)**	Variable **5 - 10** years increments	**YES**	**YES**	**- Parcel**	**YES**	Pijankowski *et al.*, 1997
LUCAS	Modelling land use and environment changes	Raster **(90 x 90)** m cell	**5** years increments **100** years	**NO**	**YES**	**- Parcel**	**YES**	Berry *et al.*, 1996
SLEUTH	Urban growth simulation	Raster cells **(CA)**	Annual variable	**YES**	**YES**	**- Local and regional**	**YES**	http://www.ncgia.ucsb.edu/projects/gig/
TRANUS	Urban and regional modelling	**GIS** layers	Static equilibrium	**NO**	**YES**	**- Local** (intensive)	**NO**	http://www.modelistia.com/modelistica.html

Table (4-22) Comparison of the **general characteristics** of urban dynamics models

Model	Aim	Spatial Resolution	Temporal Resolution	Dynamic Visualization	Real Applications	Data Dis-aggregation	Free	More info (Ref & Web)
UPLAN	Simulate urban sprawl and development policies	Raster cell **(50 x 50)** m	Annual **50** years	**NO**	**YES**	**- Parcel** **- Zone**	**YES**	Bob Johnston, Department of Environmental Science & Policy University of California, Davis
UrbanSim	Land use, Transportation planning, public policy, urban sprawl, (Discrete choice)	**GIS** Vector based and grid cells **(150 x 150)** m	Annual dynamic	**NO**	**YES**	**- Parcel Data** (intensive)	**YES**	www.urbansim.org
What if ?	Modelling urban policies and planning	Overlay **GIS** vector layers	Variable: **5 - 10** years, time frame **25** years.	**NO**	**YES**	**- Parcel Data** (intensive)	**NO**	www.what-if-pss.com

Table (4-22) Comparison of the **general characteristics** of urban dynamics models (Cont.)

Models	Model Type	Thematic Scope	Methodologies	Output
CUF-1	▪ Urban growth.	▪ Urban development evaluation and simulation.	▪ Regression.	▪ Acreage tabulations and total. ▪ Maps of newly developed areas.
CUF-2	▪ Land use change.	▪ Urban development evaluation and simulation.	▪ Multi-nominal Logit ▪ Regression	▪ New development or redevelopment acreage total by land use type. ▪ Maps of existing and projected development by land use type.
LTM	▪ GIS ▪ Urban impact. ▪ Neural network.	▪ Land use. ▪ Ecology integrity. ▪ Economic Sustainability.	▪ Markov chains. ▪ Regression. ▪ Artificial neural networks.	▪ Land use projection maps. ▪ Data summaries.
LUCAS	▪ GIS	▪ Land use. ▪ Environmental impacts. ▪ Socioeconomic.	▪ Time-Series.	▪ Area by land use type. ▪ Amount of edge by land use type. ▪ Edge/area ratio by land use type. ▪ Mean patch size by land use type. ▪ Number of patches by land use type. ▪ Proportion of land cover by land use type. ▪ Amount of total edge. ▪ Size of largest patch by land use type.

Table (4-23) Comparison of the **technical characteristics** of urban dynamics models

Models	Model Type	Thematic Scope	Methodologies	Output
SLEUTH	▪ Cellular automata. ▪ GIS	▪ Urban growth. ▪ Environmental impacts.	▪ Cellular automata. ▪ Time-Series. ▪ Monte-Carlo imaging.	▪ Snapshot of a particular year. ▪ Cumulative image that results from multiple runs and shows a probability of urbanization for a given year.
TRANUS	▪ GIS ▪ Urban impact ▪ Travel demand ▪ Urban economic / Land use market.	▪ Transportation. ▪ Economics. ▪ Environmental impacts.	▪ Causal inference. ▪ Multi-nominal logit. ▪ Network analysis. ▪ Time-series. ▪ Discrete choice analysis. ▪ Decision theory. ▪ Random utility theory. ▪ Input-Output analysis. ▪ Algorithms.	▪ All paths between each **O-D** pair for each travel mode and combination of modes. ▪ General assignment results for each link. ▪ Detailed assignment results for each link. ▪ Indicators of the performance of the transportation system. ▪ Results from the transportation model. ▪ Transit route profile, with demand-supply information for each route on each link. ▪ Activity location and land use consumption outputs.
UPLAN	▪ GIS ▪ Urban impact.	▪ Land use evaluation and change analysis.	▪ Not specified.	▪ Grid maps *(attraction grids, exclusion grids, general plan grids, and existing urban grids)* ▪ Analysis and assumptions report. ▪ Image files.

Table (4-23) Comparison of the **technical characteristics** of urban dynamics models (Cont.)

Models	Model Type	Thematic Scope	Methodologies	Output
UrbanSim	▪ Random utility Logit. ▪ Urban economic /Land use market ▪ GIS ▪ Hedonic.	▪ Land use. ▪ Transportation. ▪ Economics. ▪ Environmental impacts.	▪ Expert Systems. ▪ Multi-nominal Logit. ▪ Random Utility Theory. ▪ Regression. ▪ Monte Carlo Simulation.	▪ Households by type *(income, size, age of head, children, workers)* and zone. ▪ Businesses and employment by type *(sector)* and zone. ▪ Acres by land use and zone ▪ Prices of land, housing and commercial space by type and zone. ▪ Simulated development by type and zone.
What If?	▪ GIS	▪ Land use evaluation and change analysis.	▪ Mapping	▪ Suitability analysis map. ▪ Suitability analysis results report. ▪ Suitability analysis assumptions report. ▪ Growth analysis results report. ▪ Growth analysis assumptions report. ▪ Allocation map. ▪ Allocation analysis results report. ▪ Allocation analysis assumptions report.

Table (4-23) Comparison of the **technical characteristics** of urban dynamics models (Cont.)

(4-6) Conclusions

Urban dynamics models are shaped and bound by many factors such as the developer's research interests, funding, data availability, and the scope of the study.

These factors appear from the review of urban dynamics models that the high level of complexity exhibited by a model reinforces the likelihood for realistic representation.
Urban dynamics models assessed in this Chapter are constantly under construction *(as illustrated by the creation of new versions, for instance in* ***CUF*** *and Clarke's models).*

These models are constantly updated over many years to accommodate new objectives, such as: **changes to computer technology**, **the exploration of new simulation techniques**, and **the enhancement of their complexity**. *(For example,* ***CUF-1*** *was originally conceived to predict developable land on a vector basis, while* ***CUF-2*** *incorporated new features and functions which handle cell based modelling to explore urban growth).*

This review has also revealed an emergence of a new trend in urban dynamics modelling. This new trend is related to the advancement of simulation techniques, data availability, dynamic visualization and animation using many output media, such as the internet, *(e.g., SLEUTH, What if?)*. The next generation of urban modelling is the **open source web modelling packages**. Such as, **UPLAN** gives an indication of the ***"new age"*** of greater accessibility, interactive visualization and availability of community evaluation of urban dynamics simulation.

The review of the different models has raised many weakness points for the existing urban dynamics models such as:

- Current dynamics models are **not flexible enough** in regards to the spatial and temporal resolutions.
- Current dynamics models are **lack to access and modification of source code**. Especially, simulation timeframe and input data.
- Current dynamics models are **difficult to apply to new contexts**. *(e.g.,* ***CUF-1*** *and* ***CUF-2*** *models is customized for one region),* hence reducing the potential of being applied to other locations and situations.

For example, the review of different models has shown that each model was conceived with specific objectives accordingly, application of the model to another context usually requires modification, and is also controlled by data availability.

- The review process has also highlighted that the **cost of some urban dynamics packages would prevent many potential users**, *(e.g., TRANUS, and What if?)*.

> Based on the criteria developed at the beginning of this Chapter, it also follows that the choice of the model to be used to simulate urban and **IH** growth in **GCR** is directed to those which seek **realistic representation** and can **handle complexity** by integrating a vast range of data.
> Similarly, models that had **reasonable spatial** and **temporal resolution were flexible** and **sensitive** to **changes**, **freely accessible**.

Chapter 5

Modelling and Simulation of Greater Cairo Region Urban Dynamics Using SLEUTH Program

(5-1) Introduction

The complexity of urban and **I**nformal **H**ousing **(IH)** dynamics can be explored using various approaches included modelling and simulation techniques. **Realistic simulation is**, **however**, **rarely achieved by existing urban dynamics models.** This is because most urban models are limited by the developer's field of study, available resources and data, and fail to replicate realistic predictions compared with real expansion and growth.

This research will attempt to use simulation and modelling techniques to investigate the spatial distribution of unplanned developments. **As stated in the introduction section**, **the main objective of this research is to develop a realistic predictive model capable for simulating the future expansion and growth of informal housing in LDC's cities**.

The previous Chapter discussed and evaluated **eight** urban dynamics packages according to some selected criteria based on the defined objectives for this research *(see Chapter one)* such as, the limitations in resources and the availability of the required data to operate these models.

This review revealed that, **Clarke's Urban Growth Model (UGM or SLEUTH)** is the most promising package to simulate urban growth in the context of unplanned areas, compared to other models, **SLEUTH** offers numerous advantages including:

- **a)** Flexibility in data input and data dis-aggregation,
- **b)** Multiple spatial and temporal output products,
- **c)** The integration of **GIS** and **C**ellular **A**utomata use *"loose coupling"* procedure,
- **d)** Strict calibration procedure,
- **e)** Accessibility to define new growth coefficients and **modify the model source code**,
- **f)** The model accessible and can obtained free of charge from the **SLEUTH** web site,
- **g)** Worldwide applications.

This Chapter applies **SLEUTH** program to investigate its applicability and capacity in simulating the future urban expansion of **G**reater **C**airo **R**egion **(GCR)**.

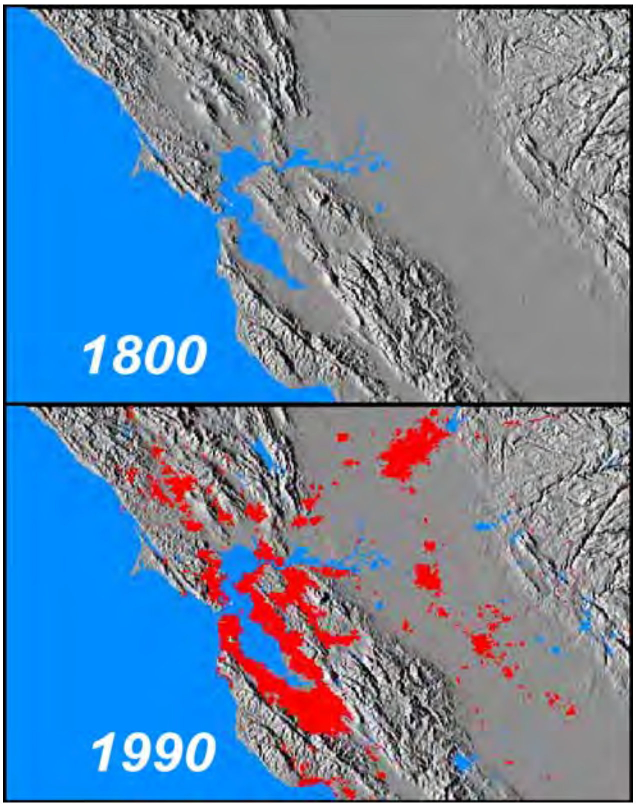

Figure (5-1) Simulation of **San-Francisco Bay** area from 1800 to 1990 [1]

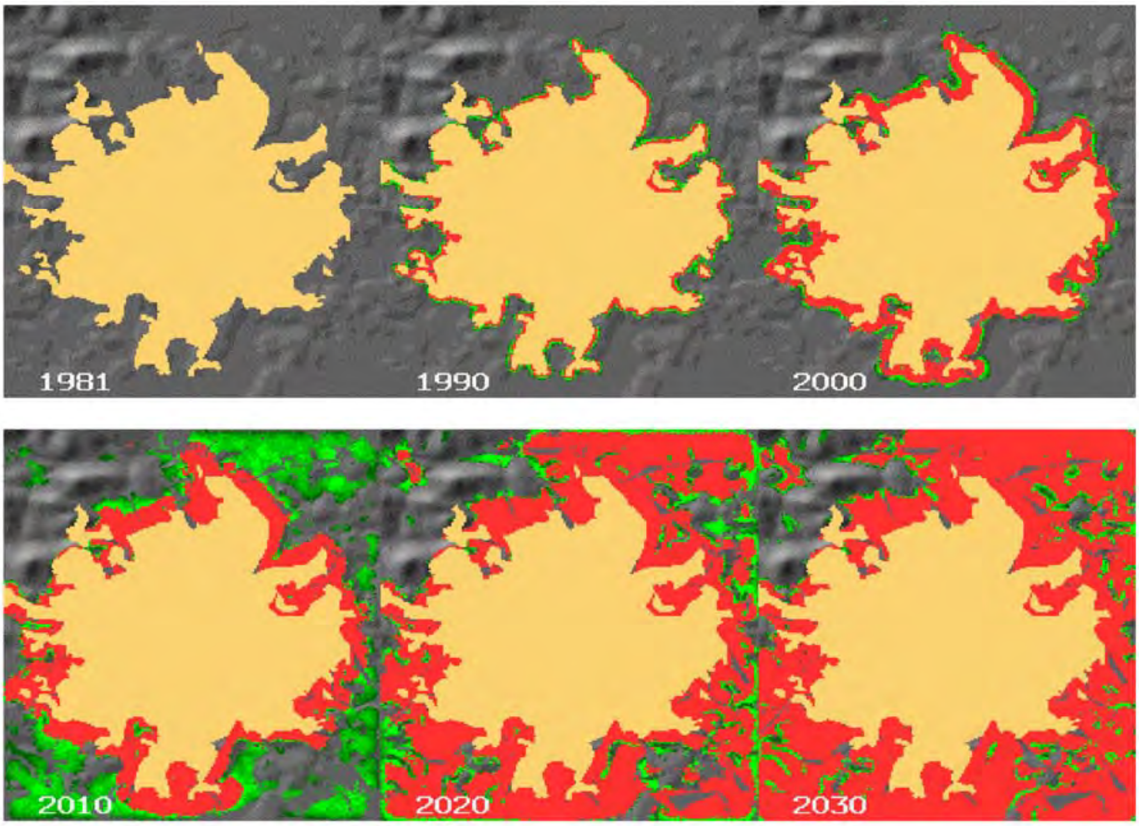

Figure (5-2) Simulation of **Yaoundé** urban growth from 1981 to 2030
(Source: Sietchiping, Remy. 2004)

[1] Source: http://www.ncgia.ucsb.edu/projects/gig/v2/Pubs/pbDynamics.htm

The objectives of this Chapter can classified into three main points as follows:

- **First,** test and investigate the applicability of **SLEUTH** model to simulate the growth and expansion of unplanned areas, especially **G**reater **C**airo **R**egion.
- **Second,** test the capacity of **SLEUTH** model to produce realistic simulation, by comparing the model outputs with real world expansion and check the level of accuracy between the model's predictions with reality.
- **The final goal,** examine the possibility of applying **SLEUTH** model to explore the **Informal Housing (IH)** emergence and growth in **LDC** through the case of **GCR**.

Chapter Four, section (4-4-4), presents the **SLEUTH** main concepts, theory, structure, data requirements and preparation, strength and limits to use the program in the context of **unplanned areas** in **LDC**. This Chapter will presents how to apply the **SLEUTH** model in a real world data to investigate the future urban pattern, and it will contains **four** main sections as follows:

- **Section one**: describes the necessary steps to prepare the **GCR** spatial data and the involved programs to generate the required data for **SLEUTH** program.
- **Section two**: discusses the **SLEUTH** three phases of calibration procedure.
- **Section three**: uses the calibration results to simulate and predict future urban growth based on the case of **G**rater **C**airo **R**egion in **Egypt**.
- **Section four**: presents the advantage features and limits of the **SLEUTH** model in relation to **informal housing simulation**.

(5-2) Clarke's Urban Growth Model (UGM / SLEUTH)

SLEUTH stands for the input needs for driving the model *(**S**lope, **L**and use, **E**xclusion, **U**rban, **T**ransportation, **H**illshading).* **SLEUTH** is a coupled **GIS** and **CA** program to model urban and land cover changes, it was originally developed by **Keith C. Clarke** at the University of California at Santa Barbara under the support of **U**nited **S**tates **G**eological **S**urvey **(USGS)**. **SLEUTH Release 3.0** is the most recent version of the program , and it will used in this chapter to predict the **GCR** future expansion.

As discussed in previous Chapter, **C**larke's **U**rban **G**rowth **M**odel **(UGM or SLEUTH)** initially intended to model the urban growth of American cities has so far been successfully applied in several American urban regions, such as New York, Chicago, Washington D.C., San Francisco Bay, and the South Coast of California.

SLEUTH Release 3.0 is a computer program written in the C programming language, runs only on **UNIX** or **LINUX** operating system machines. The **Urban Growth Model (UGM)** is the main component of **SLEUTH** model. A complete documentation and downloadable code may be found at the Project Gigalopolis website**:** ***www.ncgia.ucsb.edu/projects/gig***.

The **SLEUTH** growth coefficients are calibrated using historical urban and land cover data that aid to calculate the ideal numerical values of growth coefficients for **forecasting future urban change**. The oldest data sets are used to initialize the model and subsequent, or *"control"*, data were used for **goodness-of-fit** measurements over time (Candau, 2002).

The model uses the ***brute force calibration*** [(1)] approach to identify the **best-fit** score for each of the **five growth coefficients**: *dispersion, breed, spread, slope resistance, and road gravity*. The final stage of the calibration produces a **single score for each growth coefficient** that is then used to predict the future urban expansion (Sietchiping, 2004).

The next section will discuss the model's data requirements and data preparation procedure to run the model.

[(1)] **Brute force calibration** refers to the estimation of values for each parameter from known historical growth patterns.

(5-2-1) SLEUTH Initial Conditions

The **SLEUTH** modelling technique begins with an initial set of conditions, then a set of transition rules are applied, as follows:

- **a)** **<u>The initial conditions</u>** are defined by a group of input data images. The input data serve as information layers of that create a **non-homogenous cellular space** and influence cell transition suitability.
- **b)** **<u>The transition rules</u>** are affected by growth coefficients. These coefficient values may be modified at the end of each time step by self-modification constants. **SLEUTH's self-modification** behavior simulates **increases** and **decreases** in urban growth trends, simulating rapid, system-wide **"BOOM"** [(1)] and **"BUST"** [(2)] states.

(5-2-2) SLEUTH Data Requirements

Data preparation is one of the most important steps for successful implementation of **SLEUTH** program. The program accepts the input of six ***.gif*** grayscale format datasets that represent **slope**, **land use,** **excluded**, **urban**, **transportation**, and **hillshade**. The land use map is optional and was not used in this case study. To run the model effectively, all images should have the following properties:

- **1-** All maps must be in **grayscale** raster format *(grid)* and should be named by the **SLEUTH** naming convention method.
- **2-** All maps must have identical spatial resolution, i.e., the same number of rows and columns for each dataset.
- **3-** The **grayscale** data maps must be binary *(0-1, black & white)* format.

The number and function of input files can, however, vary extensively from one application to another.

[(1)] **BOOM** is a Self-modification parameter applied to the diffusion, breed and spread coefficients when the system is in a boom state. *(A boom state occurs when the urban growth rate exceeds the CRITICAL_HIGH).*

[(2)] **BUST** is a Self-modification parameter applied to the diffusion, breed and spread coefficients when the system is in a bust state. *(A bust occurs when the urban growth rate goes below the CRITICAL_LOW)*

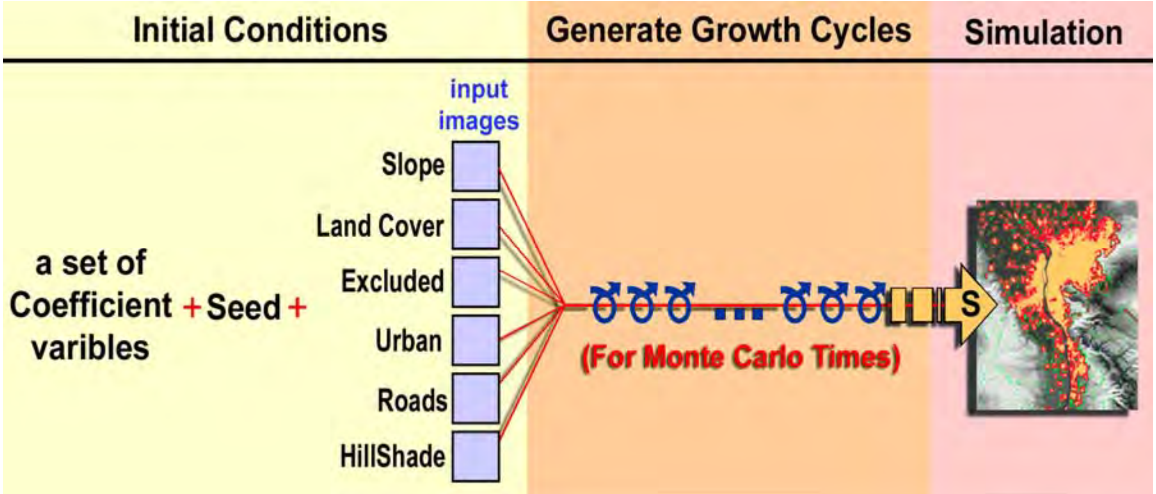

Figure (5-3) **SLEUTH** growth cycle

(Source: SLEUTH web site: http//:www.ncgia.ucsb.edu/projects/gig/)

(5-3) Cairo Data Preparation for SLEUTH Program

SLEUTH uses many types of urban data to generate the initial configuration and transition suitability surface. **The input raster data defines the initial state of the CA simulation space**. This section will discuss the required maps and data preparation procedure for input in the **SLEUTH** program.

(5-3-1) Urban Maps

The **SLEUTH** requires at least **four urban maps** at different dates in order to **calculate the best-fit statistics**. During the calibration, the starting year urban map *(called seed)* is used as the origin of the calibration, whereas other urban year maps are used to determine the growth coefficients for the prediction based on the historical growth trends.

In addition of the **SLEUTH** general properties discussed above, the urban maps should be in a binary format ***(urban and non-urban).*** i.e., each pixel with a value of zero *(0)* is classified as **non-urban** and all other pixels *(values 1 to 255)* are classified as **urban.** There are many approaches used to prepare the historical urban data. Such as, digitizing city maps, aerial photographs, remotely sensed images.

On the basis of this principle, the **GCR** historical urban data was prepared from topographic maps and satellite imagery *(LandSat images)* [1] represents five different periods **1952**, **1972**, **1986**, **1991** and **2001**, these maps was geo-referenced and digitized by using **ArcGIS** (*Arcinfo*).

The **SLEUTH** program uses the historical urban maps to calibrate the **growth coefficients** relative to historical urban trends, and then use the values of these coefficients to simulate future urban extent. The simulated map can then be compared with recent **satellite image** to evaluate the accuracy of the prediction.

<u>The sources of the historical urban maps as follows:</u>

- The **1952** urban map was produced from Cairo topographic map, scale **1:75000** obtained from the **E**gyptian **S**urvey **A**uthority **(ESA)**.
- The **1972** urban map was produced from **LandSat** satellite image with **28 meter/pixel** resolution, the source image was obtained from *http://glcfapp.umiacs.umd.edu:8080/esdi/ftp?id=31178* [2] web site.
- The **1986** urban map was produced from **LandSat** satellite image, with **14 meter/pixel** resolution, the source image was obtained from *http://glcfapp.umiacs.umd.edu:8080/esdi/ftp?id=12425* [3] web site.
- The **1991** urban map was produced from 29 topographic maps represents the **G**reater **C**airo **R**egion **(GCR)**, with scale **1:10000**, obtained from the **M**ilitary **S**urvey **D**epartment **(MSD)**.
- The **2001** urban map was produced from digital topographic maps with scale **1:5000**, obtained from the **C**entral **A**gency of **P**ublic **M**obilization and **S**tatistics **(CAPMAS**).

Figures (5-6 to 5-10) show the **five** historical urban maps that used in the application of **SLEUTH** program in **G**reater **C**airo **R**egion.

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(1) Source: http://www.glcfapp.umiacs.umd.edu

(2) Other location at: *ftp://ftp.glcf.umiacs.umd.edu/glcf/Landsat/WRS1/p190/r039/p190r39_1m19720831.MSS-EarthSat-Orthorectified/*

(3) Other location at: *ftp://ftp.glcf.umiacs.umd.edu/glcf/Landsat/WRS2/p176/r039/p176r39_5t840920.TM-EarthSat-Orthorectified/*

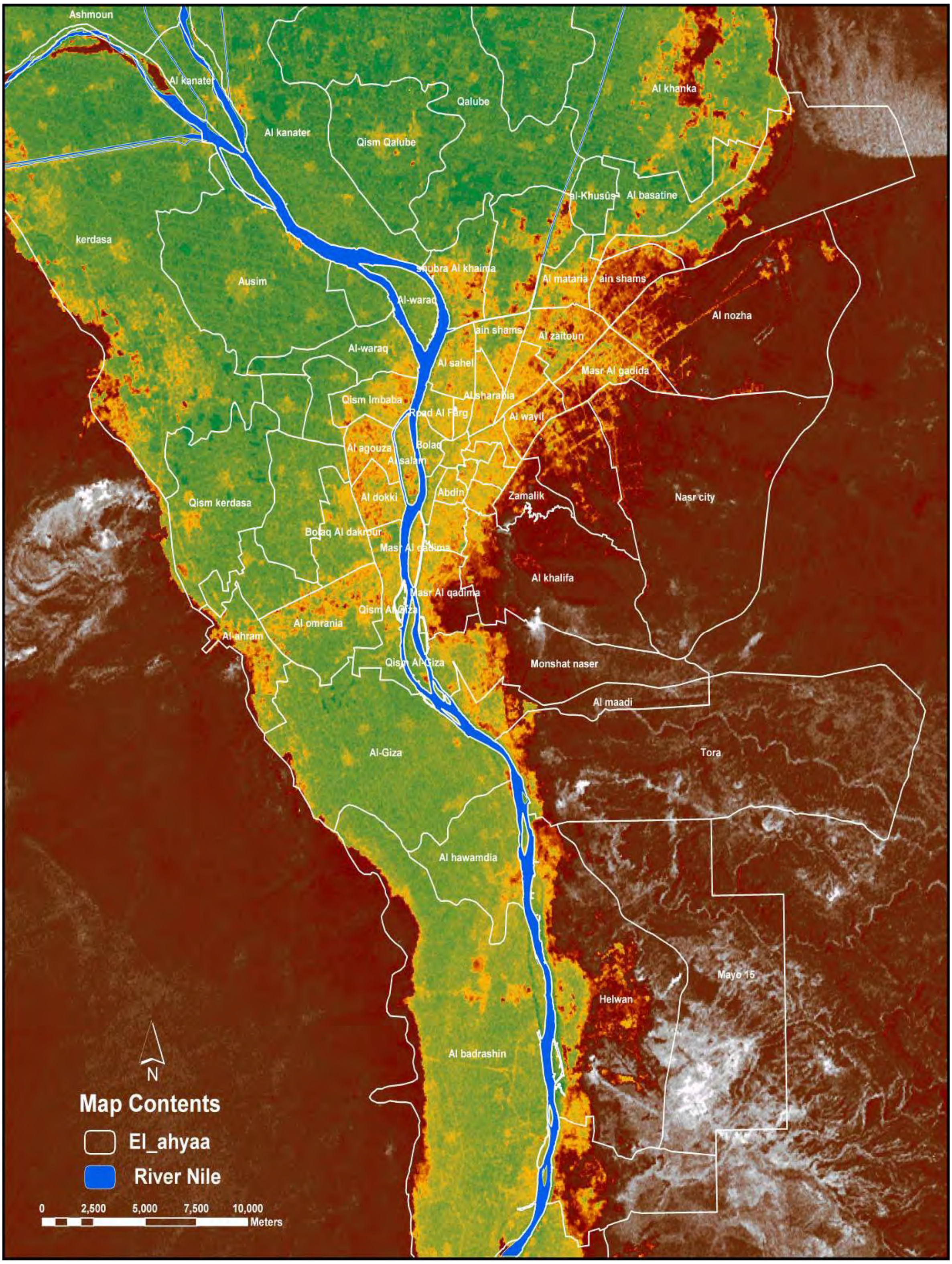


Figure (5-4) **LandSat** satellite image for **GCR** in **1972**, with **28 meter/pixel** resolution

(Source: http://glcfapp.umiacs.umd.edu:8080/esdi/ftp?id=31178)

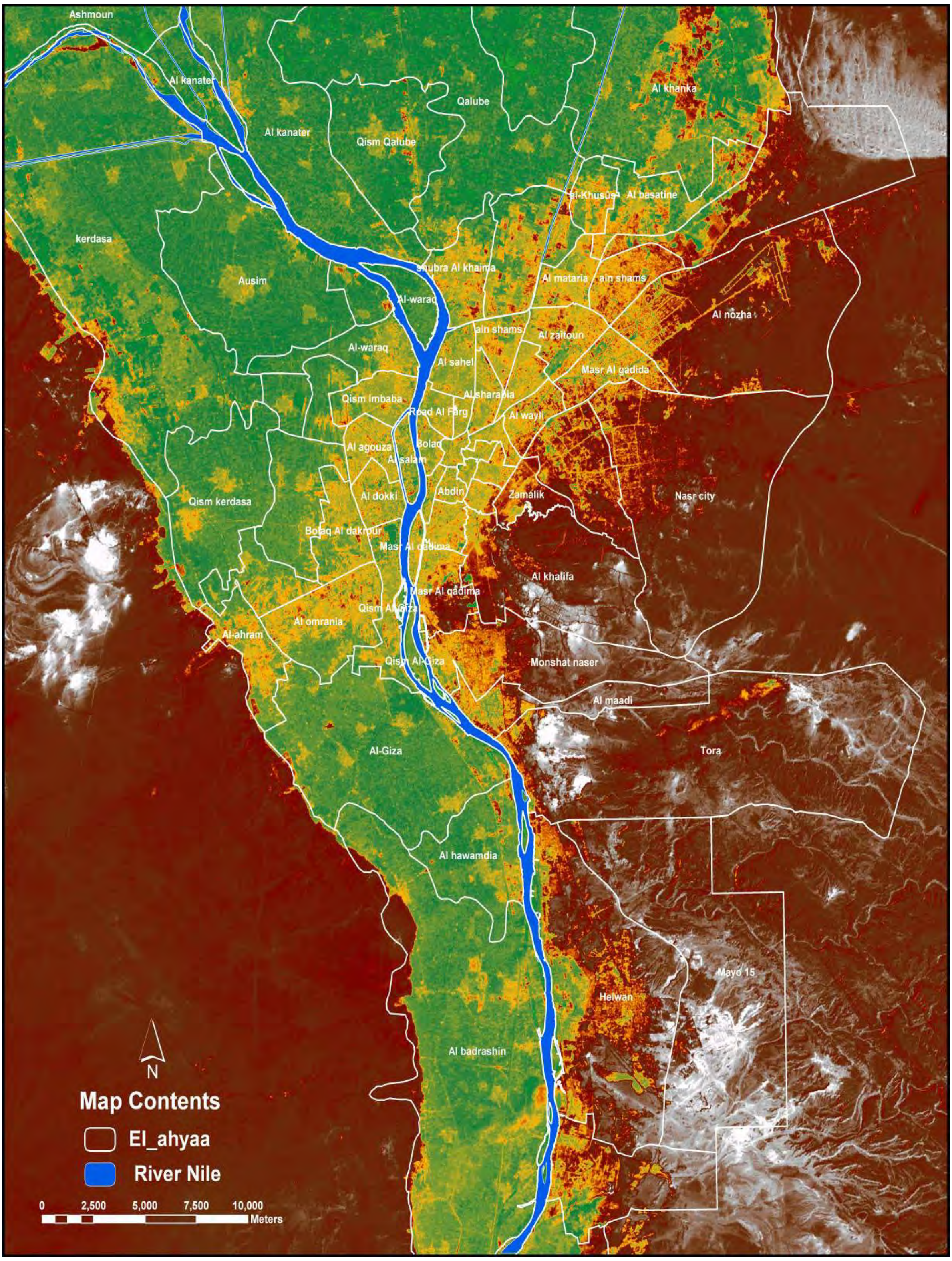


Figure (5-5) **LandSat** satellite image for **GCR** in **1986**, with **14 meter/pixel** resolution

(Source: http://glcfapp.umiacs.umd.edu:8080/esdi/ftp?id=12425)

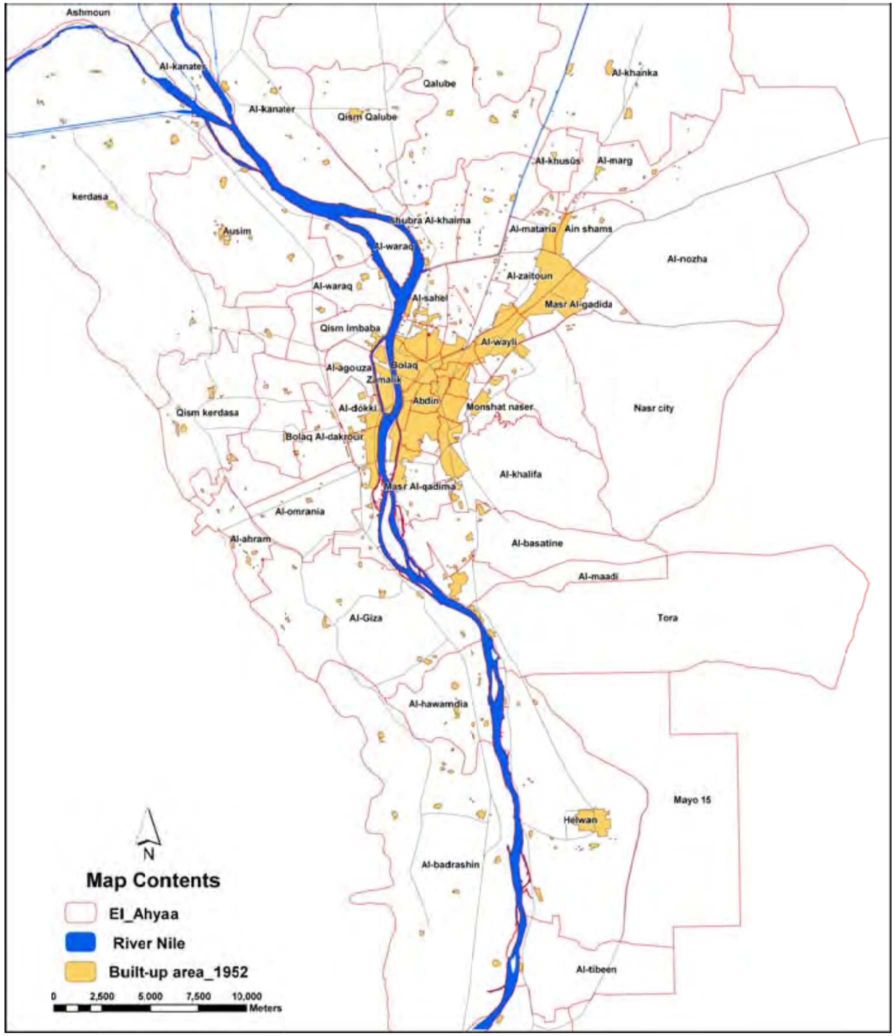


Figure (5-6) **G**reater **C**airo **R**egion urban extents in **1952**

(Source: **E**gyptian **S**urvey **A**uthority, **ESA**)

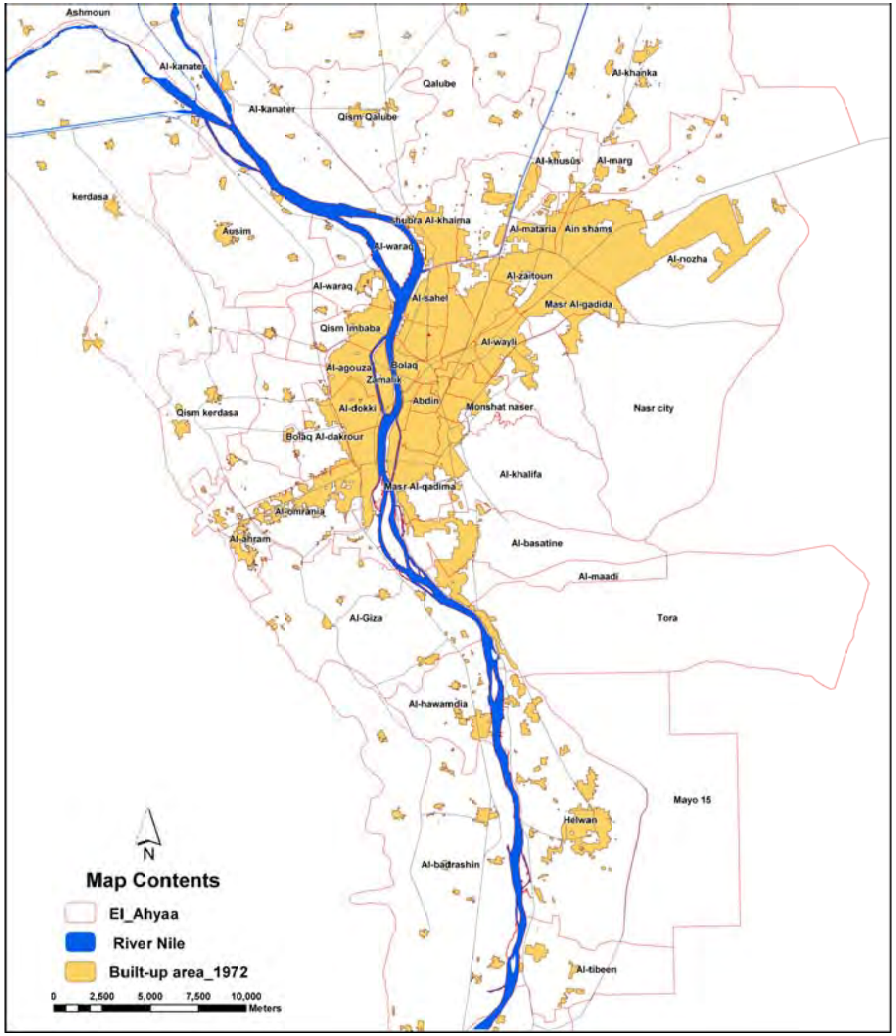


Figure (5-7) **G**reater **C**airo **R**egion urban extents in **1972**

(Source: http://www.glcfapp.umiacs.umd.edu)

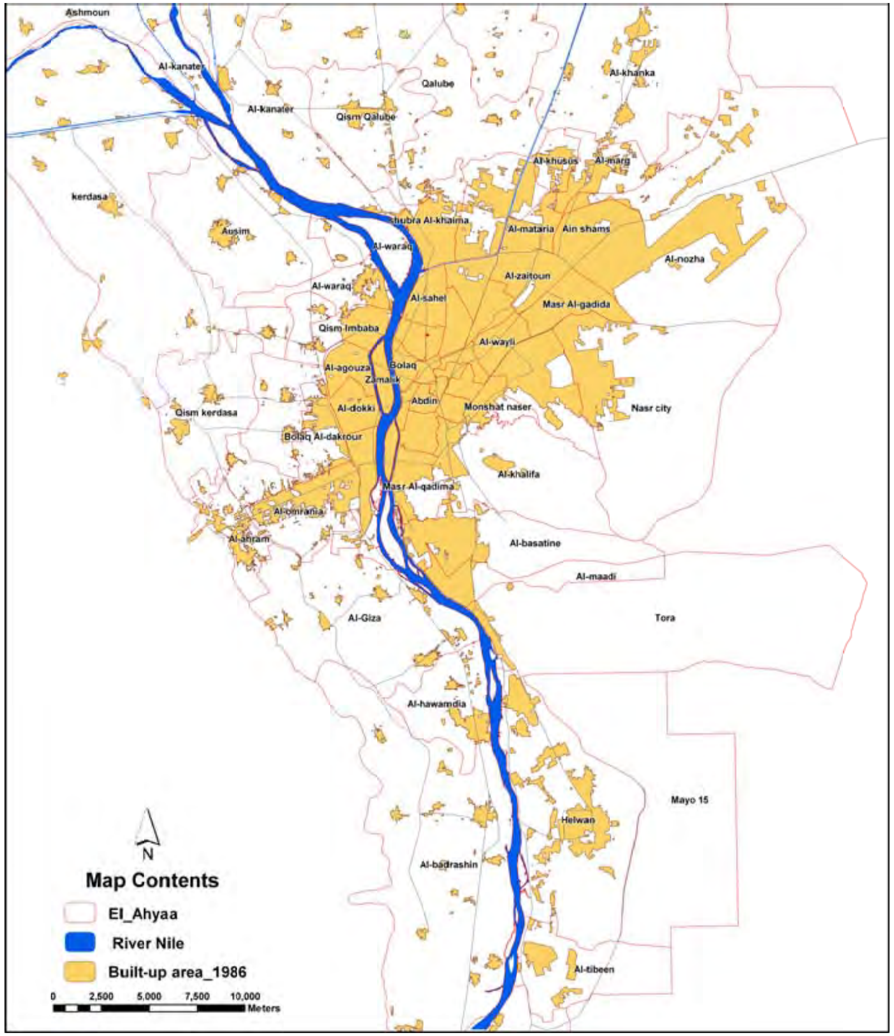


Figure (5-8) **G**reater **C**airo **R**egion urban extents in **1986**

(Source: http://www.glcfapp.umiacs.umd.edu)

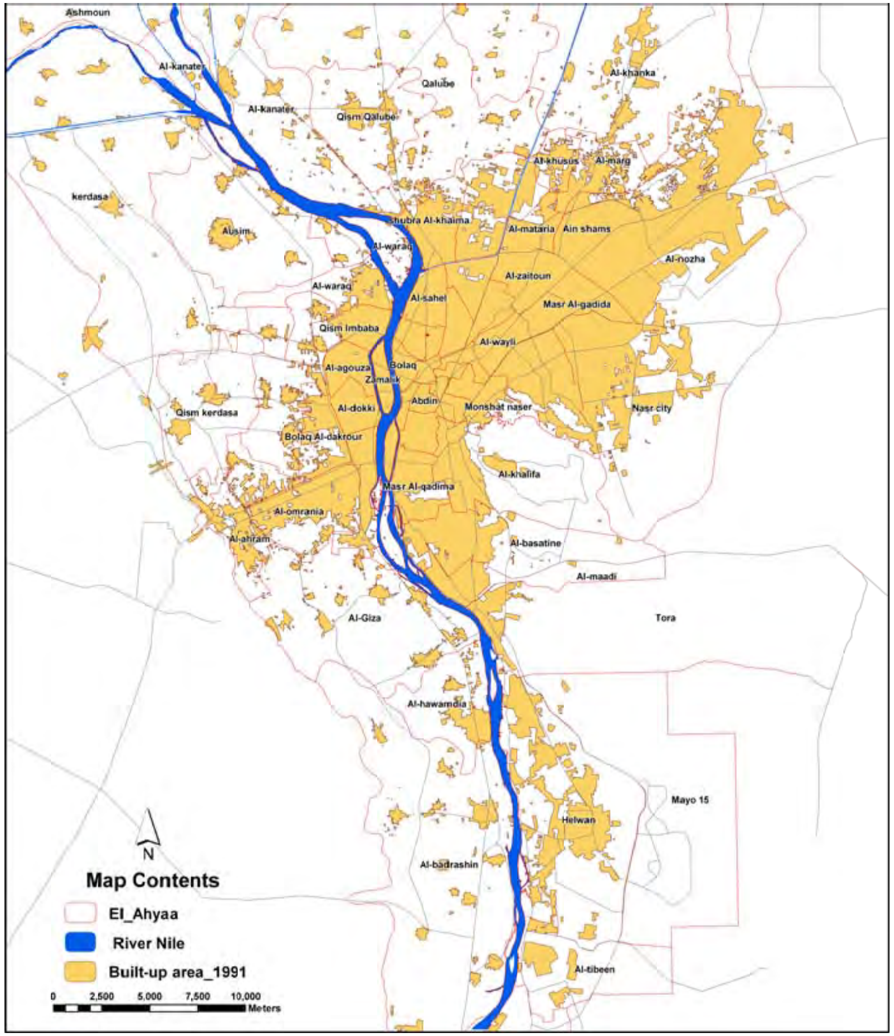


Figure (5-9) **G**reater **C**airo **R**egion urban extents in **1991**

(Source: **M**ilitary **S**urvey **D**epartment, **MSD**)

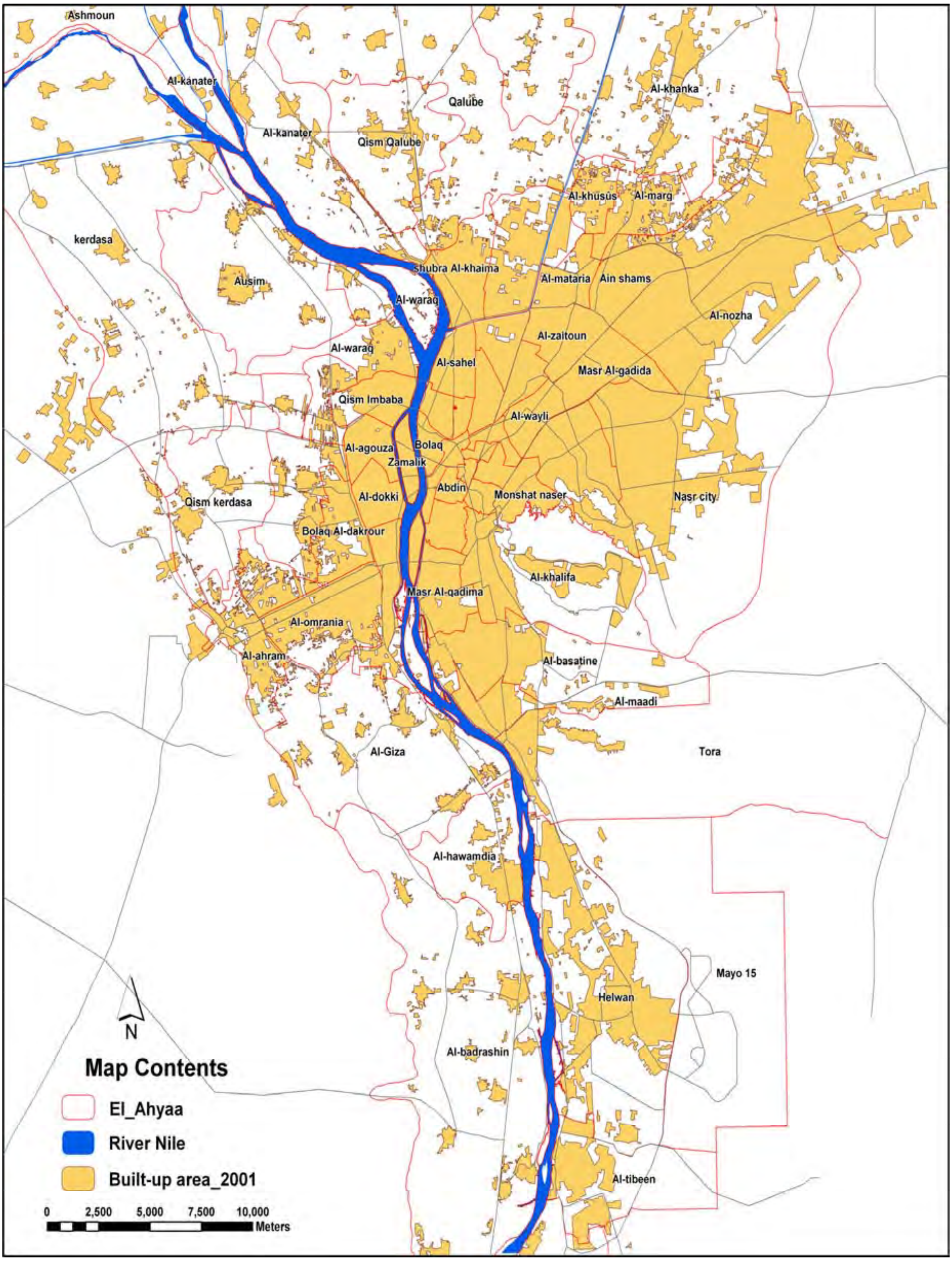


Figure (5-10) **G**reater **C**airo **R**egion urban extents in **2001**

(Source: the **C**entral **A**gency of **P**ublic **M**obilization and **S**tatistics, **CAPMAS**)

The importance of these years can explain as follows :

- After the **1952 revaluation** the new Egyptian government moved to the massive industry and centrally planning approach, as a result, housing projects were established by the revaluation government, particularly in **Cairo** city, new districts appeared in the northern, southern, and western parts of the city.
- The **Cairo** metropolitan area emerged, with a population of **6.7** million in 1970. **After the 1973 war,** the policy of the government moved from a socialist, centrally planned, and the domination of public sector on economy to the **open door policy,** with the aim of encouraging the private sector and attracting international and Arab investment (Yousry, M and Aboul atta, T. 1998). [1]

  A large part of such investment was directed to Cairo and its region, supporting further rapid urban development.
- The period between **1980** s to **1986** s represents the **post-independence period of rapid urbanization of grater Cairo**; by 1980 the population of greater Cairo reached to 8 million. **Informal and illegal popular housing** appeared in this period in many areas on the suburbs of the city and in the cemetery areas.
- The rapid urbanization of the city was continued to **1990** s, and many **informal and popular areas were emerged**. Such as, **Shubra El-Khima, Bahtem and El-Marg** to the north, **Embaba**, **Boulak El-Dakror** to the west and **Dar El-Salam, Mansheyt Naser** to the east of River Nile.

On the other hand, the efforts of the government to control the growth of the city have not been sufficient and **the urbanization kept growing in most directions, to reach an estimated population of over 12 million in 1994, with more than 4 million people were living in illegal and informal areas in Greater Cairo Region (GCR)**.

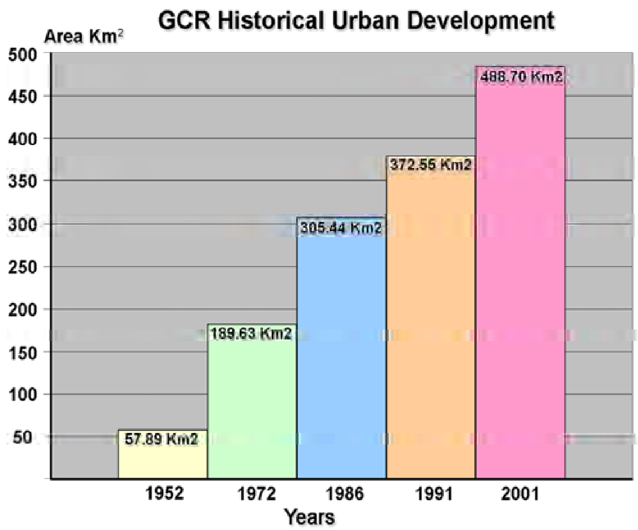


Figure (5-11) The historical urban expansion of **GCR** (The researcher work)

[1] This article available at: http://www.unu.edu/unupress/unupbooks/uu26ue/uu26ue0d.htm

(5-3-2) Transportation Maps

The **SLEUTH** program requires at least **two transportation maps** at different stages of the city development to calibrate the dynamic effect of **roads** and **transportation networks** in the city's developing structure. The **SLEUTH** program is initialized with the earliest road layer.

The program uses the ***road gravity*** coefficient and assumes better accessibility and connectivity to the road network attracts more urbanization, **the road maps are not necessarily binary, but may be weighted to simulate one type of road's greater attractiveness to urbanization relative to another type.** Therefore, roads can be weighted according to their level of accessibility and importance as **high**, **medium**, **low** or **none**.

In this application to **GCR**, all roads carry the same weight because only major roads were selected for prediction process. Roads were digitized at three stages of the region development (1953, 1991 and 2001); all roads maps were deriving from different official topographic maps, which used to produce urban data as follows :

- The **1953** road map was produced from Cairo topographic map, scale **1:75000** obtained from the **E**gyptian **S**urvey **A**uthority **(ESA).**
- The **1991** road map was produced from **29** topographic maps represents **GCR**, with scale **1:10000**, obtained from the **M**ilitary **S**urvey **M**anagement **(MSM)**.
- The **2001** road map was produced from digital topographic maps for **GCR**, scale **1:5000**, obtained from **CAPMAS**.

Figures (5-12 to 5-14) show three road network maps that used in the application of **SLEUTH** program in **GCR**.

(5-3-3) Slope Map

In general, topography defines the most suitable areas for urban development. Because of ease of development, flat areas are the easiest to build upon. Lands get less suitable as slope increases, and eventually become impossible to develop due to structural infeasibility, **at this point the slope constraint is defined as *CRITICAL_SLOPE***.

SLEUTH requires **one slope map;** the slope map can generated from any mapping software provides **D**igital **E**levation **M**odel **(DEM)** functionality. Each slope cell should be classified as percentage (0-100%) of the slope.

The **DEM** of **GCR** was build by combining digitized contour lines at 20m intervals *(from 1:25,000 map scale)*, with about 25000 spot heights points *(from 1:5000 map scale)* and **Nile River** map, using **ArcGIS** extensions *(Spatial Analyst and 3D Analyst Extensions)*, then the **DEM** was used to generate the slope and hillshade maps, for the study area

(5-3-4) Hillshade Map

The program requires at least **one hillshade map** that acts as a background image for the simulation process. **This layer is inactive input for SLEUTH simulation, but can greatly assist the visual examination and analysis of the simulated images.**

The **hillshade** map is prepared with the **SLEUTH** requirements, such as, the same spatial resolution of other input maps. Other physical features can included in the **hillshade** map, such as a **water body**, could be added to increase the visual realism of the simulation. However, all **hillshade** cells should have a value (0), so that the file will remain constant during all the iterations and simulations.

(5-3-5) Exclusion Map

The **SLEUTH** model requires **one excluded map;** the excluded map contains the areas that are not available for urbanization. Such as, **parklands, military lands, and water bodies, like Nile River**. Also, the exclusion layer is not necessarily binary, it may contain cell of value **zero** (0) that being open to urbanization, while other cell may include levels, or probabilities, of growth resistance with values range from (1 to 100).

Excluded areas are avoided during the simulation processes and no changes occur to cells in these areas. However, the urbanization process for **GCR** was not significantly restricted by any major physical feature except **River Nile** and the **Pyramids plateau**; therefore, all excluded map cells take the value (0), except River Nile boundary and Pyramids area.

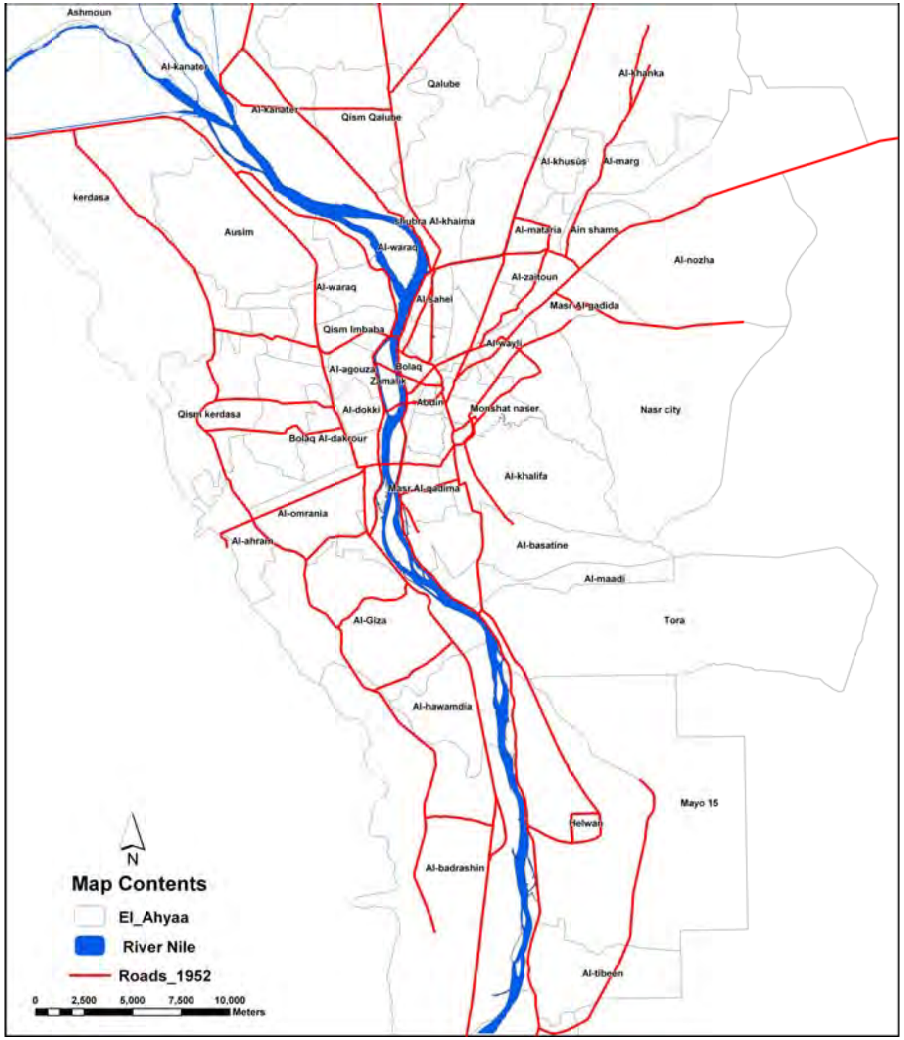


Figure (5-12) **G**reater **C**airo **R**egion roads map in **1952**

(Source: **E**gyptian **S**urvey **A**uthority, **ESA**)

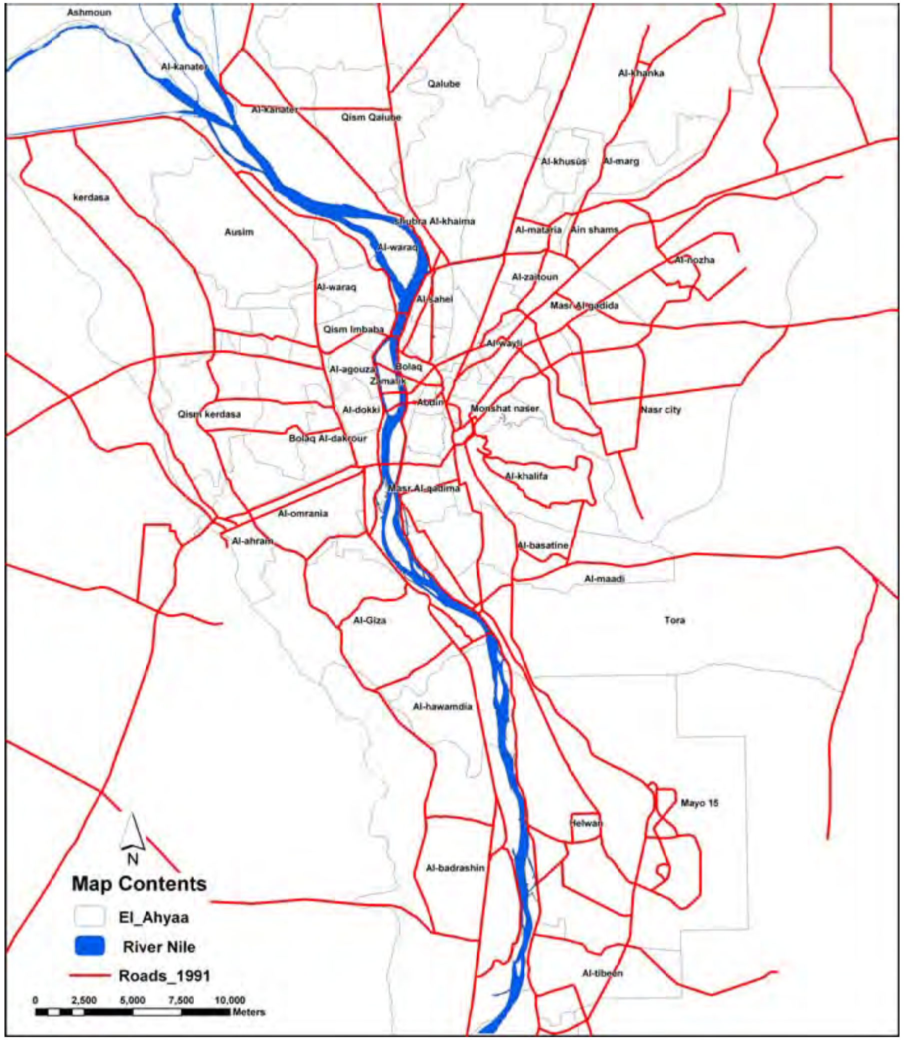


Figure (5-13) **G**reater **C**airo **R**egion roads map in **1991**

(Source: **M**ilitary **S**urvey **D**epartment, **MSD**)

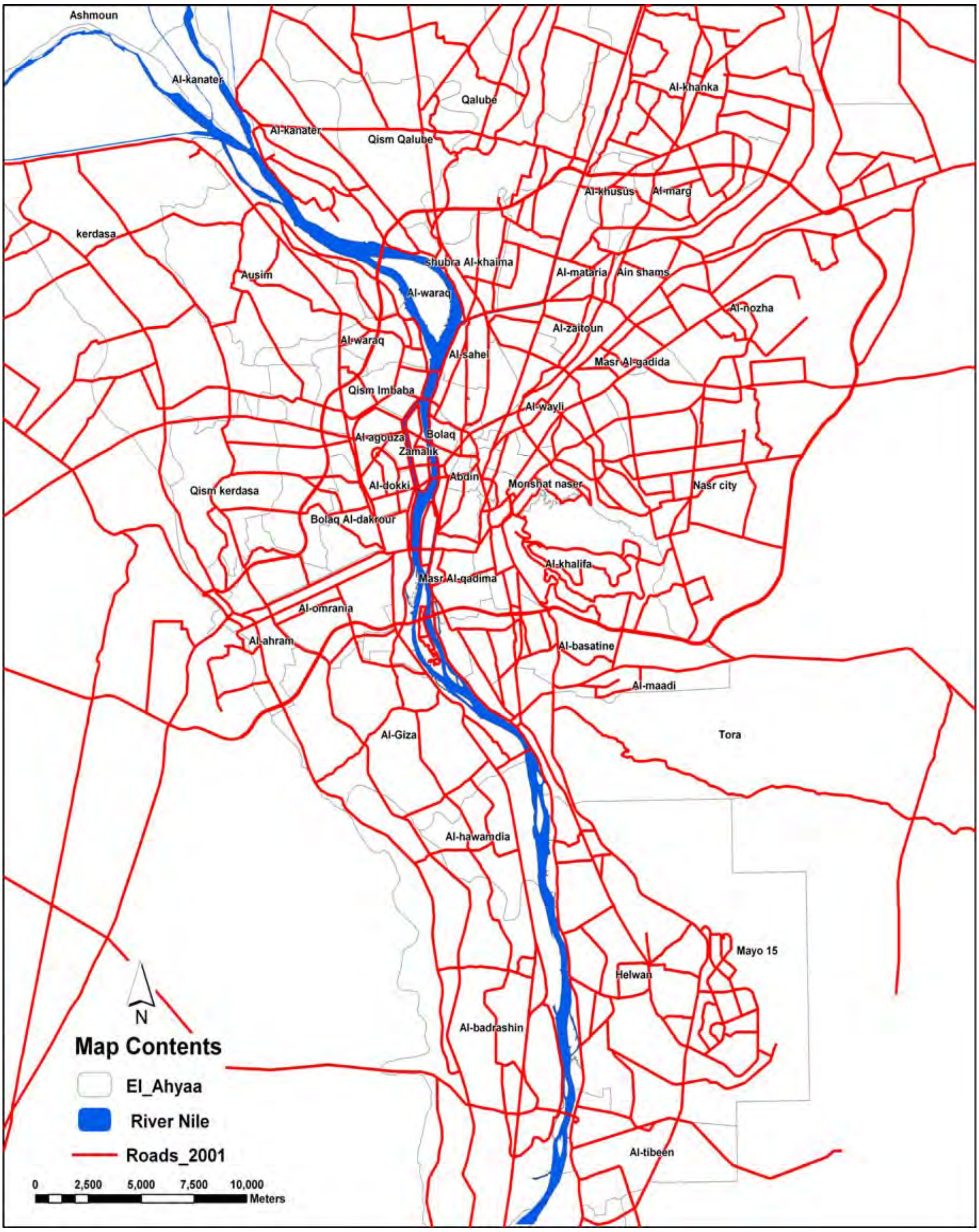


Figure (5-14) **G**reater **C**airo **R**egion roads map in **2001**

(Source: **CAPMAS**)

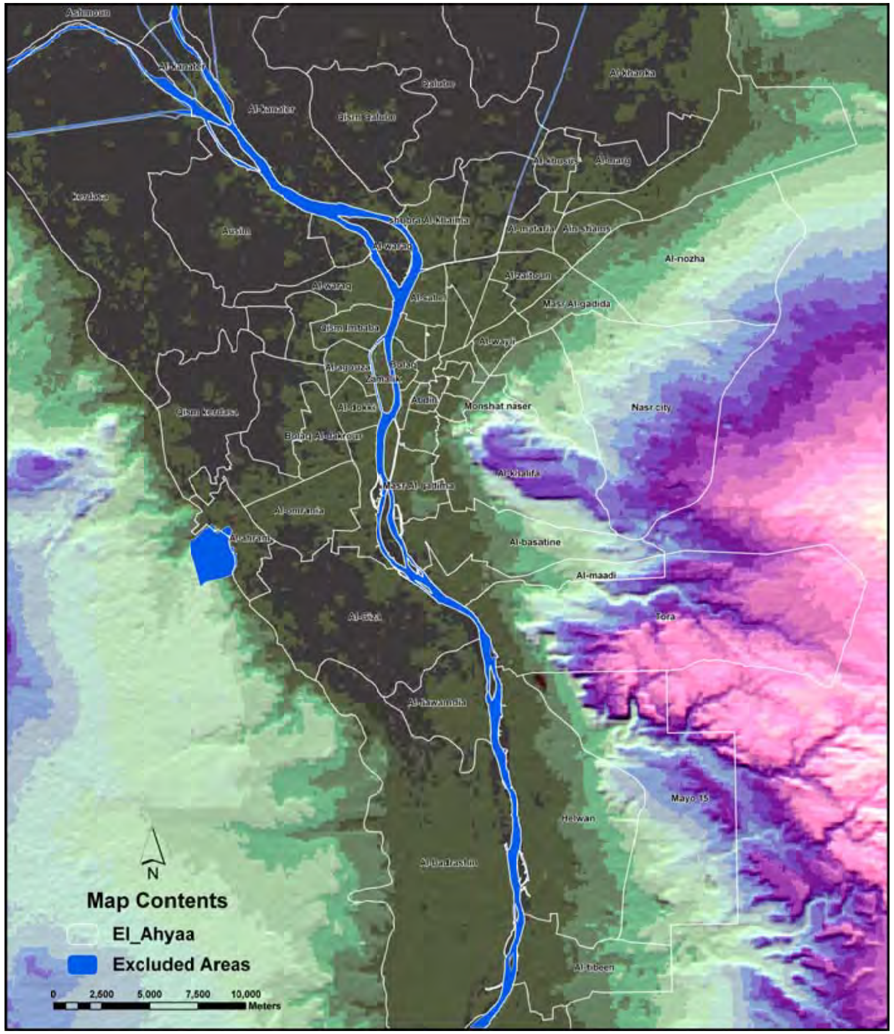


Figure (5-15) Classified color **Hillshade** map for the study area

(Source: http://www.glcfapp.umiacs.umd.edu)

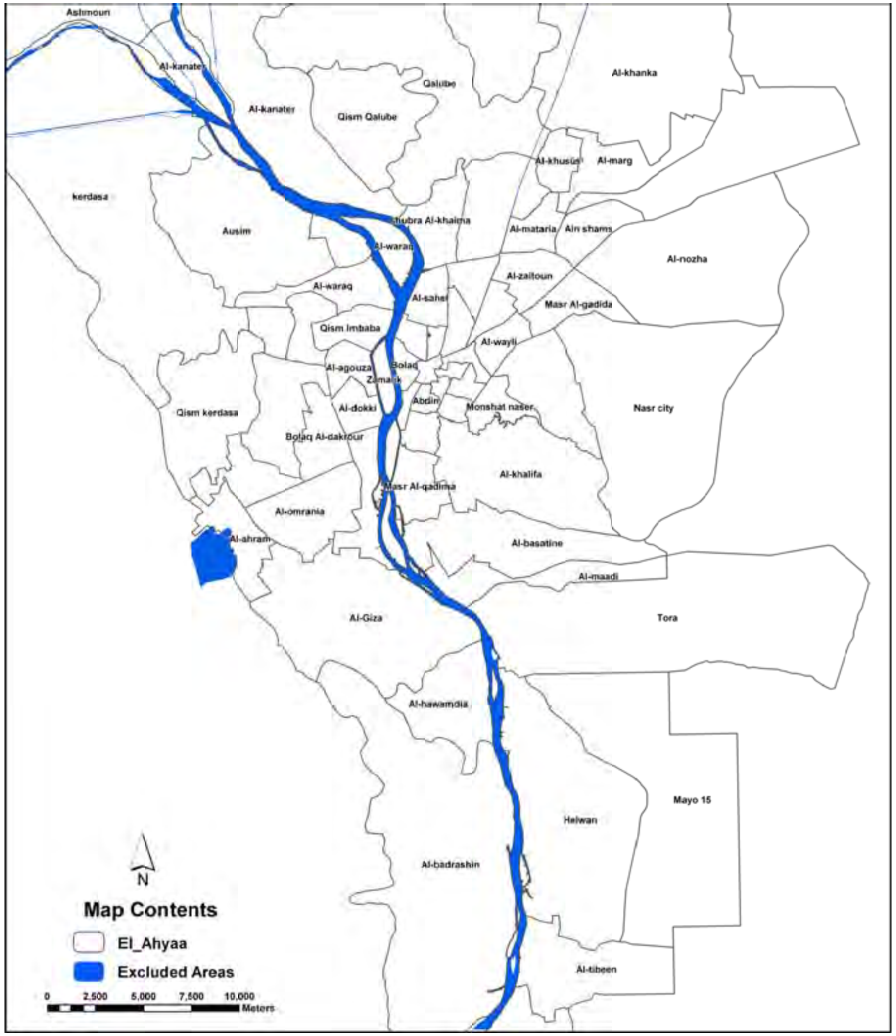


Figure (5-16) **Excluded** areas from the prediction process

(5-3-6) Land use Map

Land use map is additional to urban map and may be modeled in **SLEUTH**. This is an optional input, and was not utilized in this application.

All these layers were **digitized** and **geo-referenced** by using **ArcGIS** *(ArcInfo Software)*, and exported to **ERDAS** Imagine Software to derive and classify the maps at various resolutions required by **SLEUTH** program *(200, 100, 50 and 30m)*. Table (5-1) explains the role of each program involved in the preparation of the input files.

Software	Task	Input	Output
ArcGIS, ArcInfo Software	1- Digitizing maps, 2- Geo-referencing, 3- Editing.	Maps sheets: topographic maps, historical urban maps, and **LandSat** satellite image	**ArcGIS Geo-database,** containing roads, urban boundaries, river, and spot height.
ArcGIS 3D Analyst and Spatial Analyst Extensions	1- Generate **DEM** 2- Create *Slope* and *hillshade* map	**ArcGIS Geo-database**, *(contour, river and spot height).*	**DEM** Raster files
ERDAS IMAGINE	Convert all vector files to raster format, where *(live = 0 and dead = 1- 255).*	**ArcGIS Geo-database**, files and Bitmap Raster files.	Generating raster files with **2** states *(0 or 1)*
Adobe PhotoShop	1- Convert images into **GIF** files. 2- Renaming files to the **SLEUTH** conventional name.	Exported Bitmap files from **ArcGIS**.	**SLEUTH** *(gif)* conventional files
SLEUTH *(Release -3.0)*	1- **Calibration** *(coarse, fine and final).* 2- **Prediction**	**(10) GIF** images renamed according to **SLEUTH** requirements	1- Calibration results. 2- Prediction maps
Excel	Sorting calibration results	Calibration statistics	Selection of the best coefficient results

Table (5-1) Software and programs used to generate the required data for **SLEUTH** program

Once, all the required maps have been obtained, the next step is to clearly define how to prepare them in an acceptable format for SLEUTH program.

(5-3-7) Data Preparation for SLEUTH Calibration and Prediction

When all maps were ready, **the next step is to clearly define how to prepare them in an acceptable format for the SLEUTH program;** they needed to be checked for consistency and agreement with regard to **spatial resolution**, **same extent, temporal evolution and projection**.

In this step, we prepare **four** similar set of input files at different resolutions to be used during the **calibration phases and prediction**. Because running the calibration at a fine resolution takes a great deal of time, the program breaks the calibration down into three steps: **coarse, fine, and final**.

Accordingly, **four** sets of input data files were prepared for the simulation of **GCR**. These were :

- **200 meter/pixel** resolution for coarse calibration,
- **100 meter/pixel** resolution for fine calibration,
- **50 meter/pixel** resolution for final calibration,
- **30 meter/pixel** resolution for prediction.

In this application, each set contains **eleven** input maps as follows :

- **Five urban maps** *(1952, 1972, 1986, 1991 and 2001),*
- **Three transportations maps** *(1952, 1991 and 2001),*
- **One slope map**,
- **One excluded map**,
- **One hillshade map**.

Once all maps are prepared and satisfied the **SLEUTH** format, the next step consisted of naming each file in accordance with **SLEUTH's** coding convention.

200 m/pixel

100 m/pixel

50 m/pixel

30 m/pixel

Figure (5-17) Example of urban extent with **four** different resolutions used during the calibration phase of urban growth in **GCR**

(5-3-8) Naming the Input Files With SLEUTH Naming Convention

SLEUTH requires grayscale **G**raphic **I**mage **F**iles **(GIF)** as input. All maps should be consistent with the **SLEUTH** file format requirements as follows:

- Grayscale **GIF** images.
- Images are derived from grids in the same projection.
- Images are derived from grids with the same map extent.
- Images have identical dimensions *(row and column count is consistent)*.
- Images follow the **SLEUTH** naming format.

The **SLEUTH** program will only read input files with specific **naming convention** and **appropriate dates**. Specifically, all input **urban** and **transportation** maps must match the following naming convention: ***<location.type.year.gif>***, where:

a) ***Location*** refers to the area of study and may also include an indication of resolution, with a length of up to 100 characters.

b) ***Type*** indicates the layer type such as *urban*, *roads*, *slope*, *hillshade* and *excluded*.

c) ***Year*** indicates the year to which the data relates, displayed in **four-digit** format.

For example, the **1952** urban map of Cairo with **100 meter/pixel** spatial resolution was named as *Cairo100.urban.1952.gif,* whereas a **1952** road map of Cairo with **100 meter/pixel** spatial resolution was named *Cairo100.road.1952.gif.*

Additionally, *excluded*, *hillshade* and *slope* maps had to follow the following naming convention: ***<location.type.gif>.*** Thus, **excluded, hillshade and slope maps of Cairo** with **100 meter/pixel** spatial resolution were respectively named *Cairo100.excluded.gif, Cairo100.hillshade.gif* and *Cairo100.slope.gif.*

Data	Naming code	No of layers	No of classes	Remarks
Urban	**Cairo100.urban.1952.gif** **Cairo100.urban.1972.gif** **Cairo100.urban.1986.gif** **Cairo100.urban.1991.gif** **Cairo100.urban.2001.gif**	**5**	**2 class** *(urban and non urban)*	The model will calibrate the **5** different stages of the urban development. **Two** images can be used but the model is more effective with four or more urban images.
Roads	**Cairo100.roads.1952.gif** **Cairo100.roads.1991.gif** **Cairo100.roads.2001.gif**	**3**	**2 class** *(roads and non roads)*	At least **2** sets of transportation networks *(rail, roads and others)* files are required. Their dates are independent from the urban maps.
Slope	**Cairo100.slope.gif**	**1**	**0-100**	**Slope:** the slope average percent is derived from a **DEM,** with **v**alues from 0 – 100, the slope percent define the weights of urbanization resistance.
Excluded	**Cairo100.excluded.gif**	**1**	**2 classes** *(excluded and non excluded areas)*	**2** classes **(excluded and non-excluded),** Excluded Areas where urbanization cannot occur *(e.g., water bodies, archaeological sites, military areas, etc.)*
Hillshade	**Cairo100.hillshade.gif**	**1**	---	Use as background only

Table (5-2) Summarizes the number of input files, as well as their function in the **SLEUTH** model

The **SLEUTH** program was downloaded from the ***Gigalopolis*** website: *(http://www.ncgia.ucsb.edu/projects/gig/index.html)*, then the downloaded file **SLEUTH3.0beta_p01_linux.tar.gz** was unzipped and compiled using the **GCC** Compiler, which available inside Linux environment. (1)

After that, a simulation test was run using demonstration data to ensure that the program was fully operational. Although the **SLEUTH** model was executed under **LUNIX** environment, the outputs had to be transferred to **WINDOWS** environment, for further analysis and testing the model outputs by other programs such as ***ArcGIS*** and ***Microsoft EXCEL*.**
After all input files was prepared and named with the **SLEUTH** naming convention, then these files were uploaded to their respective folders in **SLEUTH** to start the calibration phase.

The purpose of running a calibration test is to check the quality of the input data that prepared to model the **GCR** urban growth. If an error message *("bug")* is generated, this means that the input files do not fit the program format, incorrect naming codes, or images with different pixel resolution.
If the error is corrected *(or no error is identified)*, then the program is ready to start the calibration phase.

(1) **LINUX CentOS-4** was used as the **Operating System** for the application of **SLEUTH** program in **G**reater **C**airo **R**egion case study.

(5-4) Calibration of SLEUTH Growth Coefficients

The goal of urban models is to simulate some aspect of the urban system. If a model is developed for particular geographical area its applicability to another area is likely to be impossible. Because of **local characteristics**, **growth forces**, **site conditions,** and **economic base situations** ensure that different development trends have been occurred.

Alternatively, if a model handles some factors that are general to the process of urbanization, such as **land use, land value, road attraction, edge growth, filling urban gaps,** and give the expected growth in prediction maps, then the usefulness of this model is greatly increased and can use or adapt for other cities.

> So, the **general-purpose model** may be applied to multiple cities and can adapt for any new application through the process of calibration.

The **SLEUTH** calibration procedure measures if the model can successfully replicate the historical urban expansion as presented in the input data files. <u>**The main objective of the calibration phase is to determine the numerical values of the SLEUTH growth coefficient,**</u> based on the historical patterns and trends, that tend to guide the direction of future expansion.

Clarke and Gaydos (1998) suggest that calibration can be done by **statistically** testing the **observed** values against those **expected**. This method seeks to find which set of parameters produces the **best-fit** values, within a reasonable computing time. Coefficient values obtained from calibrations are then used for prediction. This calibration approach is known as ***"brute force calibration"*** (Yang & Lo, 2003).
In **SLEUTH**, the calibration proceeds by progressively <u>reducing increments</u> of **SLEUTH** coefficient values, while increasing the <u>spatial resolution</u> of input maps at three calibration phases: **coarse, fine and final**.

(5-4-1) Running SLEUTH Coarse Calibration *(First phase)*

The **coarse calibration** is the first level of narrowing down the **five** growth coefficients values *(Diffusion, Breed, Spread, Slope resistance, and Road gravity)* [(1)]

To reduce the computation time, **coarse calibration** uses low spatial resolution such that the program recommends **¼** of the full size image *(200 meter/pixel)*. Moreover it uses large increments for each growth coefficient. At this primary stage, the program considers all possibilities *(from 0 to 100)***,** with a large increment of **25**.
Table (5-3) shows the input scores at the **coarse calibration** phase.

The *coarse calibration scenario file* should include the values of the following variables:

- The group of images with **200 meter/pixel** spatial resolution was used for **coarse calibration**; all these images were put together in the input folder *(Cairo200),*
- The Monte Carlo iteration *(4),*
- The echo parameter *(yes),*
- The seed number *(1000),*
- The num_working_grids *(2).*

When all these values are defined in the *coarse calibration scenario file*, then we can start the **coarse calibration** process.

In the case of **GCR**, the **coarse calibration** phase ran for **4 hours, 22 min and 26 seconds,** different scores but no image files are produced. The operation executed **3125** iterations and generated ***.log*** files such as ***control.stats.log, memory.log,*** and ***log_0.***
The most important of these files is the ***control.stats.log*** which contains **thirteen** different output classes for all the iterations, as well as values for the **five** growth coefficients *(diffusion, breed, spread, slope resistance, and road gravity).* The control.stats.log file contains the calibration results that provide clues as to which statistical values will **best-fit the historical trend.** These results should be sorted to find out which iterations are most suitable in this phase.

[(1)] more details about **SLEUTH** growth coefficients are available in Chapter 4 section (4-4-4)

(5-4-2) Selection of "best" Results from the Coarse Calibration Phase

Best results are considered as the **closest values**, which can used to compare the **observed** changes *(historical patterns)* with those **expected** *(simulated)*. **So, the higher the value, the more accurate the growth coefficient value for that set of iterations.**

The objective of sorting the **"best"** results is to narrow down the range of calculated coefficients scores during the coarse calibration phase. **Sorting is the simplest procedure to review and select the most successful iteration coefficients**. For instance, about **30** results were selected from **3125** iterations during the coarse calibration, to be used at the fine calibration as shown in Table (5-4). The step of sorting best results contains:

- **Reducing the range of all possible values** to scores that are positively and efficiently correlated with the historical growth trends,
- **Implies the selection of the best-fit iteration values** from the calibration results *(recorded in control.stats.log file).*

Clarke and Gaydos (1998) suggest that the best parameters for **urban simulation** are derived from the classes in which predicted coefficients are correlated *(high **r-squared** values)* with values computed from the historical data layers.

These classes are ***compare, r^2pop, r^2edge*** and ***r^2cluster*.** The **first three** classes are enough to give an idea of the best growth coefficient values. The function of each parameter can described as follows:

- **The Compare class**, used to compare the amount of modelled urban area to known *(or actual)* urban area for the stop date year,
- The **r^2pop class**, is a least squares regression score for the modelled urbanization pixels compared to the actual number of urbanization pixels for the control years;
- The **r^2edge class**, is a least squares regression score for the modelled amount of urban perimeter , or edge, compared to actual urban edge for the control years;

The calibration results can be sorted either within or outside **SLEUTH**. In the case of **GCR** growth, the *Microsoft office Excel® 2003* was chosen to perform the statistical analysis because it has the capacity to **analyze tables** and **perform multiple functions** such as **single or multiple sorting and classification**.

In the case of **GCR**, The *control.stats.log* file was imported to *Microsoft Excel*, and **sorted** using the three categories: <u>**compare**</u>**,** <u>**r^2pop**</u> **and** <u>**r^2edge**</u> in order to select the **best-fit** results for the next calibration step. The calibration scores were sorted by the likeliness of the iteration to produce reasonable input coefficient values for the next calibration phase.

Table (5-4) shows an example of sorting best results using *Microsoft Excel spreadsheet*.

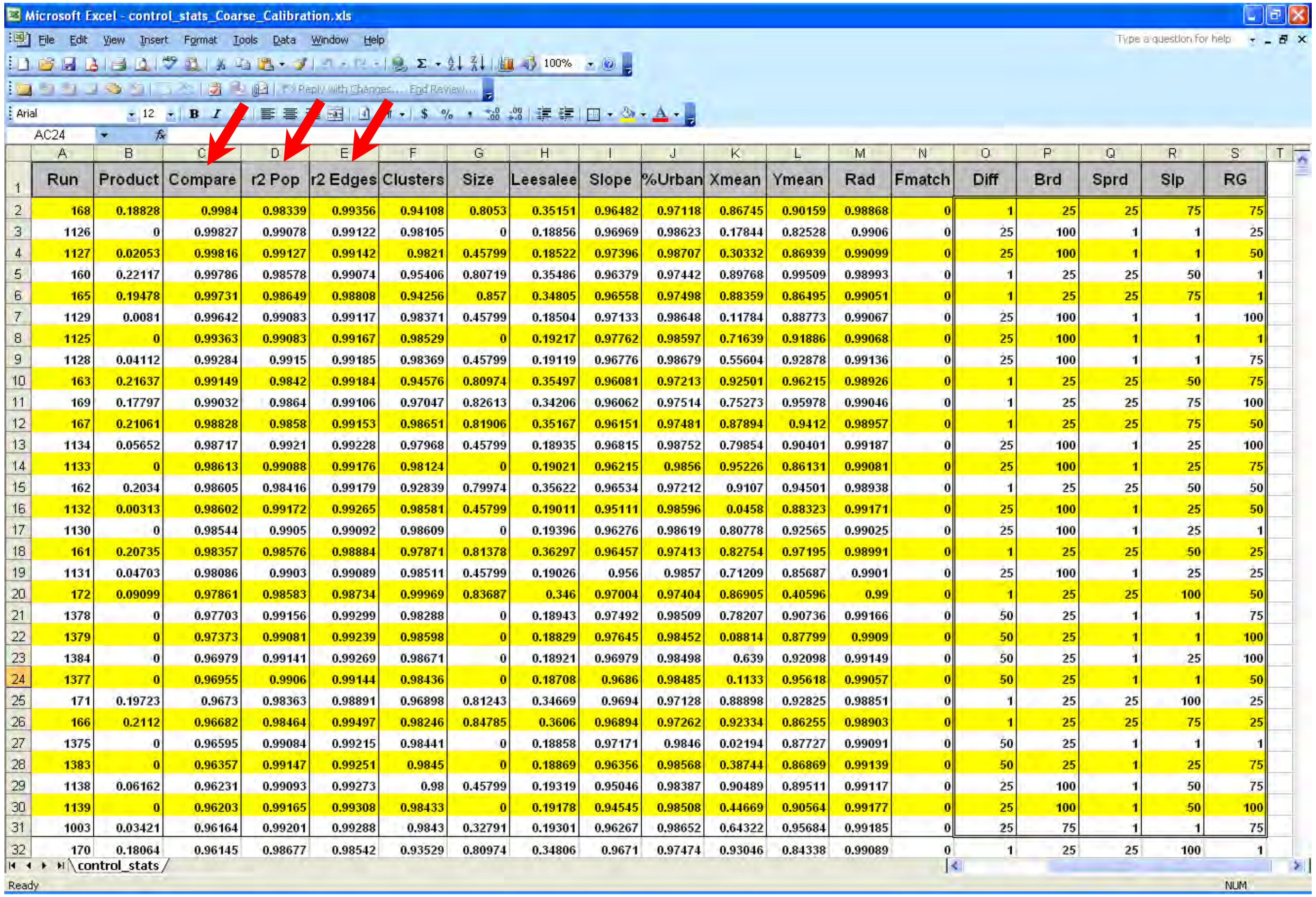
Thirty best results were then recorded *(see table 5-4)* to derive the growth coefficients range that will be used as input for the next calibration phase.

- In the case of ***diffusion***, good results were obtained for parameters ranging between **5** and **25**,
- The ***breed,*** can give good results for parameters ranging between **20** and **80**,
- The ***spread***, can give good results when it is calibrated from **5** to **25**,
- The ***slope resistance,*** can give good results when it is calibrated from **0** to **50**,
- The ***road gravity***, however, varied all along the classes, from **20** to **100**.

In light of the **coarse calibration results**, input variables should be narrowed down during the next calibration phase to obtain more reasonable values for each growth coefficient.

Diffusion coefficient			Breed coefficient			Spread coefficient			Slope resistance			Road gravity		
Initial	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**
0	**25**	**100**	**0**	**25**	**100**	**0**	**25**	**100**	**0**	**25**	**100**	**0**	**25**	**100**

Table (5-3) Input scores at the **coarse calibration** phase



	Run	Product	Compare	r2 Pop	r2 Edges	Clusters	Size	Leesalee	Slope	%Urban	Xmean	Ymean	Rad	Fmatch	Diff	Brd	Sprd	Slp	RG
2	168	0.18828	0.9984	0.98339	0.99356	0.94108	0.8053	0.35151	0.96482	0.97118	0.86745	0.90159	0.98868	0	1	25	25	75	75
3	1126	0	0.99827	0.99078	0.99122	0.98105	0	0.18856	0.96969	0.98623	0.17844	0.82528	0.9906	0	25	100	1	1	25
4	1127	0.02053	0.99816	0.99127	0.99142	0.9821	0.45799	0.18522	0.97396	0.98707	0.30332	0.86939	0.99099	0	25	100	1	1	50
5	160	0.22117	0.99786	0.98578	0.99074	0.95406	0.80719	0.35486	0.96379	0.97442	0.89768	0.99509	0.98993	0	1	25	25	50	1
6	165	0.19478	0.99731	0.98649	0.98808	0.94256	0.857	0.34805	0.96558	0.97498	0.88359	0.86495	0.99051	0	1	25	25	75	1
7	1129	0.0081	0.99642	0.99083	0.99117	0.98371	0.45799	0.18504	0.97133	0.98648	0.11784	0.88773	0.99067	0	25	100	1	1	100
8	1125	0	0.99363	0.99083	0.99167	0.98529	0	0.19217	0.97762	0.98597	0.71639	0.91886	0.99068	0	25	100	1	1	1
9	1128	0.04112	0.99284	0.9915	0.99185	0.98369	0.45799	0.19119	0.96776	0.98679	0.55604	0.92878	0.99136	0	25	100	1	1	75
10	163	0.21637	0.99149	0.9842	0.99184	0.94576	0.80974	0.35497	0.96081	0.97213	0.92501	0.96215	0.98926	0	1	25	25	50	75
11	169	0.17797	0.99032	0.9864	0.99106	0.97047	0.82613	0.34206	0.96062	0.97514	0.75273	0.95978	0.99046	0	1	25	25	75	100
12	167	0.21061	0.98828	0.9858	0.99153	0.98651	0.81906	0.35167	0.96151	0.97481	0.87894	0.9412	0.98957	0	1	25	25	75	50
13	1134	0.05652	0.98717	0.9921	0.99228	0.97968	0.45799	0.18935	0.96815	0.98752	0.79854	0.90401	0.99187	0	25	100	1	25	100
14	1133	0	0.98613	0.99088	0.99176	0.98124	0	0.19021	0.96215	0.9856	0.95226	0.86131	0.99081	0	25	100	1	25	75
15	162	0.2034	0.98605	0.98416	0.99179	0.92839	0.79974	0.35622	0.96534	0.97212	0.9107	0.94501	0.98938	0	1	25	25	50	50
16	1132	0.00313	0.98602	0.99172	0.99265	0.98581	0.45799	0.19011	0.95111	0.98596	0.0458	0.88323	0.99171	0	25	100	1	25	50
17	1130	0	0.98544	0.9905	0.99092	0.98609	0	0.19396	0.96276	0.98619	0.80778	0.92565	0.99025	0	25	100	1	25	1
18	161	0.20735	0.98357	0.98576	0.98884	0.97871	0.81378	0.36297	0.96457	0.97413	0.82754	0.97195	0.98991	0	1	25	25	50	25
19	1131	0.04703	0.98086	0.9903	0.99089	0.98511	0.45799	0.19026	0.956	0.9857	0.71209	0.85687	0.9901	0	25	100	1	25	25
20	172	0.09099	0.97861	0.98583	0.98734	0.99969	0.83687	0.346	0.97004	0.97404	0.86905	0.40596	0.99	0	1	25	25	100	50
21	1378	0	0.97703	0.99156	0.99299	0.98288	0	0.18943	0.97492	0.98509	0.78207	0.90736	0.99166	0	50	25	1	1	75
22	1379	0	0.97373	0.99081	0.99239	0.98598	0	0.18829	0.97645	0.98452	0.08814	0.87799	0.9909	0	50	25	1	1	100
23	1384	0	0.96979	0.99141	0.99269	0.98671	0	0.18921	0.96979	0.98498	0.639	0.92098	0.99149	0	50	25	1	25	100
24	1377	0	0.96955	0.9906	0.99144	0.98436	0	0.18708	0.9686	0.98485	0.1133	0.95618	0.99057	0	50	25	1	1	50
25	171	0.19723	0.9673	0.98363	0.98891	0.96898	0.81243	0.34669	0.9694	0.97128	0.88898	0.92825	0.98851	0	1	25	25	100	25
26	166	0.2112	0.96682	0.98464	0.99497	0.98246	0.84785	0.3606	0.96894	0.97262	0.92334	0.86255	0.98903	0	1	25	25	75	25
27	1375	0	0.96595	0.99084	0.99215	0.98441	0	0.18858	0.97171	0.9846	0.02194	0.87727	0.99091	0	50	25	1	1	1
28	1383	0	0.96357	0.99147	0.99251	0.9845	0	0.18869	0.96356	0.98568	0.38744	0.86869	0.99139	0	50	25	1	25	75
29	1138	0.06162	0.96231	0.99093	0.99273	0.98	0.45799	0.19319	0.95046	0.98387	0.90489	0.89511	0.99117	0	25	100	1	50	75
30	1139	0	0.96203	0.99165	0.99308	0.98433	0	0.19178	0.94545	0.98508	0.44669	0.90564	0.99177	0	25	100	1	50	100
31	1003	0.03421	0.96164	0.99201	0.99288	0.9843	0.32791	0.19301	0.96267	0.98652	0.64322	0.95684	0.99185	0	25	75	1	1	75
32	170	0.18064	0.96145	0.98677	0.98542	0.93529	0.80974	0.34806	0.9671	0.97474	0.93046	0.84338	0.99089	0	1	25	25	100	1

Table (5-4) Selection of the best **coarse calibration** results by using *Microsoft Excel*

(5-4-3) Fine Calibration *(Second phase)*

The purpose of the **fine calibration** phase is to narrow down the selection and to achieve better combinations with a smaller range of growth coefficients values *(for example: an increment of the **5** to **10** instead of **25** used in coarse calibration)*. Sorting *control.stats.log* file which produced from the **coarse calibration** reduces the range of growth coefficients values, which can now be used during the **fine calibration** phase.

The *fine calibration scenario file* should include the values of the following variables:

- The group of images with **100 meter/pixel** spatial resolution was used for **fine calibration**; all these images were put together in the input folder *(Cairo100)*,
- The Monte Carlo iteration *(6)*,
- The echo parameter *(yes)*,
- The seed number *(1000)*,
- The num_working_grids *(2)*.

The input procedure is identical to that described above for the **coarse calibration**, but the growth coefficient input values were chosen as shown in Table (5-6).

In the case of **GCR**, the **fine calibration** ran for **56 hours, 9 min and 25 seconds** and generated **9450** iterations. **The length of the calibration could be explained by the high number** of *Monte Carlo* iterations *(6)*, the **lower number of increments** *(5)* and **large spatial resolution** of input data images (½ of the full size image, *100 meter/pixel)*.

The *control.stats.log* file that produced from the **fine calibration** phase was exported to *Microsoft Excel* for sorting and selecting the best results of this step.

Scores of 0.999 were ordered for the ***compare, r^2pop*** and ***r^2edge*** classes. Although the *diffusion* and *breed* coefficients and their increments were significantly reduced, the *spread*, *slope* and *road* coefficients and their increments did not vary as much. Table (5-5) shows the **best-fit values** for the **five** growth coefficients as follows:

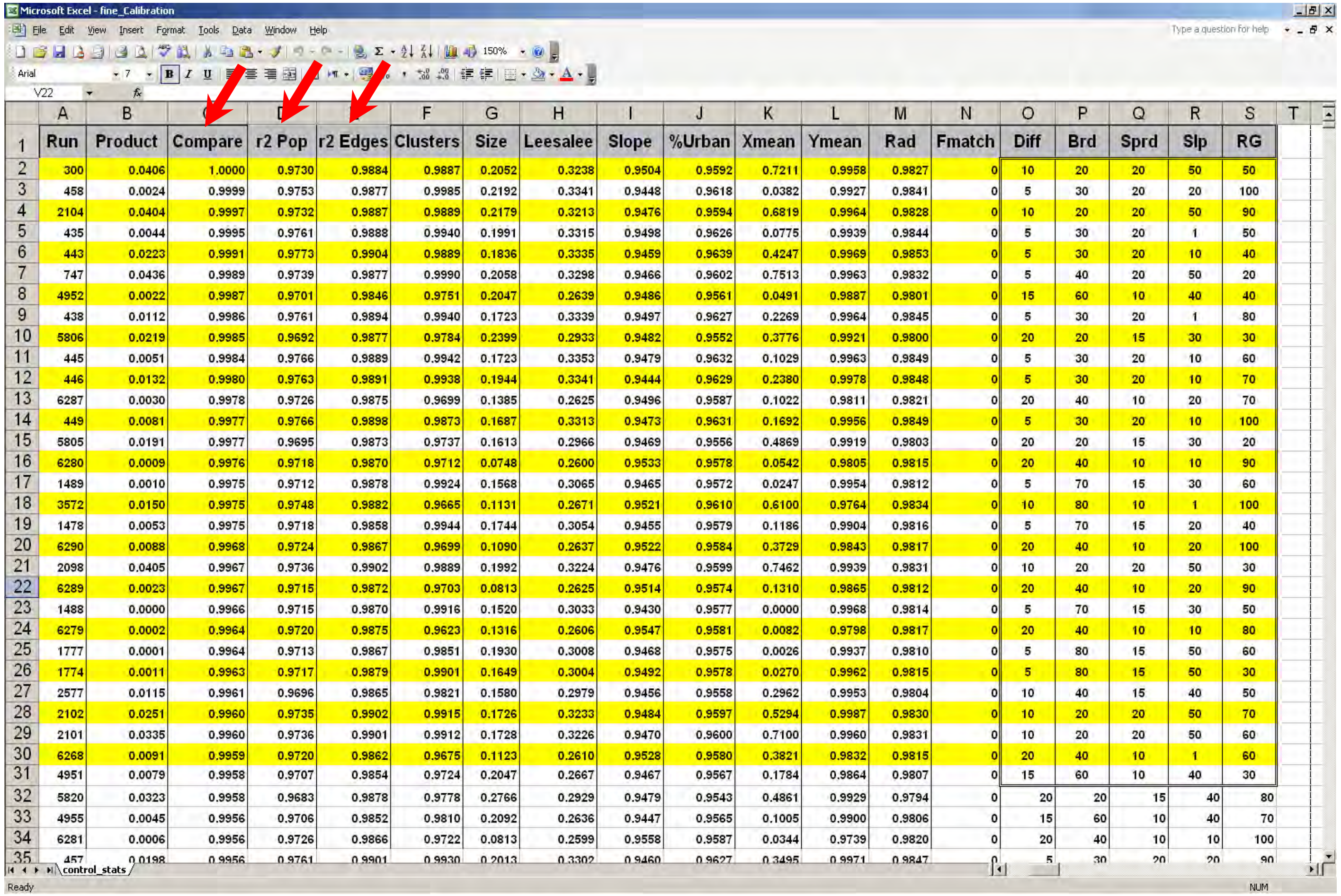
Coefficient	Diffusion	Breed	Spread	Slope	Road gravity
Range Values	1-20	20-40	10-25	10-50	20-60

Table (5-5) The range of **fine calibration** best-fit results

Although the range of values for each coefficient was still broad, the final calibration will aim to narrow this down.

Diffusion coefficient			Breed coefficient			Spread coefficient			Slope resistance			Road gravity		
Initial	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**
5	**5**	**25**	**20**	**10**	**80**	**5**	**5**	**25**	**0**	**10**	**50**	**20**	**10**	**100**

Table (5-6) Input scores at the **fine calibration** phase



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Run	Product	Compare	r2 Pop	r2 Edges	Clusters	Size	Leesalee	Slope	%Urban	Xmean	Ymean	Rad	Fmatch	Diff	Brd	Sprd	Slp	RG
2	300	0.0406	1.0000	0.9730	0.9884	0.9887	0.2052	0.3238	0.9504	0.9592	0.7211	0.9958	0.9827	0	10	20	20	50	50
3	458	0.0024	0.9999	0.9753	0.9877	0.9985	0.2192	0.3341	0.9448	0.9618	0.0382	0.9927	0.9841	0	5	30	20	20	100
4	2104	0.0404	0.9997	0.9732	0.9887	0.9889	0.2179	0.3213	0.9476	0.9594	0.6819	0.9964	0.9828	0	10	20	20	50	90
5	435	0.0044	0.9995	0.9761	0.9888	0.9940	0.1991	0.3315	0.9498	0.9626	0.0775	0.9939	0.9844	0	5	30	20	1	50
6	443	0.0223	0.9991	0.9773	0.9904	0.9889	0.1836	0.3335	0.9459	0.9639	0.4247	0.9969	0.9853	0	5	30	20	10	40
7	747	0.0436	0.9989	0.9739	0.9877	0.9990	0.2058	0.3298	0.9466	0.9602	0.7513	0.9963	0.9832	0	5	40	20	50	20
8	4952	0.0022	0.9987	0.9701	0.9846	0.9751	0.2047	0.2639	0.9486	0.9561	0.0491	0.9887	0.9801	0	15	60	10	40	40
9	438	0.0112	0.9986	0.9761	0.9894	0.9940	0.1723	0.3339	0.9497	0.9627	0.2269	0.9964	0.9845	0	5	30	20	1	80
10	5806	0.0219	0.9985	0.9692	0.9877	0.9784	0.2399	0.2933	0.9482	0.9552	0.3776	0.9921	0.9800	0	20	20	15	30	30
11	445	0.0051	0.9984	0.9766	0.9889	0.9942	0.1723	0.3353	0.9479	0.9632	0.1029	0.9963	0.9849	0	5	30	20	10	60
12	446	0.0132	0.9980	0.9763	0.9891	0.9938	0.1944	0.3341	0.9444	0.9629	0.2380	0.9978	0.9848	0	5	30	20	10	70
13	6287	0.0030	0.9978	0.9726	0.9875	0.9699	0.1385	0.2625	0.9496	0.9587	0.1022	0.9811	0.9821	0	20	40	10	20	70
14	449	0.0081	0.9977	0.9766	0.9898	0.9873	0.1687	0.3313	0.9473	0.9631	0.1692	0.9956	0.9849	0	5	30	20	10	100
15	5805	0.0191	0.9977	0.9695	0.9873	0.9737	0.1613	0.2966	0.9469	0.9556	0.4869	0.9919	0.9803	0	20	20	15	30	20
16	6280	0.0009	0.9976	0.9718	0.9870	0.9712	0.0748	0.2600	0.9533	0.9578	0.0542	0.9805	0.9815	0	20	40	10	10	90
17	1489	0.0010	0.9975	0.9712	0.9878	0.9924	0.1568	0.3065	0.9465	0.9572	0.0247	0.9954	0.9812	0	5	70	15	30	60
18	3572	0.0150	0.9975	0.9748	0.9882	0.9665	0.1131	0.2671	0.9521	0.9610	0.6100	0.9764	0.9834	0	10	80	10	1	100
19	1478	0.0053	0.9975	0.9718	0.9858	0.9944	0.1744	0.3054	0.9455	0.9579	0.1186	0.9904	0.9816	0	5	70	15	20	40
20	6290	0.0088	0.9968	0.9724	0.9867	0.9699	0.1090	0.2637	0.9522	0.9584	0.3729	0.9843	0.9817	0	20	40	10	20	100
21	2098	0.0405	0.9967	0.9736	0.9902	0.9889	0.1992	0.3224	0.9476	0.9599	0.7462	0.9939	0.9831	0	10	20	20	50	30
22	6289	0.0023	0.9967	0.9715	0.9872	0.9703	0.0813	0.2625	0.9514	0.9574	0.1310	0.9865	0.9812	0	20	40	10	20	90
23	1488	0.0000	0.9966	0.9715	0.9870	0.9916	0.1520	0.3033	0.9430	0.9577	0.0000	0.9968	0.9814	0	5	70	15	30	50
24	6279	0.0002	0.9964	0.9720	0.9875	0.9623	0.1316	0.2606	0.9547	0.9581	0.0082	0.9798	0.9817	0	20	40	10	10	80
25	1777	0.0001	0.9964	0.9713	0.9867	0.9851	0.1930	0.3008	0.9468	0.9575	0.0026	0.9937	0.9810	0	5	80	15	50	60
26	1774	0.0011	0.9963	0.9717	0.9879	0.9901	0.1649	0.3004	0.9492	0.9578	0.0270	0.9962	0.9815	0	5	80	15	50	30
27	2577	0.0115	0.9961	0.9696	0.9865	0.9821	0.1580	0.2979	0.9456	0.9558	0.2962	0.9953	0.9804	0	10	40	15	40	50
28	2102	0.0251	0.9960	0.9735	0.9902	0.9915	0.1726	0.3233	0.9484	0.9597	0.5294	0.9987	0.9830	0	10	20	20	50	70
29	2101	0.0335	0.9960	0.9736	0.9901	0.9912	0.1728	0.3226	0.9470	0.9600	0.7100	0.9960	0.9831	0	10	20	20	50	60
30	6268	0.0091	0.9959	0.9720	0.9862	0.9675	0.1123	0.2610	0.9528	0.9580	0.3821	0.9832	0.9815	0	20	40	10	1	60
31	4951	0.0079	0.9958	0.9707	0.9854	0.9724	0.2047	0.2667	0.9467	0.9567	0.1784	0.9864	0.9807	0	15	60	10	40	30
32	5820	0.0323	0.9958	0.9683	0.9878	0.9778	0.2766	0.2929	0.9479	0.9543	0.4861	0.9929	0.9794	0	20	20	15	40	80
33	4955	0.0045	0.9956	0.9706	0.9852	0.9810	0.2092	0.2636	0.9447	0.9565	0.1005	0.9900	0.9806	0	15	60	10	40	70
34	6281	0.0006	0.9956	0.9726	0.9866	0.9722	0.0813	0.2599	0.9558	0.9587	0.0344	0.9739	0.9820	0	20	40	10	10	100
35	457	0.0198	0.9956	0.9761	0.9901	0.9930	0.2013	0.3302	0.9460	0.9627	0.3495	0.9971	0.9847	0	5	30	20	20	90

Table (5-7) Selection of the best **fine calibration** results by using *Microsoft Excel*

(5-4-4) Final Calibration *(Third phase)*

In the previous step, we have seen that the **fine calibration** produced a large range of scores for the growth coefficients. The aim of the **final calibration** is to use the classified **best-fit values** obtained from the ***"controls.stats.log"*** file that produced from the **fine calibration** step and to investigate the closest value for each of the five growth coefficients.

The increment will be significantly reduced from **10** at previous stage to **5** or less during the **final calibration**.

The *final calibration scenario file* should include the values of the following variables:

- The group of images with **50 meter/pixel** spatial resolution was used for **final calibration**; all these images were put together in the input folder *(Cairo50)*,
- the Monte Carlo iteration (10),
- the echo parameter (yes),
- The seed number (1000),
- The num_working_grids (5).

The input procedure is identical to that described above for the previous calibration phases, but the growth coefficient input values were chosen as shown in Table (5-8).

In this step, the **final calibration** ran for **5 days, 11 hours, 13 min and 57 seconds** and generated **6480** iterations. The ***"control.stats.log"*** file produced from the **final** calibration was exported to *Microsoft Excel* and sorted according to the same procedure that used for the **fine** calibration as shown in Table (5-9).

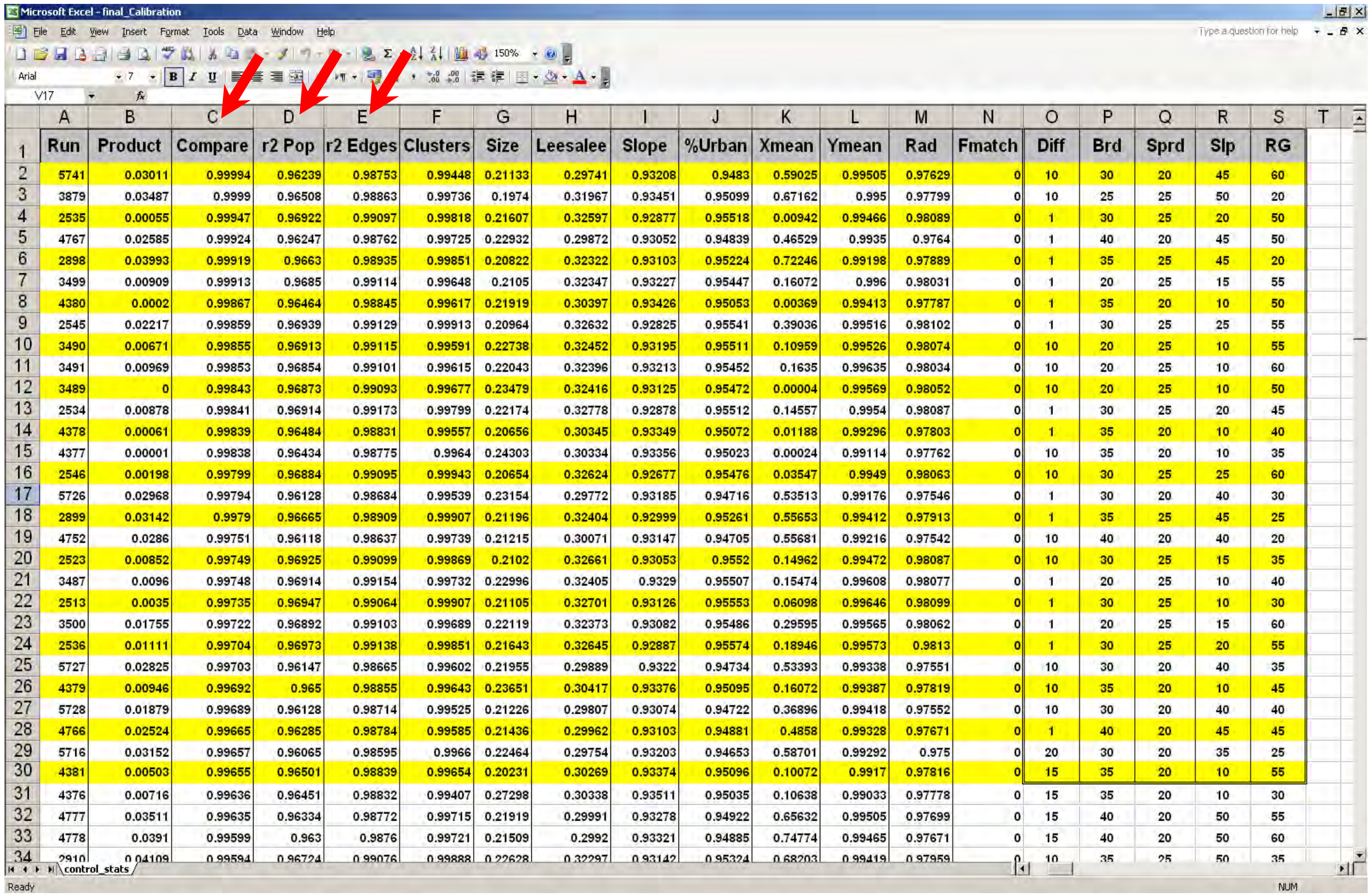
This time the first **ninety** best-fit iterations indicate the growth coefficient ranges, as shown in Table (5-10).

However, due to the random variability of the model, averaged coefficient results of many *monte_carlo* iterations will produce a more powerful forecasting coefficient values [(1)]. So that, we will use the values of best ninety iterations to calculate the mean for each growth coefficient to use it in the prediction phase.

[(1)] http://www.ncgia.ucsb.edu/projects/gig/v2/Imp/imCalibrate.htm#final (Accessed 12/10/2009)

Diffusion coefficient			Breed coefficient			Spread coefficient			Slope resistance			Road gravity		
Initial	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**	**Initial**	**Step**	**Final**
1	**5**	**20**	**20**	**5**	**40**	**10**	**5**	**25**	**10**	**5**	**50**	**20**	**5**	**60**

Table (5-8) Input scores at the **final calibration** phase



Run	Product	Compare	r2 Pop	r2 Edges	Clusters	Size	Leesalee	Slope	%Urban	Xmean	Ymean	Rad	Fmatch	Diff	Brd	Sprd	Slp	RG
5741	0.03011	0.99994	0.96239	0.98753	0.99448	0.21133	0.29741	0.93208	0.9483	0.59025	0.99505	0.97629	0	10	30	20	45	60
3879	0.03487	0.9999	0.96508	0.98863	0.99736	0.1974	0.31967	0.93451	0.95099	0.67162	0.995	0.97799	0	10	25	25	50	20
2535	0.00055	0.99947	0.96922	0.99097	0.99818	0.21607	0.32597	0.92877	0.95518	0.00942	0.99466	0.98089	0	1	30	25	20	50
4767	0.02585	0.99924	0.96247	0.98762	0.99725	0.22932	0.29872	0.93052	0.94839	0.46529	0.9935	0.9764	0	1	40	20	45	50
2898	0.03993	0.99919	0.9663	0.98935	0.99851	0.20822	0.32322	0.93103	0.95224	0.72246	0.99198	0.97889	0	1	35	25	45	20
3499	0.00909	0.99913	0.9685	0.99114	0.99648	0.2105	0.32347	0.93227	0.95447	0.16072	0.996	0.98031	0	1	20	25	15	55
4380	0.0002	0.99867	0.96464	0.98845	0.99617	0.21919	0.30397	0.93426	0.95053	0.00369	0.99413	0.97787	0	1	35	20	10	50
2545	0.02217	0.99859	0.96939	0.99129	0.99913	0.20964	0.32632	0.92825	0.95541	0.39036	0.99516	0.98102	0	1	30	25	25	55
3490	0.00671	0.99855	0.96913	0.99115	0.99591	0.22738	0.32452	0.93195	0.95511	0.10959	0.99526	0.98074	0	10	20	25	10	55
3491	0.00969	0.99853	0.96854	0.99101	0.99615	0.22043	0.32396	0.93213	0.95452	0.1635	0.99635	0.98034	0	10	20	25	10	60
3489	0	0.99843	0.96873	0.99093	0.99677	0.23479	0.32416	0.93125	0.95472	0.00004	0.99569	0.98052	0	10	20	25	10	50
2534	0.00878	0.99841	0.96914	0.99173	0.99799	0.22174	0.32778	0.92878	0.95512	0.14557	0.9954	0.98087	0	1	30	25	20	45
4378	0.00061	0.99839	0.96484	0.98831	0.99557	0.20656	0.30345	0.93349	0.95072	0.01188	0.99296	0.97803	0	1	35	20	10	40
4377	0.00001	0.99838	0.96434	0.98775	0.9964	0.24303	0.30334	0.93356	0.95023	0.00024	0.99114	0.97762	0	10	35	20	10	35
2546	0.00198	0.99799	0.96884	0.99095	0.99943	0.20654	0.32624	0.92677	0.95476	0.03547	0.9949	0.98063	0	10	30	25	25	60
5726	0.02968	0.99794	0.96128	0.98684	0.99539	0.23154	0.29772	0.93185	0.94716	0.53513	0.99176	0.97546	0	1	30	20	40	30
2899	0.03142	0.9979	0.96665	0.98909	0.99907	0.21196	0.32404	0.92999	0.95261	0.55653	0.99412	0.97913	0	1	35	25	45	25
4752	0.0286	0.99751	0.96118	0.98637	0.99739	0.21215	0.30071	0.93147	0.94705	0.55681	0.99216	0.97542	0	10	40	20	40	20
2523	0.00852	0.99749	0.96925	0.99099	0.99869	0.2102	0.32661	0.93053	0.9552	0.14962	0.99472	0.98087	0	10	30	25	15	35
3487	0.0096	0.99748	0.96914	0.99154	0.99732	0.22996	0.32405	0.9329	0.95507	0.15474	0.99608	0.98077	0	1	20	25	10	40
2513	0.0035	0.99735	0.96947	0.99064	0.99907	0.21105	0.32701	0.93126	0.95553	0.06098	0.99646	0.98099	0	1	30	25	10	30
3500	0.01755	0.99722	0.96892	0.99103	0.99689	0.22119	0.32373	0.93082	0.95486	0.29595	0.99565	0.98062	0	1	20	25	15	60
2536	0.01111	0.99704	0.96973	0.99138	0.99851	0.21643	0.32645	0.92887	0.95574	0.18946	0.99573	0.9813	0	1	30	25	20	55
5727	0.02825	0.99703	0.96147	0.98665	0.99602	0.21955	0.29889	0.9322	0.94734	0.53393	0.99338	0.97551	0	10	30	20	40	35
4379	0.00946	0.99692	0.965	0.98855	0.99643	0.23651	0.30417	0.93376	0.95095	0.16072	0.99387	0.97819	0	10	35	20	10	45
5728	0.01879	0.99689	0.96128	0.98714	0.99525	0.21226	0.29807	0.93074	0.94722	0.36896	0.99418	0.97552	0	10	30	20	40	40
4766	0.02524	0.99665	0.96285	0.98784	0.99585	0.21436	0.29962	0.93103	0.94881	0.4858	0.99328	0.97671	0	1	40	20	45	45
5716	0.03152	0.99657	0.96065	0.98595	0.9966	0.22464	0.29754	0.93203	0.94653	0.58701	0.99292	0.975	0	20	30	20	35	25
4381	0.00503	0.99655	0.96501	0.98839	0.99654	0.20231	0.30269	0.93374	0.95096	0.10072	0.9917	0.97816	0	15	35	20	10	55
4376	0.00716	0.99636	0.96451	0.98832	0.99407	0.27298	0.30338	0.93511	0.95035	0.10638	0.99033	0.97778	0	15	35	20	10	30
4777	0.03511	0.99635	0.96334	0.98772	0.99715	0.21919	0.29991	0.93278	0.94922	0.65632	0.99505	0.97699	0	15	40	20	50	55
4778	0.0391	0.99599	0.963	0.9876	0.99721	0.21509	0.2992	0.93321	0.94885	0.74774	0.99465	0.97671	0	15	40	20	50	60
2910	0.04109	0.99594	0.96724	0.99076	0.99888	0.22628	0.32297	0.93142	0.95324	0.68203	0.99419	0.97959	0	10	35	25	50	35

Table (5-9) Selection of the best **final calibration** results by using *Microsoft Excel*

Coefficient	Diffusion	Breed	Spread	Slope	Road gravity
Range Values	1-10	30-35	20-25	20-45	40-60
Mean value (Prediction Values)	**3**	**32**	**23**	**27**	**43**

Table (5-10) **Final calibration** best fit-results

The final step is running an **averaging best results module** that will achieve the coefficients reduction. Averaging best results module was used the **best-fit results** that obtained from the **final calibration** phase, this time; the increment was set at (**1**) for all growth coefficients.

Table (5-11) shows the input and output scores for the **averaging best results** module.

Coefficient	Averaging best results	
	Input scores	Output scores
Diffusion coefficient	**3**	**1**
Breed coefficient	**32**	**20**
Spread coefficient	**23**	**23**
Slope resistance	**27**	**3**
Road gravity	**43**	**46**

Table (5-11) Coefficients average **best results** values

In summary of the above, these results indicate that the historical trend of **GCR** is firstly correlated by **road gravity** *(48%)* and secondly by **spread coefficient** *(24%)*. On the other hand, the degree of influence of **slope** and **diffusion** coefficients is the lowest.

Then, the obtained results were used for the simulation and prediction of urban growth in **GCR**.

(5-5) Simulation and Prediction

This section will **first** demonstrate how to predict the future expansion of **GCR** urban area using the calibration scores obtained from the previous section. **Second,** discuss the reliability of the predicted future expansion of **GCR**.

(5-5-1) Expected Urban Expansion of GCR

So far, the **SLEUTH** program has produced only statistics and log files that have been analyzed to define the **best-fit** numerical values for each growth coefficient. The prediction of **Cairo's** urban expansion uses the same output scores as in the **averaging best results module**, Table (5-11).

The prediction phase will now generate **annual color maps** for the defined number of prediction years, beginning with the year **1993**, the final year **2040**, and **200** ***Monte Carlo*** iterations. The simulation phase of **GCR** ran in **4 hours, 12 min, and 28 seconds.**

The Program simulated the future expansion of **GCR** urban area from **1993** to **2040**. The simulation produced a series of **annual maps** and **growth animation file**. Figures (5-18) to (5-23) illustrate the prediction results at **six** different instances of the simulation period. Each simulated image is colored to illustrate **three** main states:

- **First,** the original status or urban seed *(light yellow)*,
- **Second,** the predicted urbanization areas *(in red)*,
- **Finally,** the future urbanization areas at different levels of probability *(green)*.

The first frame *(1993)* shows the first simulated urban extent. No significant change is noticeable. While, the other frames show new urbanized areas in ***red***. The probability to urbanization at the next iterations (year) in ***green***, with light green represents the highest probability and dark green the lowest probability. ***Grey*** areas contained cells that have a negligible chance of being urbanized in future.

Code	Color	Description
1		Existing urban areas *(Urban Seed)*
2		**< 60%** Probability of urbanization.
3		**60 – 70 %** Probability of urbanization.
4		**70 – 80 %** Probability of urbanization.
5		**80 – 95 %** Probability of urbanization.
6		**90 – 80 %** Probability of urbanization.
7		**95 – 100 %** Probability of urbanization.
8		Background image *(HillShade map)*

Table (5-12) **Color scheme** of the future simulated maps

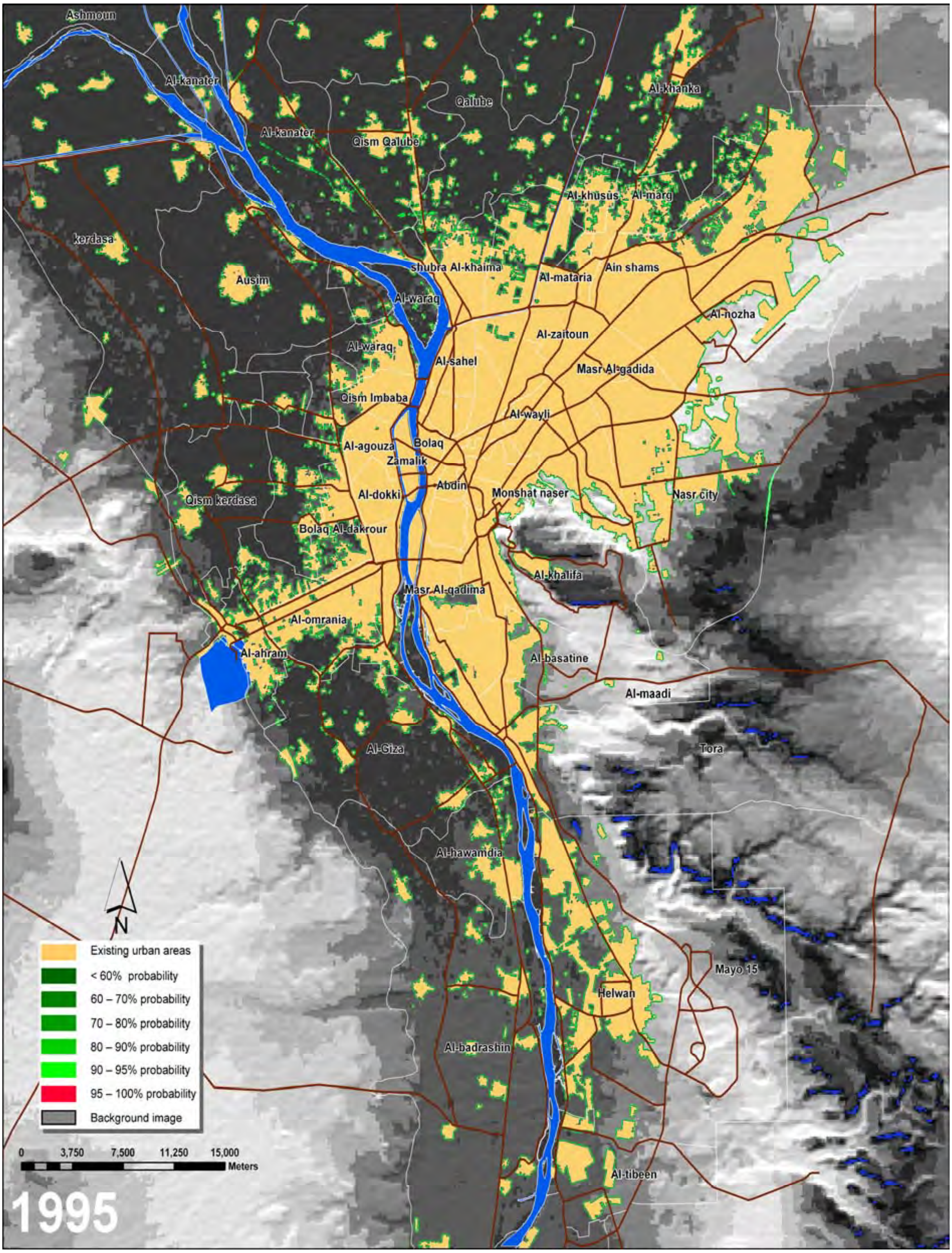


Figure (5-18) The predicted **GCR** urban extent in **1995**

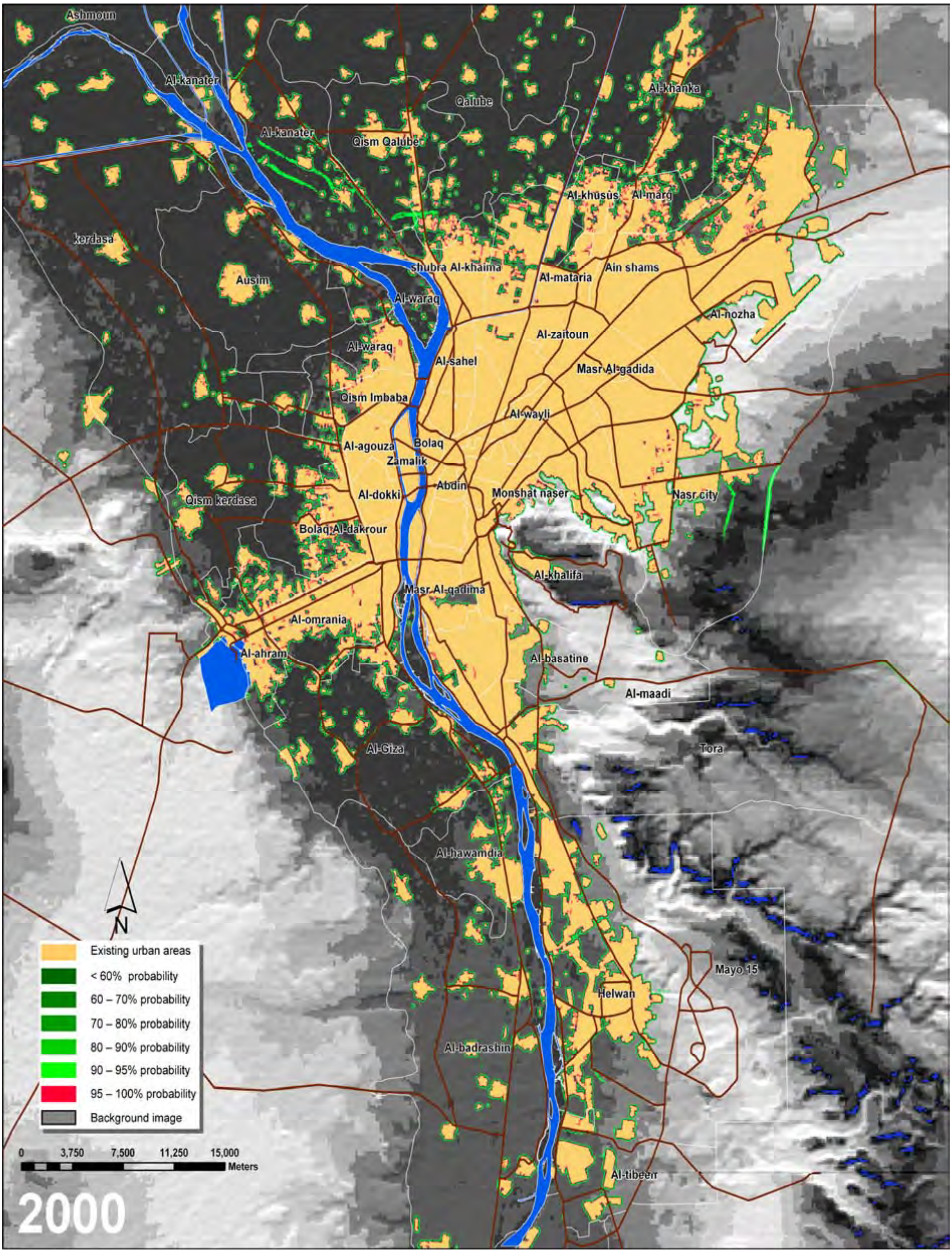


Figure (5-19) The predicted **GCR** urban extent in **2000**

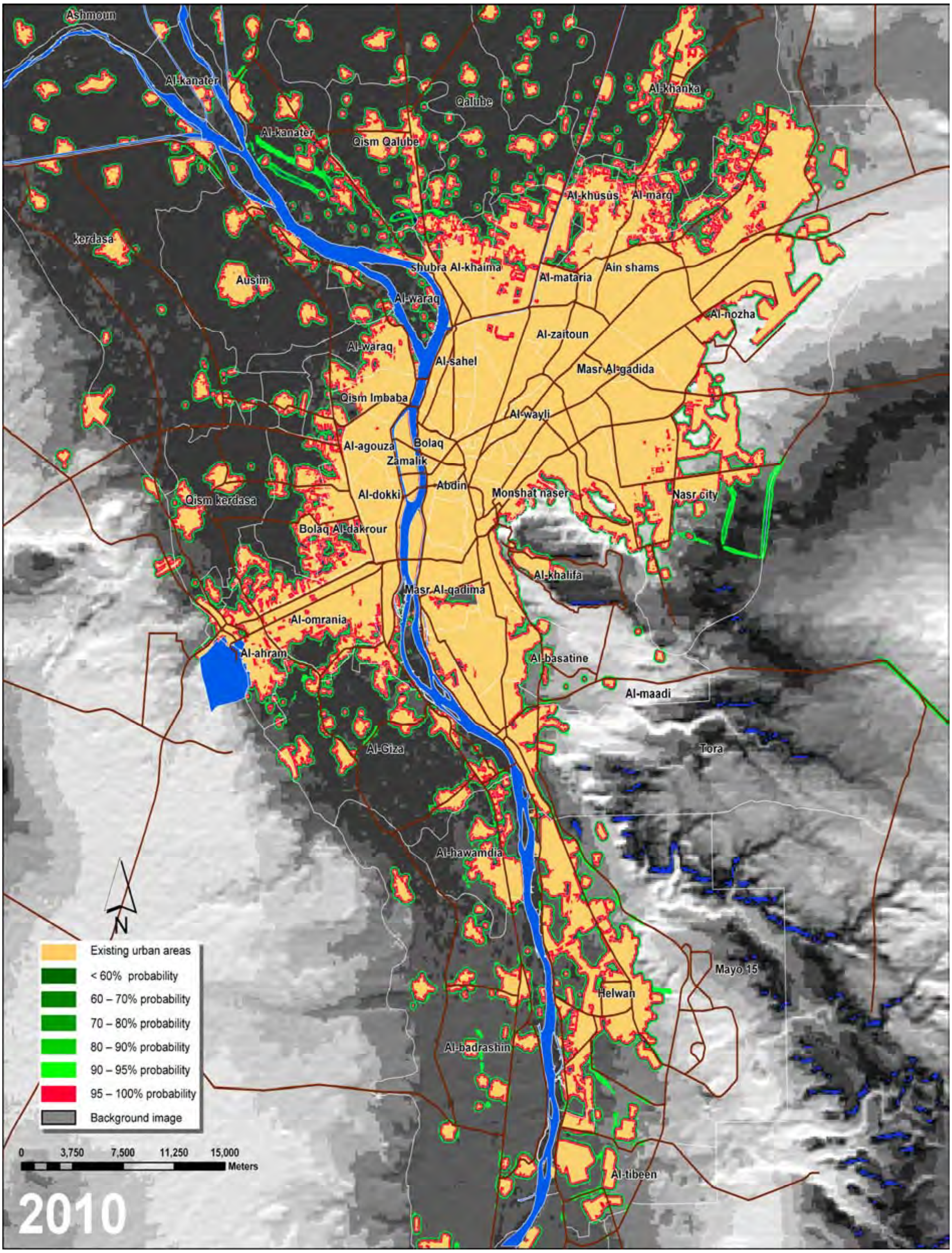


Figure (5-20) The predicted **GCR** urban extent in **2010**

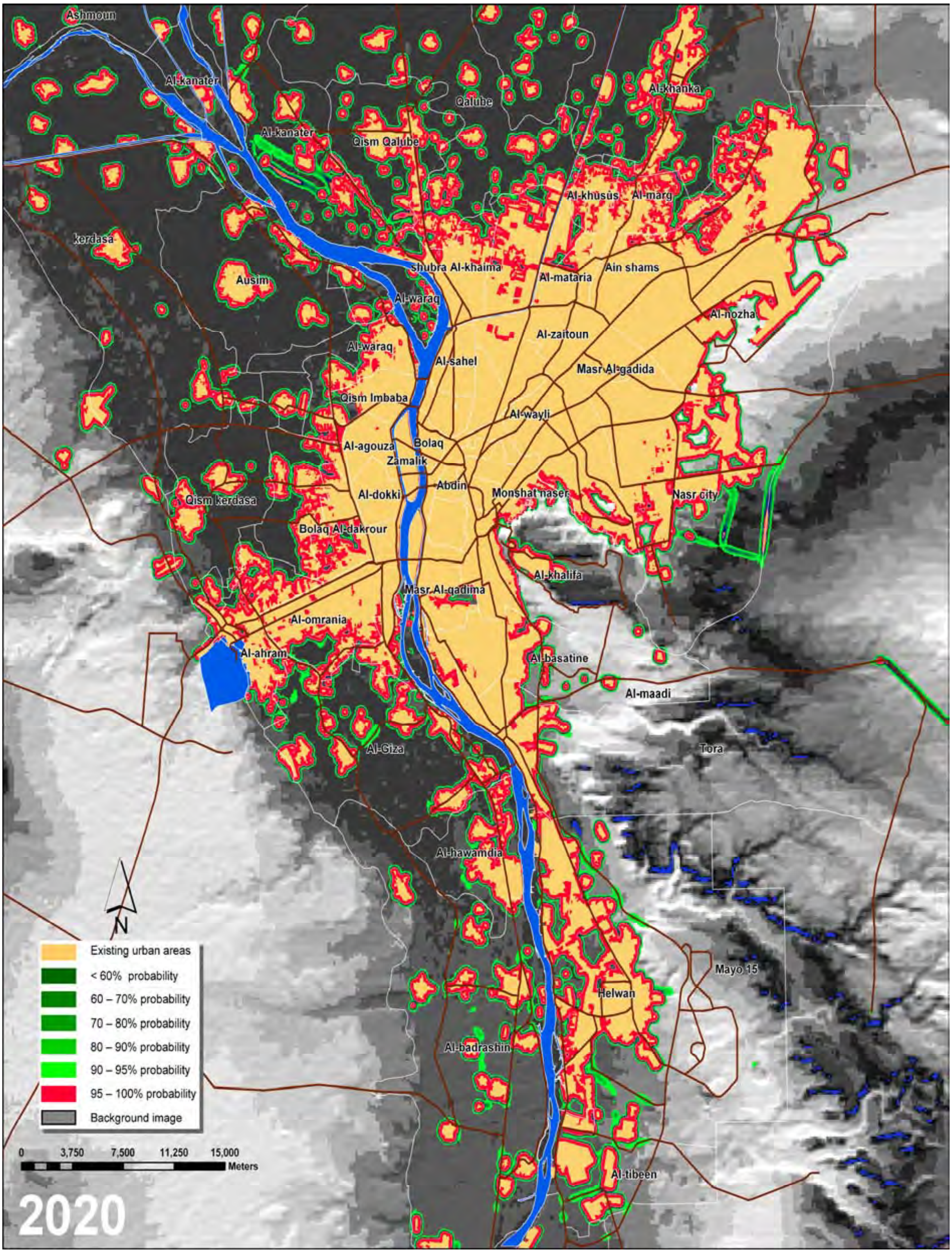


Figure (5-21) The predicted **GCR** urban extent in **2020**

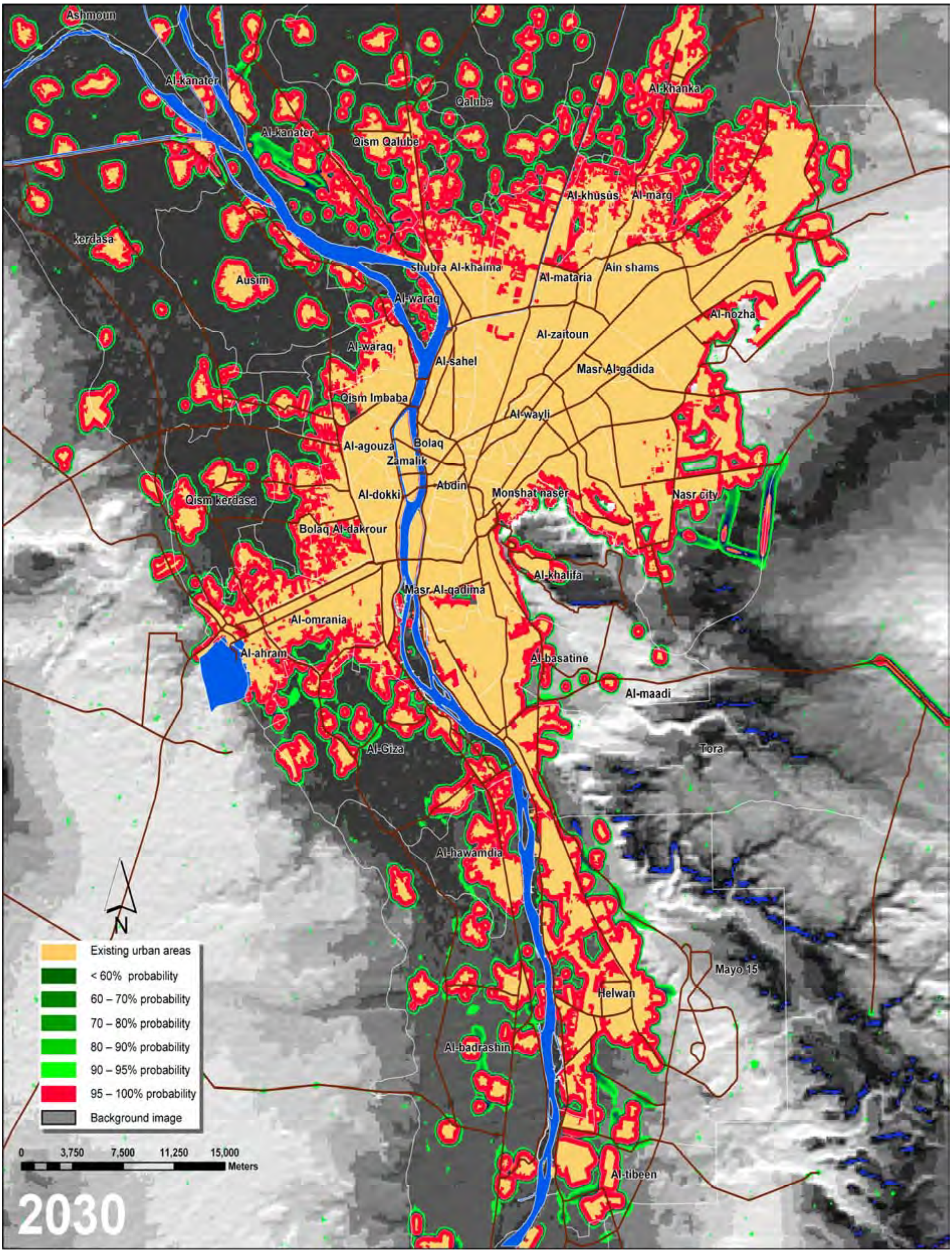


Figure (5-22) The predicted **GCR** urban extent in **2030**

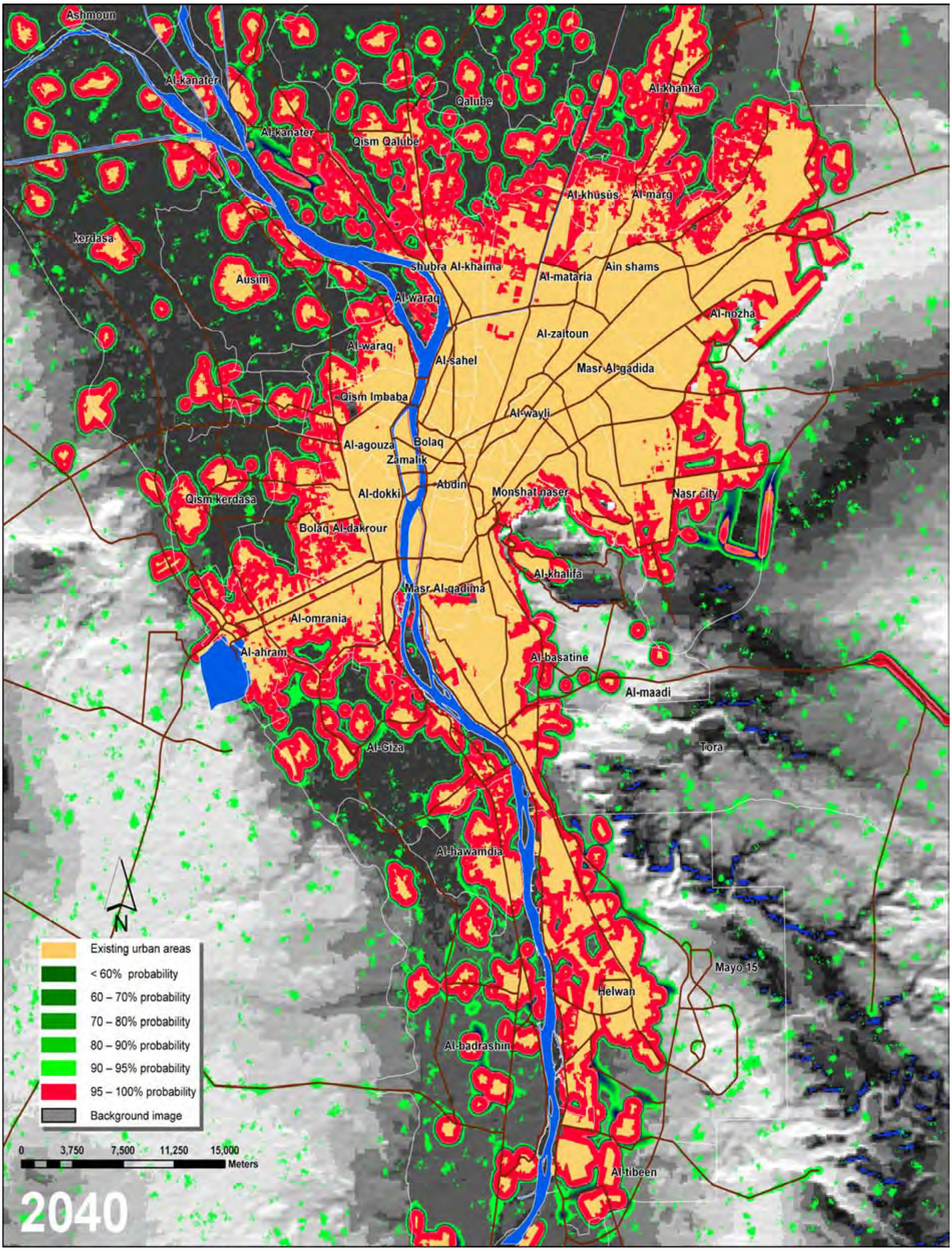


Figure (5-23) The predicted **GCR** urban extent in **2040**

(5-5-2) Reliability of the Simulation Results

Considering modelling and simulation as an abstraction of the real world, **the results of the SLEUTH simulation considered to be satisfactory**. For instance, multi-date images were produced to enhance the visualization of urban expansion. Also, the model has provided a good opportunity to develop a visual animation movie for the simulation results, which essentially adds value to the representation of urban growth.

This section evaluates the model's results compared with the most available recent Quick-Bird satellite image for Greater Cairo Region.

The simulation results considered to be satisfactory with some defining features, such as:

- The simulation illustrates the importance of the **road attraction effect** on the urbanized cells. However, **the urbanization rate is quite slow during the first 15 years**, **and increases after half of the total simulation period,** and it is clear during the last **10 years** of the simulation period.
- Similarly, the probability to urbanize emerges in the **year 2000** with new urbanized centers starting to form urban pattern **five** years later in the **north-east** and **south-west** sections of the Cairo map, *(for example: Shubra Al-khaima, Bahtiem, Al-Marg, Bolaq Al-dakrour, Bashteel, Al- Omrania and Faysal).*
- **Sloping areas**, such as the **eastern part** of the city *(for example: Tora, El-Dewika and Al-Gabal Al-Asfar)*, demonstrate resistance to urbanization for all stages of the simulation.
- The slope effect is also contribute in the rapid rate of urbanization in the **approximately flat areas** such as in the **north east**, **south**, and **south western** parts of the region.

A **GCR Quick-Bird** satellite image taken in **2005** illustrates **urban and non-urban space**, was used to verify and compare the **SLEUTH** simulated maps and reality. Figure (5-24) illustrates visual comparison between the simulated images suggested by **SLEUTH** model with **GCR** satellite image in **2005**. The visual comparison reveals some inconsistencies in the simulated years with reality.

By reviewing the projected the annual maps produced from the model, it appears that a **very little** change was emerged in the first **twelve years** of the simulation period, while between **2030** and **2040**; the spatial expansion was **very fast**. Due to the fluctuation of the **growth rate**, the simulated dates did not correspond to the real spatial expansion of **GCR** at the same dates. There was at least **ten years** difference between the suggested date and the possible matching period.

The simulation results pointed to the fact that Greater Cairo Region spatial expansion was mostly influenced only by the current urban forms and existing road networks. In addition, the simulated urban areas spread without consideration of the surrounding land use types. This is due to the properties of the cellular automata procedure embedded into the **SLEUTH** model.

In the case of **GCR** growth model, new urban expansions tend to be influenced by accessibility to road and topography. For instance, moderate slope at the **south, south west** and **north east**, were the earliest areas to be urbanized by **SLEUTH** model, **and in reality, they constitute one of the most dynamic urban fringe developments in GCR.** On the other hand, the mountainous areas *(such as: El_Mokattam)* in the **Eastern** part of the map were least attractive to urbanization.

Therefore we can conclude that, the **SLEUTH** model **was sensitive to the slope resistance and road gravity factors** and it considers these two factors as the main factors affecting on the growth trends. This assumption was proved in the application of **SLEUTH** model on **GCR**.

Finally, the **SLEUTH** model performed well in reproducing the future patterns of Cairo's growth. But, **it fails to locate the spread of urban areas with reasonable accuracy**, also, the simulation was **misled** by the neighborhood effect of the cellular automata macro and the historical calibration approach adopted by **SLEUTH**, the model gave the general form and tendency of Cairo's future spatial expansion.

	Al-Khanka District	Shubra Al-Khaima District
Recent **Quick-bird** satellite image in **2005**		
Predicted expansion by **SLEUTH** in **2005**		

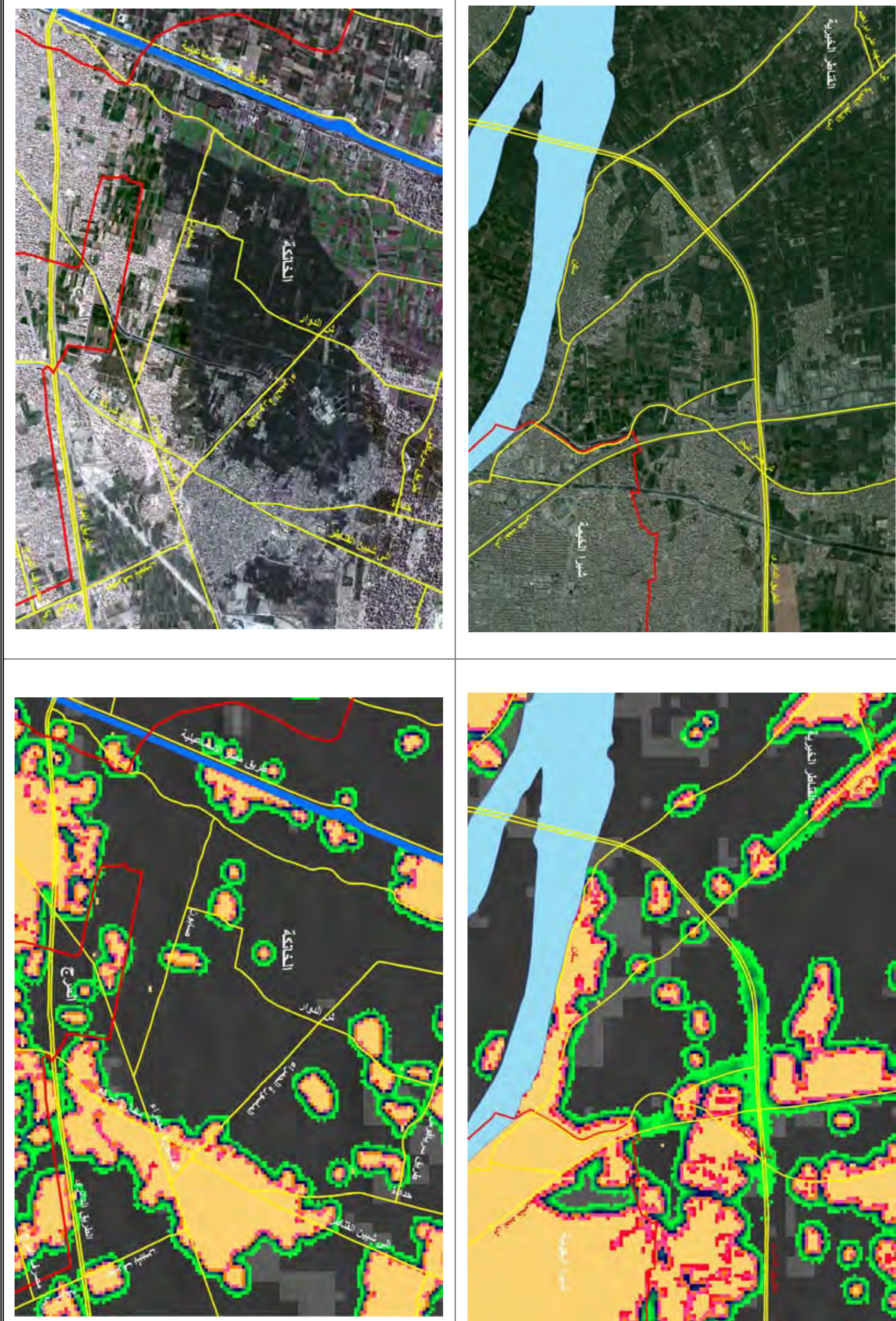


Figure (5-24) Visual comparison between simulated maps and recent **Quick-bird** satellite image of **GCR**

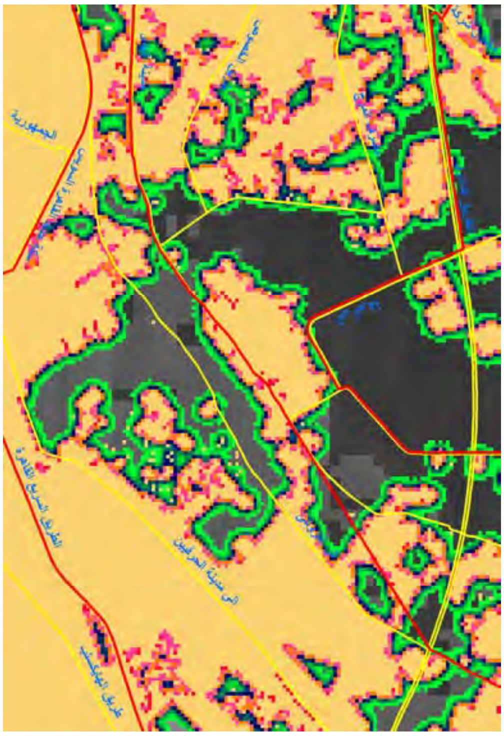
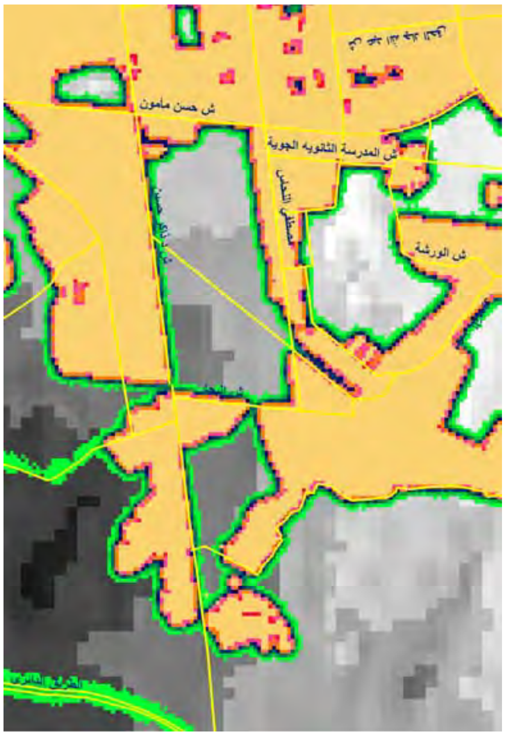
	Al-Marg District	Nasr City District
Quick-bird satellite image in **2005**		
Predicted expansion by **SLEUTH** in **2005**		

Figure (5-24) Visual comparison between simulated maps and recent **Quick-bird** satellite image of **GCR** (Cont.)

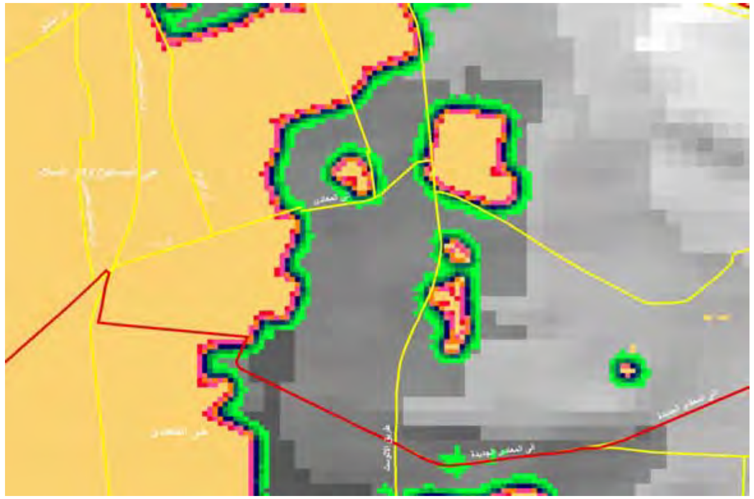
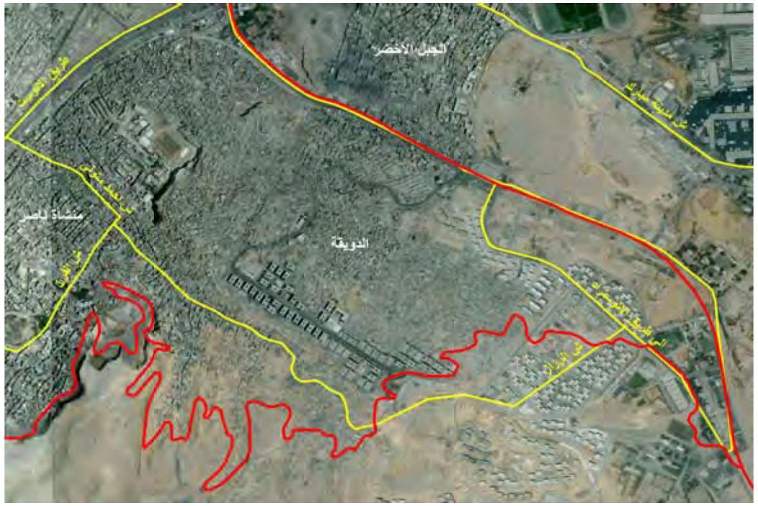
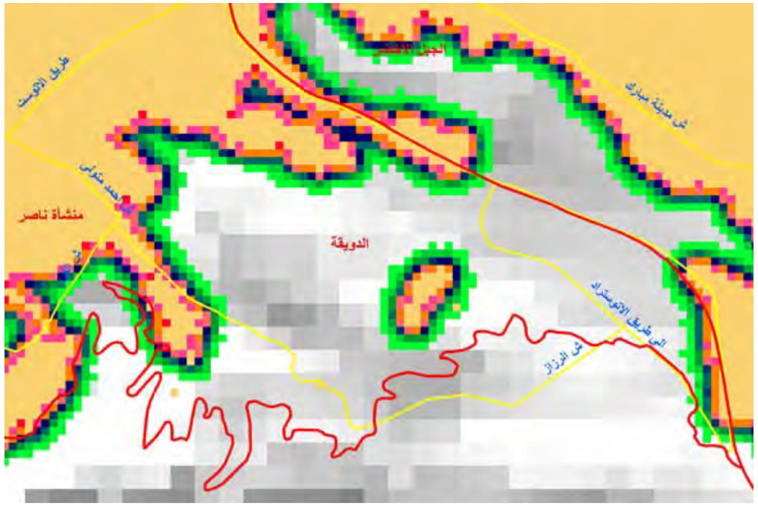
	Quick-bird satellite image in **2005**	Predicted expansion by **SLEUTH** in **2005**
Al-Basatine District		
El-Dewika District		

Figure (5-24) Visual comparison between simulated maps and recent **Quick-bird** satellite image of **GCR** (Cont.)

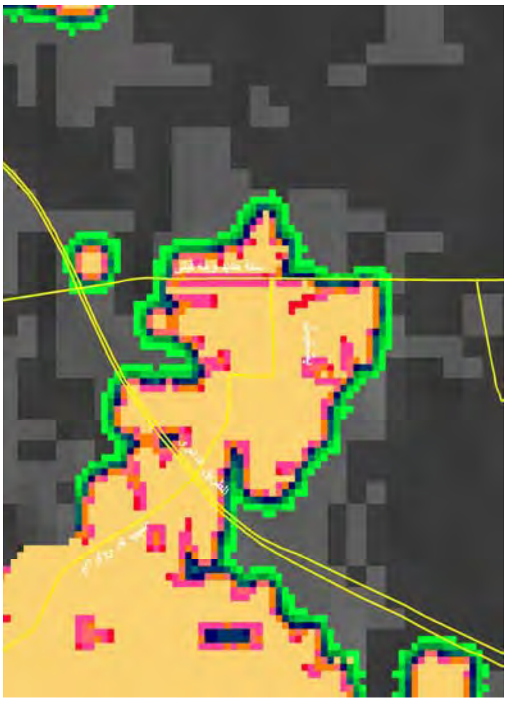
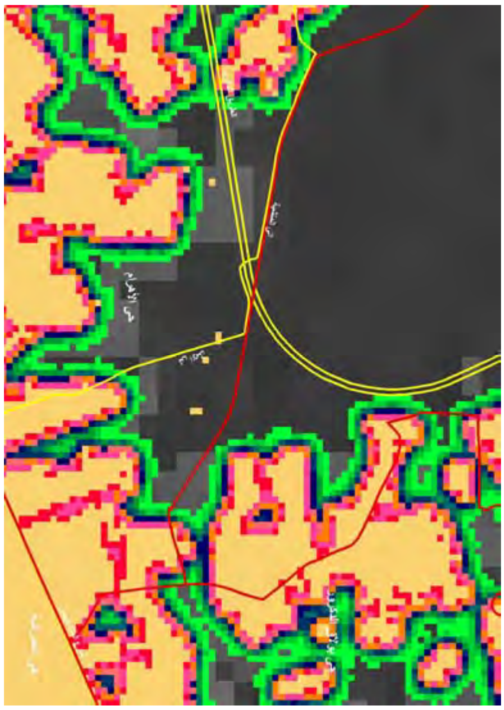
	Bashteel District	Bolaq Al-Dakrour District
Quick-bird satellite image in **2005**		
Predicted expansion by **SLEUTH** in **2005**		

Figure (5-24) Visual comparison between simulated maps and recent **Quick-bird** satellite image of **GCR** (Cont.)

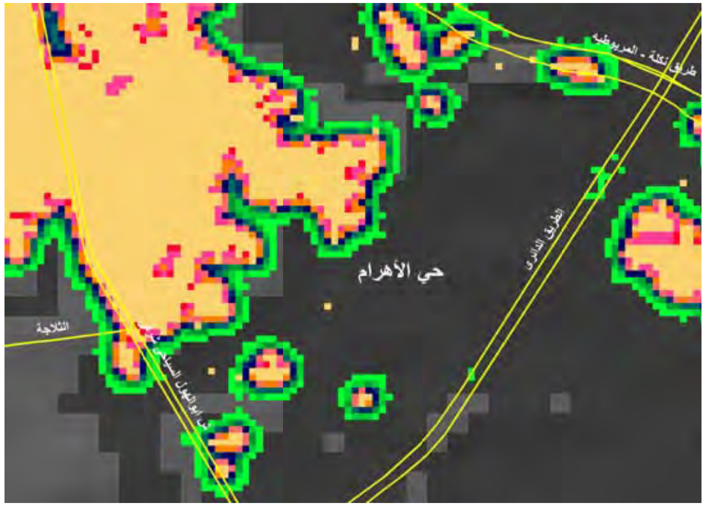
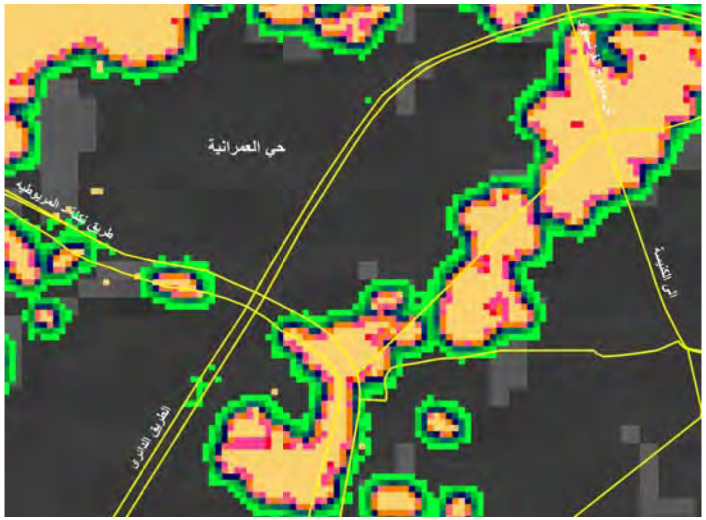
	Quick-bird satellite image in **2005**	Predicted expansion by **SLEUTH** in **2005**
Al-Ahram District		
Al-Omrania District		

Figure (5-24) Visual comparison between simulated maps and recent **Quick-bird** satellite image of **GCR** (Cont.)

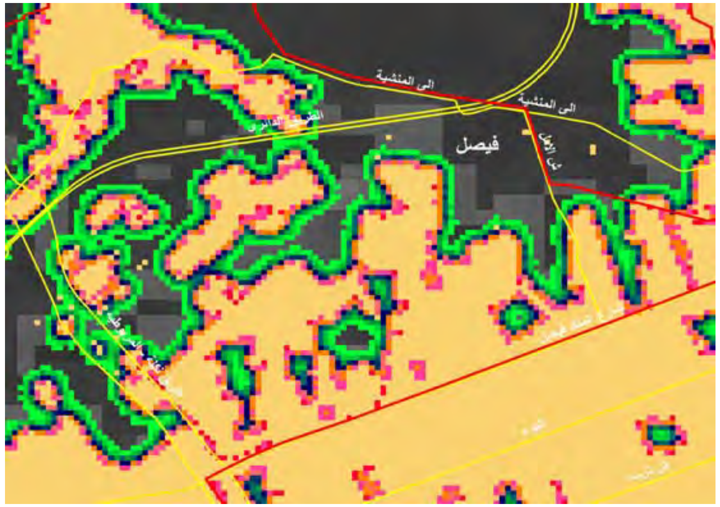
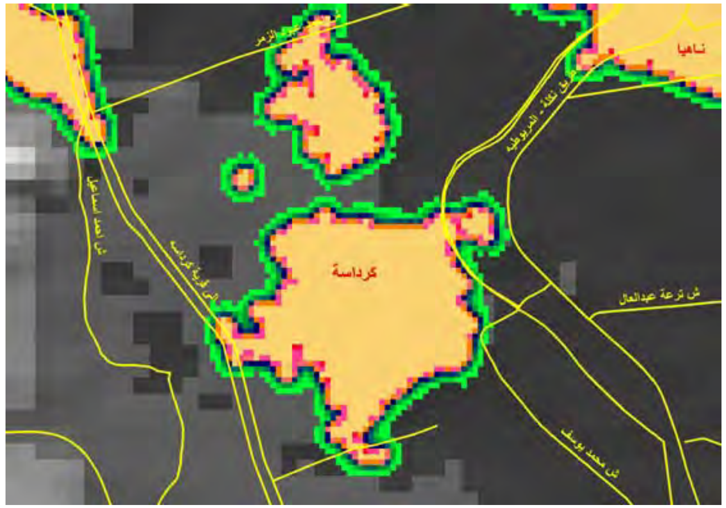
	Quick-bird satellite image in **2005**	Predicted expansion by **SLEUTH** in **2005**
Faysal District		
Kerdasa District		

Figure (5-24) Visual comparison between simulated maps and recent **Quick-bird** satellite image of **GCR** (Cont.)

(5-6) Discussion and Conclusions

The aim of this Chapter was to apply the **SLEUTH** model to predict the future urban expansion in **GCR**, **Egypt**. The required data were prepared and named according to **SLEUTH** conventions to explore the future spatial expansion of urban areas.

The main limitation in **SLEUTH** model emerged from its assumptions. **Some of the SLEUTH assumptions proved theoretically questionable and unreliable;** For instance, many researchers have articulated the importance to incorporate both socio-economic and demographic parameters into urban dynamics models (Varanka, 2001) [(1)].

The SLEUTH growth coefficients are limited, because the model implements an urban theory and ignores other urban dynamics variables, such as **physical**, **demographic regulations**, **social**, **socio-economic**, **and many other factors which differ from region to other**. These factors were not part of the **SLEUTH** growth types. Moreover, the growth coefficients incorporated into the model were not **sufficiently** and **theoretically explicit** enough to simulate and predict the unplanned growth in **LDC**. The model identifies only **four** growth types:

- **Spontaneous growth** *(or Dispersion),*
- **New spreading center growth** *(or Diffusion),*
- **Edge growth** *(or Organic - past urban spread),*
- **Road gravity growth**.

In **SLEUTH** the probability for future expansion is **calculated** and **located** according the historical growth trend. In this case study, only two factors *(road network and slope)* effectively influenced the urban expansion. This assumption of urban changes is not sufficient to explore and predict the diffusion of urban areas, especially informal and popular housing in **GCR**.

In addition, the state of any cell at the next iteration is calculated according to **the current urban pattern** and **the historical state** of the adjacent cells. However, it is well known that the **CA** neighborhood could be expanded to include a larger neighborhood cells. The expanding of **CA** neighborhood remains a point of research *(differs from one region to another),* because many researchers *(specially in computer science)* argue that

(1) This article available at: http://mcmcweb.er.usgs.gov/phil/modeling.html, (Accessed 12/07/2009)

only **4-cell** and **8-cell** 2-Dimensional could be considered as a **CA** model (Sietchiping, Remy. 2004).

On the other hand, there were a number of difficulties that emerged during the implementation of the **SLEUTH** in **GCR** that can be summarized as follows:

- **GIS data preparation for SLEUTH model was a time-consuming task;** the preparation of data involved a vast range of software outside **SLEUTH** model.
- The calibrations phase within **SLEUTH** used thousands of iterations, and ran in several hours on a high-speed computer. In the case of **GCR**, only the **final calibration** ran in **5 days** and **11 hours**.
- The **SLEUTH** model runs only on **UNIX or LINUX** operating system machines, which constrains the user by limiting access to the appropriate operating system.
- The output files were exported to **GIS** software on **WINDOWS** operating system to check the prediction reliability and to perform any other required analysis. i.e., many forward and backward operations between **UNIX** and **WINDOWS**.

From the previous limitations, it could be argued that the application of **SLEUTH** *(Release 3.0)* **failed to explore and predict the future possible conditions that might arise from the current urban system's evolution and socio-economic behavior.** Because the **SLEUTH** neglects the demographic, socio-economic, and neighbor land use factors that are represents an important role in the urbanization processes in **GCR**.
Also there is a clear fluctuation of the growth rate; and inconsistency between the spatial locations of the expected growth with reality at the same dates.

According to the previous discussion, the **SLEUTH** model is less likely to produce reasonable development scenarios in **LDC**, unless many changes needed in the source codes. These changes can only be implemented on the growth coefficients, rather than the choice of input files. This represents a major limitation for the **SLEUTH** as a possible option for building a **flexible** and **informed** urban dynamics model for **LDC**.

Therefore, the SLEUTH model is not suitable for modelling and simulating the urban growth in the case of unplanned areas. It is clear that there is a need to develop a generic model handles more factors that are general for urbanization and growth, in order to predict the emergence of informal housing in unplanned areas, such as GCR.

Chapter 6

Modelling Future Informal Housing Growth

A Proposed growth model (IHGM)

(6-1) Introduction

Revision of urban dynamics models revel a variety of urban dynamics models have been developed for cities in developed countries with different levels of **complexity**, **structure**, **and purpose**. So far, **Chapter Four** showed that many limitations and constrains to use these models in the cities of **L**ess **D**eveloped **C**ountries; in fact these models can be adapted to model **planned growth in LDC, but not uncontrolled or unplanned areas such as I**nformal **H**ousing (Sietchiping, Remy. 2004).

Although, **I**nformal **H**ousing **(IH)** is growing fast, very little attention is oriented to **explore tools** and **suggest approaches** to expect and simulate their future extension. Many researches shows that **IH** are now widespread *(about of 60% of recently urban areas in **GCR** are informal)* and represent one of the most dominant urbanization features in **LDC**.

Chapter Two reviewed different attempts to curb the expansion of **IH**, and demonstrated that these attempts poorly achieved their aims, because decision makers and urban planners do not have complete vision of the future informal growth. Many **Planning policies and strategies** have been developed as a reaction to the emergence and expansion of **IH**, rather than **protective actions** based upon a clear understanding of the process and behavior of the system.
In addition, it is clear that local governments and urban planners have a very limited knowledge of the possible locations and directions of **IH growth**; this led to the ineffectiveness of current urban policies toward the uncontrolled zones in cities in **LDC**.

In this Chapter, I hope to design and implement a simulation model to predict where probable **IH** will occur over a certain time period, based on known variables *(except future transportation networks, future markets, and places of workshop).* This model will contribute to the development of **efficient urban strategies** to manage and guide the growth of **IH**.

This Chapter will focus on some important issues:

1. **What tools can be used for IH expansion process?**
2. **How can these tools be used to support the planning decision-making process?**

3. **How can encourage the popular participation to manage IH growth, by giving the stakeholders a continuously realistic information about IH mechanisms, instead of proposing ready-made solutions?**

This research uses an experimental approach, based on a multi-criteria concept, including **the known parameters and conditions related to the IH emergence and growth, besides the IH evolution from the past to the current situations**.

There are numerous advantages to use prediction and simulation techniques in **IH** management, for example, it can model and test some **IH** hypotheses and contribute to answering some ***what if?*** Questions using different parameters and scenarios. In this way, the proposed model can serve urban stakeholders *(local government, urban planner, decision maker, infrastructure, housing dweller, and services providers)* to predict and simulate the future expansion of **IH** in the context of unplanned areas.

This Chapter proposes a **S**imulation **G**rowth **M**odel **(SGM)** based upon the conceptual framework of **G**eographic **I**nformation **S**ystems **(GIS)** and **C**ellular **A**utomata **(CA)** discussed in **Chapter Three**.

The proposed model is specifically aiming to:

1. Enrich the discussion around urban dynamics and the prediction of **IH** expansion in **LDC** cities.
2. Support the oriented planning policies to **IH**, and decision-making process.
3. Suggest an integrated approach to define how to deal with the rapid expansion of **IH** through the involvement of stakeholders in urban areas.
4. Simulate **IH** dynamics and growth using different coefficients and conditions through different scenarios.
5. Innovation of new perception about **IH** behavior by means of computer based experiments using **GIS** and **CA**.

To achieve these objectives, a series of **GIS** maps and attribute data were prepared for **Greater Cairo Region**, and a **CA** macro was designed and implemented using **V**isual **B**asic **(VB)** macro language.

This Chapter will discusses and illustrates the proposed **IHGM** model structure, its different modules, functions, and the model implementation procedure, as well as, how to test many scenarios by changing the **growth coefficients** and modify their contribution values to emerge **IH**.

The **V**isual **B**asic **CA** macro is coupled with the **GIS** database to model **IH** expansion, the **VB** macro records and performs **CA** functions like:

- **Calibration of growth factors**,
- **Calculate spatial probability**,
- **Using rules to allocate the future IH growth**,
- **Displaying the simulation results on GIS interface**.

<u>This Chapter consists of Five main sections as follows:</u>

- **<u>Section one</u>**: Presents the <u>current status</u> of **IH** in **GCR** and specify the districts that face an uncontrolled informal housing in last **30** years. In addition discusses the probable **urban growth projection scenarios**, which will use to estimate the required lands to meet the <u>future housing demand</u> in these districts.
- **<u>Section two</u>**: Presents the proposed **IHGM** main features, including the model concepts, assumptions, and transition rules.
- **<u>Section three</u>**: Discusses the functions and modules of the proposed **CA V**isual **B**asic macro, as well as the **flow-chart** implementation procedure.
- **<u>Section four</u>**: Presents the **GCR** study area including, **data preparation**, and **data requirements** to run the model. Also, the selection of informal housing growth coefficients.
- **<u>Section five</u>**: This section presents the steps to run the proposed **IHGM** including:
  1- Definition module,
  2- Growth factors calibration module,
  3- Probability to change module,
  4- Prediction module,
  5- Displaying and evaluation of the simulation results.

<u>(6-2) Urban Growth Projection Scenarios</u>

Urban growth scenarios are the primary assumptions upon which predictions are based. Growth scenarios can be expressed implicitly or explicitly as **<u>policy constraints</u>**, **<u>growth rules</u>**, and **<u>growth rates</u>**. The concept of **growth scenarios** has been widely used in the literature of urban growth studies and land use planning. <u>This concept allows us to produce multiple growth scenarios based on different urban policies, even with non-spatial data.</u>

In **GCR**, the uncontrolled urbanization of rural areas on the region boundaries represents the **fundamental force** that drives the rapid urbanization of the region, especially the rural villages of **Giza** and **Qalubyia** governorates. By studying the **GCR** built-up area at the district level *(Qism or hay)*, we found about **37** districts faced uncontrolled **I**nformal **H**ousing **(IH)** growth in the last **30** years. [1]
Table (6-1) shows the selected districts and their corresponding built-up areas, which produced from the historical maps in **1986**, **1991**, and **2001**.

In this section, we will use different statistical methods to estimate the **GCR** urban growth in the following years: ***2011***, ***2016***, ***2021***, ***2026***, ***2031***, ***2036***, ***2041***, and ***2046*** *(5 years period).* The statistical procedure will calculate the future required lands for housing at the district *(Qism or hay)* level, and then aggregate the projected built-up areas to the **G**rater **C**airo **R**egion level. The reason behind selecting these dates is to follow the **four** future census dates *(2016 - 2026 - 2036 - 2046).*

Therefore, this section will discuss **four** scenarios to estimate the future required lands for urban expansion in these districts; the proposed scenarios are based on the following statistical techniques:

1- **Regression analysis**
2- **Exponential trend analysis**
3- **Average Annual Built-up Growth Rate (AABGR)**
4- **Projection of urban growth relative to population growth**

[1] In this Chapter, I will refer to these districts by **IH districts**.

Gov. Name	Qism Code	Qism Name	Housing Area (Km^2)			ABGR % (1)	
			1986	1991	2001	1986/1991	1991/2001
Cairo	106	Masr Al-qadima	3.371	4.8830	5.684	5.23%	1.52%
	108	**Al-Khalifa**	**2.737**	**3.260**	**5.230**	**2.49%**	**4.55%**
	126	Nasr city -1	7.374	17.064	18.845	11.33%	0.99%
	127	Nasr city-2	2.073	2.191	2.470	0.79%	1.20%
	132	**Al-Salam**	**2.191**	**11.041**	**15.832**	**19.11%**	**3.57%**
	134	**Monshat Naser**	**1.469**	**1.690**	**2.9263**	**1.97%**	**5.38%**
	135	Al-Basatine	7.332	8.998	10.880	2.92%	1.89%
	136	**Al-marg**	**4.383**	**6.120**	**8.331**	**4.72%**	**3.06%**
Helwan	**901**	**Al-Tebin**	**1.280**	**1.384**	**2.177**	**1.11%**	**4.45%**
	902	Helwan	7.302	10.751	13.727	5.46%	2.43%
	905	Tora	1.063	2.382	3.043	10.94%	2.44%
	911	**Al-Saf**	**0.313**	**0.408**	**0.728**	**3.80%**	**5.62%**
October	**1006**	**Al-hram**	**0.704**	**2.280**	**3.950**	**15.09%**	**5.36%**
	1008	Al-Hawamdia	1.988	2.903	3.453	5.34%	1.73%
	1009	**Al-Giza**	**2.866**	**4.701**	**6.074**	**6.93%**	**2.55%**
	1010	Al-Badrashin	3.694	5.778	7.143	6.28%	2.11%
	1015	Madenat Ausim	0.3260	0.500	0.624	6.03%	2.20%
	1016	**Ausim**	**2.159**	**3.430**	**4.425**	**6.50%**	**2.53%**
	1017	**Al-waraq Al-Hader**	**0.2370**	**0.485**	**0.624**	**9.83%**	**2.51%**
	1018	**Bashteel**	**0.364**	**1.057**	**2.1530**	**13.92%**	**6.83%**
	1020	**Kerdasa**	**3.825**	**4.799**	**7.5150**	**3.23%**	**4.41%**
	1021	**Qism kerdasa**	**1.611**	**2.446**	**3.679**	**5.89%**	**4.03%**
Kalyoubia	**1403**	**Al-khanka**	**3.539**	**5.950**	**8.246**	**7.26%**	**3.23%**
	1404	**Al-kanater**	**2.372**	**3.958**	**6.031**	**7.16%**	**4.15%**
	1405	**Shbeen Al-kanater**	**0.651**	**0.850**	**1.511**	**3.77%**	**5.60%**
	1406	Shubra Al-khaima-1	4.808	5.072	5.669	0.76%	1.11%
	1407	Shubra Al-khaima-2	3.590	4.486	5.459	3.17%	1.96%
	1409	Qism Qalyûb	1.449	2.205	2.729	5.91%	2.12%
	1410	**Qalyûb**	**2.372**	**3.746**	**5.630**	**6.42%**	**4.02%**
	1412	**Al-Khusûs**	**2.231**	**2.799**	**2.717**	**3.23%**	**2.82%**
Giza	2101	Qism Imbaba	3.596	4.407	4.703	2.89%	0.65%
	2104	Qism Al-Giza	2.902	3.754	4.144	3.66%	0.99%
	2105	**Bolaq Al-dakrour**	**3.186**	**5.112**	**6.384**	**6.63%**	**2.21%**
	2106	Al-Ahram	2.546	4.310	5.187	7.35%	1.85%
	2117	Al-Waraq	2.048	3.439	4.163	7.24%	1.91%
	2118	Al-Omrania	6.876	10.093	11.417	5.42%	1.23%
	2120	**kerdasa**	**1.180**	**3.636**	**5.726**	**14.57%**	**4.46%**
Total			**102.01**	**162.36**	**209.23**	**6.52%**	**3.60%**

Table (6-1) Districts that faced an uncontrolled **IH** growth in the last **30** years

(1) $ABGR = \left[(B_t - B_{t-1})/N\right] \div \left[(B_t + B_{t-1})/2\right] \times 100$ --- For more details see section (6-2)

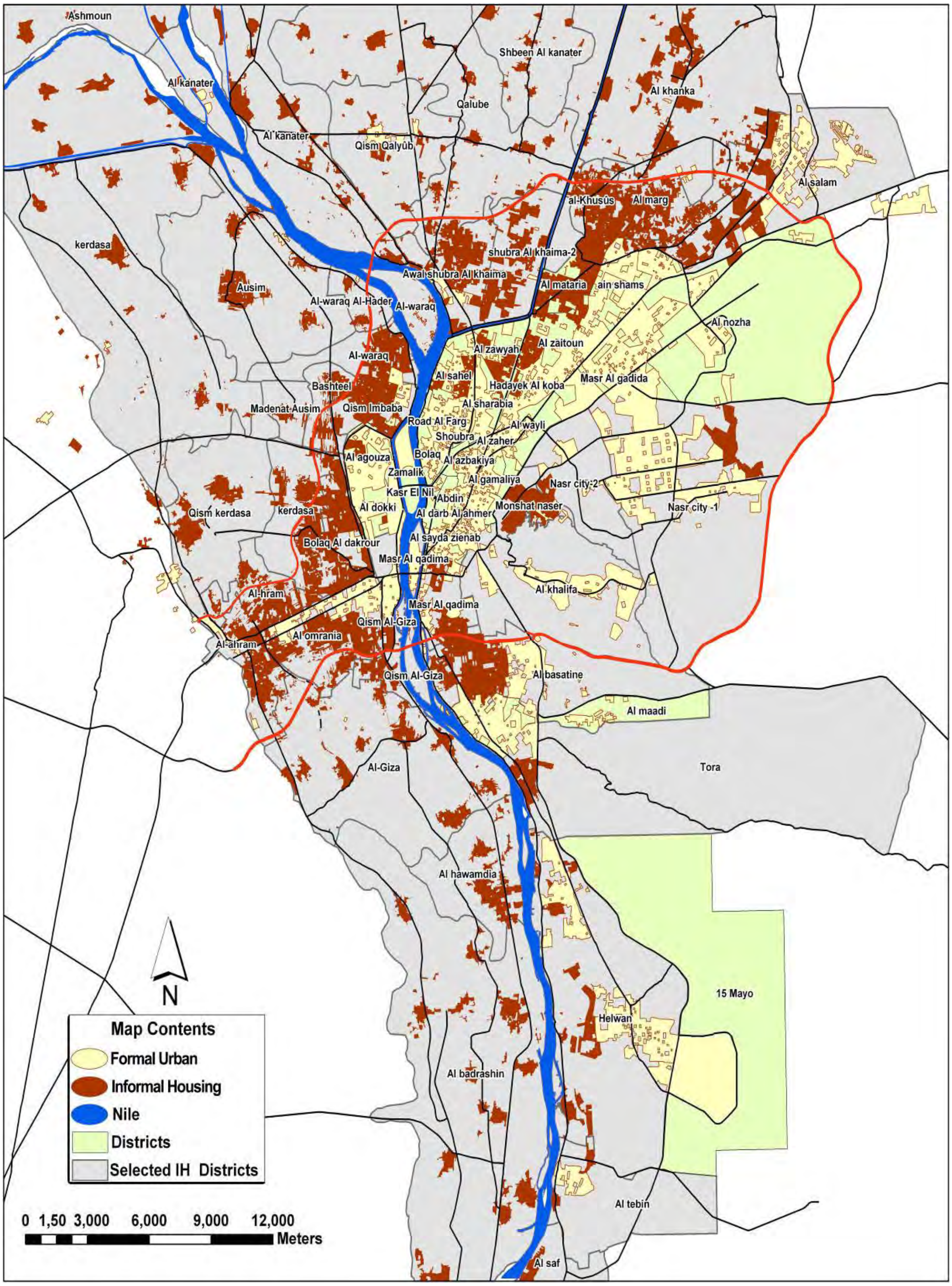


Figure (6-1) Districts that faced an uncontrolled **IH** growth in the last **30** years [1]

[1] In this Chapter, I will refer to these districts by **IH districts**.

(6-2-1) Regression Analysis Scenario

This scenario is based on using the **regression analysis** technique; the regression analysis performs a **linear analysis** by using the *"least squares"* method to fit a line through set of observations.

*With this method, you can analyze how a **single dependent variable** is affected by the values of **one or more independent variables**.*

In this scenario, we will estimate the built-up area in 2046 assuming a **<u>linear trend</u>** from the available **4** historical maps (1972, 1986, 1991, and 2001) with the following equation:

$$\bar{y} = a + bx \qquad \text{Equ. (6.1)}$$

<u>Where:</u>

- $\bar{y}$ **:** defined as the projected value of the dependent variable **y** *(which represents the estimated built-up area)* through a particular value of the independent variable ***x***,
- ***a*** **:** is the first **regression coefficient** that represents the **y** intercept, where the regression line intersects the **y** axis,
- ***b*** **:** is another **regression coefficient** represents the slope of the regression line, which represents the formula **negative** or **positive**.

The calculation of the regression coefficients ***a*** and ***b*** is the essential part of the regression analysis in this scenario. To calculate both ***a*** and ***b*** the following equations are used:

$$a = \bar{y} - bx \qquad \text{Equ. (6.2)}$$

$$b = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2} \qquad \text{Equ. (6.3)}$$

Where, ***x*** refers to the values of the independent variable, and ***y*** refers to the values of the dependent variable, $\bar{x}$ and $\bar{y}$ are the respective means of the two sets of values (Ebdon, 1985).

To apply the regression analysis, we use the **FORECAST** function from Microsoft® **EXCEL** program, the **FORECAST** function perform **linear regression analysis** based on **least-squares method**, this function estimates the future predictions using historical data.

According to the **regression analysis** from 2006 to 2046, the built-up area in the study area *(IH districts)* will be about **450.6 Km²** in year **2046** with an increase about **217.3 Km²** over the built-up area in year **2006** *(about **93.1 %** increases)*. i.e., the built-up area in the selected districts will approximately double in the next **40** years. [1]

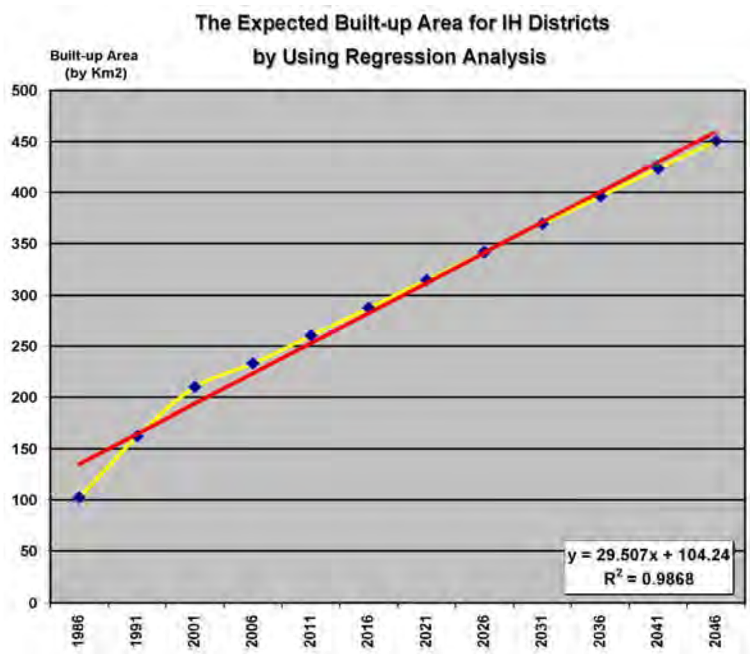


Figure (6-2) The expected built-up area for **IH districts** by using **Regression** analysis from **2001** to **2046**

Year	**Estimated Built-up Area Km²**	**Increment ratio**
1972	56.66	
1986	102.01	**80.0 %**
1991	162.36	**59.2 %**
2001	209.23	**28.9 %**
2006	**233.32**	**11.5 %**
2011	**260.49**	**11.6 %**
2016	**287.65**	**10.4 %**
2021	**314.82**	**9.4 %**
2026	**341.99**	**8.6 %**
2031	**369.15**	**7.9 %**
2036	**396.32**	**7.4 %**
2041	**423.49**	**6.9 %**
2046	**450.65**	**6.4 %**

Table (6-2) The expected built-up area for **IH districts** by using **Regression** analysis from **2001** to **2046**

[1] More details about the **Regression analysis** results are available in **Appendix c**.

(6-2-2) Exponential Trend Scenario

This scenario is based on calculating the built-up area that assumes a **constant** **A**nnual **B**uilt-up **G**rowth **R**ate **(ABGR)** for the following projected dates in each **district** *(Qism or hay)*. The constant **ABGR** can be calculated from the available **four** historical maps *(1972, 1986, 1991, and 2001)* by using the following standard equation.

$$r_b = 100 \times \ln \left(B_{t-1} / B_t \right) / t \qquad \text{Equ. (6.4)}$$

Where:

- r_b the constant **A**nnual **B**uilt-up **G**rowth **R**ate **(ABGR)** between two successive historical data,
- *ln* the natural logarithm,
- B_{t-1} the built-up area at previous year *(e.g.* 1991),
- B_t the built-up area at later year *(e.g. 2001),*
- t the number of years in the period *(e.g. 10 years).*

The calculated **ABGR** can be projected forwards as an **Exponential trend** to estimate what the built-up area would be at some point in the future. This can be a good indicator for planning purposes; the following equation can be used to calculate the **expected built-up area** in any future year:

$$B_{t+1} = B_t \times \exp \left\{ \left(r_b / 100 \right) \times t \right\} \qquad \text{Equ. (6.5)}$$

Where:

- B_{t+1} the projected built-up area in later or future year *(from 2001),*
- exp the exponential growth rate,
- r_b the constant **A**nnual **B**uitl-up **G**rowth **R**ate between two historical data,
- t the number of years for the estimated period *(e.g. 10 years, 5 years).*

The Microsoft® **EXCEL** program can be used to implement this scenario, the constant **ABGR** can be calculated by one of the following two ways:

- **First**: using the last two historical urban data *(1991-2001),*
- **Second**: using the historical urban data for the whole period between first and last year *(i.e., 1972 - 2001),* that has time difference of **29** years, this procedure ignores the growth rate for years 1986 and 1991.

The two periods **(1972-2001)** and **(1986-2001)** has very high growth rate about **4.6%** and **5.1%** respectively for the entire study area. This high growth rate is a result of the **national economic transition period** after the ending of the 1973 Egyptian-Israeli war and the beginning of **open market economy policy**.

In this scenario, we will use the **ABGR** of the last period **1991-2001** which equal **2.9%**, because this is the most reasonable rate that accommodate with the current government policy to control slums and informal housing in the **G**rater **C**airo **R**egion in the last decade.

According to the **Exponential trend** from 2006 to 2046, the built-up area in the study area *(IH districts)* will be about **864 Km²** in year **2046** with an increase about **623.7 Km²** over the built-up area in year **2006**. (1)

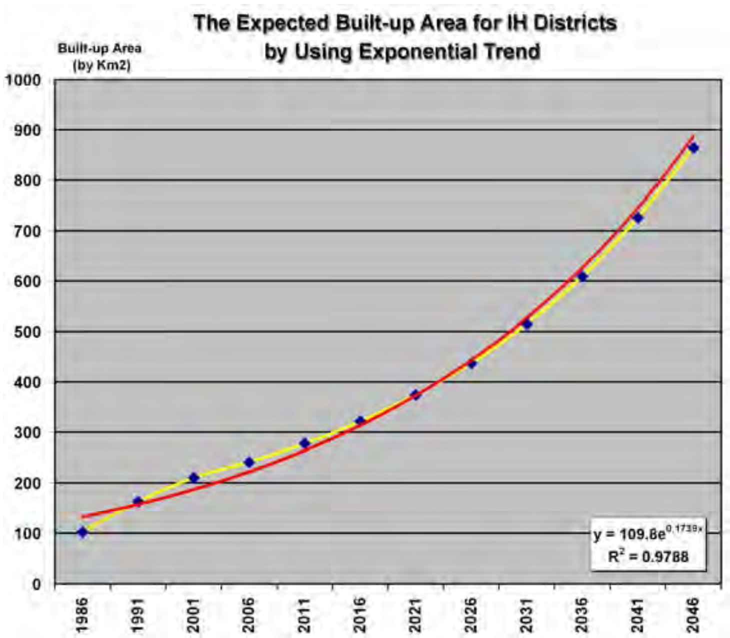


Figure (6-3) The expected built-up area for **IH** districts by using **Exponential** trend from **2001** to **2046**

Year	Estimated Built-up Area Km^2	Increment ratio
1972	56.66	
1986	102.01	80.0 %
1991	162.36	59.2 %
2001	209.23	28.9 %
2006	**240.82**	**15.1 %**
2011	**277.30**	**15.1 %**
2016	**320.97**	**15.7 %**
2021	**373.53**	**16.4 %**
2026	**437.13**	**17.0 %**
2031	**514.52**	**17.7 %**
2036	**609.23**	**18.4 %**
2041	**725.79**	**19.1 %**
2046	**864.48**	**19.1 %**

Table (6-3) The expected built-up area for **IH** districts by using **Exponential** trend from **2001** to **2046**

(1) More details about the **Exponential trend** results are available in **Appendix c**.

(6-2-3) Average Annual Built-up Growth Rate (AABGR) Scenario

This scenario is based on the assumption of calculating the future **A**verage **A**nnual **B**uilt-up **G**rowth **R**ate **(AABGR)** which can be calculated as follows:

- **First**: calculate the difference between latest two **ABGR**s of two successive growth periods, *(most recent or latest period minus previous period).*
- **Second**: adding this difference to the latest **ABGR** period, by using the following standard equation:

$$(r_b)_{t+1} = (r_b)_t + \{ (r_b)_t - (r_b)_{t-1} \} \qquad \text{Equ. (6.6)}$$

Where:

- $(r_b)_{t+1}$ defined as the projected annual built-up growth rate for the next period, or the next projected period in future *(i.e., the period from 2006-2011),*
- $(r_b)_t$ the annual built-up growth rate in **latest** period *(i.e., the period from 1991-2001),*
- $(r_b)_{t-1}$ the annual built-up growth rate in **previous** period *(i.e. the period from 1986-1991).*

By using equation (6.6), we can calculate the **AABGR** for each district in the following predictive years *2006, 2011, 2016, 2021, 2026, 2031, 2036, 2041, and 2046.* Then the following basic equation can used to estimate the **built-up area** for each district, and then aggregate the projected built-up area to the entire study area. The resultant **AABGR** for the first period *(2001-2006)* will be considered as the **constant annual growth rate**, equation (6.7) will use it to calculate the expected **built-up area in 2006**.

$$B_{t+1} = -B_t \left[(T\, r_b / 2) + 100 \right] \div \left[(T\, r_b / 2) - 100 \right] \qquad \text{Equ. (6.7)}$$

Where:

- B_{t+1} defined as the projected built-up area in the next period *(i.e., the period from 2006 - 2011),*
- B_t the built-up area in previous year *(i.e., the year 2001),*
- T the number of years for the next period *(i.e. the period from 2006-2011),*
- r_b the projected **A**nnual **B**uilt-up **G**rowth **R**ate for the next period.

In order to calculate the **AABGR** that would be expected in the next periods from **2011** to **2046** for the entire study area, an assumption of reducing the **AABGR** by **half** between any two successive periods because of the urban policies in **GCR**, that aim to reduce the growth rate in the far future or on long run plans. So that, the following equation was developed:

$$(r_b)_{t+1} = (r_b)_t + \left\{ \frac{(r_b)_t - (r_b)_{t-1}}{2} \right\} \quad \text{Equ. (6.8)}$$

According to the **AABGR** scenario from 2006 to 2046, the built-up area in the study area *(IH districts)* will reach about **468 Km²** in year **2046** with an increase about **237 Km²** over the built-up area in year **2006** *(about **106.4%** increases).* i.e., the built-up area in the selected districts will approximately double in the next **40** years [(1)].

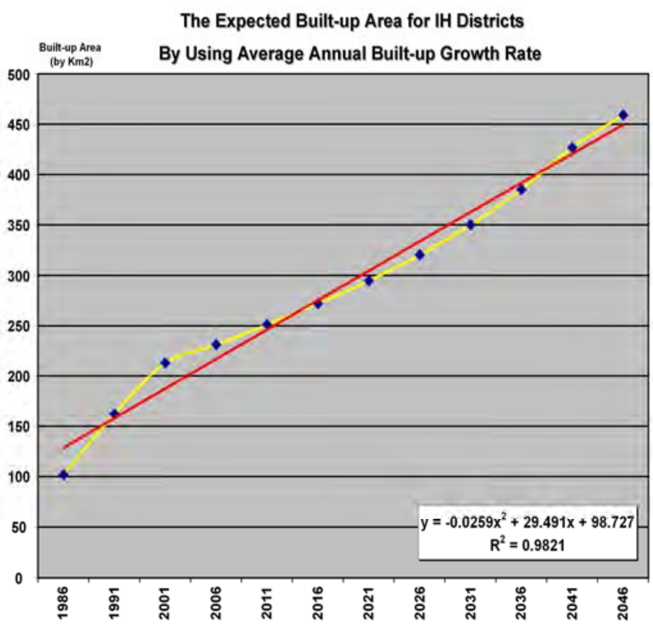


Figure (6-4) The expected built-up area for **IH districts** by using **AABGR** from **2001** to **2046**

Year	AABGR	Estimated Built-up Area Km²	Increment ratio
1972		56.66	
1986	6.33	102.01	80.0 %
1991		162.36	59.2 %
2001	3.11	209.23	28.9 %
2006	**2.24**	**231.04**	**10.4 %**
2011	**1.96**	**250.96**	**8.6 %**
2016	**1.83**	**271.53**	**8.2 %**
2021	**1.76**	**293.90**	**8.2 %**
2026	**1.73**	**319.06**	**8.6 %**
2031	**1.72**	**347.92**	**9.0 %**
2036	**1.71**	**381.55**	**9.7 %**
2041	**1.70**	**421.24**	**10.4 %**
2046	**1.70**	**468.61**	**11.2 %**

Table (6-4) The expected built-up area for **IH districts** by using **AABGR** from **2001** to **2046**

(1) More details about the **A**verage **A**nnual **B**uilt-up **G**rowth **R**ate results are available in **Appendix c**.

(6-2-4) Projection of Urban Growth Relative to Population Growth

This scenario based on the fact that, **the population distribution playing a leading role in urban expansion process in Egypt**. So, the future population growth is considered a **significant indicator** in urban and regional growth.
Therefore, the demand from future residential lands that should be added to the existing **built-up area** can be estimated as a function of the projected population size.

In this scenario we will **first**: estimate the **GCR population growth** for the following predictive years *2006, 2011, 2016, 2021, 2026, 2031, 2036, 2041, and 2046;* the estimation procedure will calculate the future population for each district *(Qism or hay),* and then aggregate the projected population to the **G**rater **C**airo **R**egion level. **Second:** estimate the future **built-up area as a ratio** relative to the projected population size for the selected districts that faced uncontrolled **IH** growth in the last **30** years, as shown in Figure (6-1).

(6-2-4-1) Projection of Future Population

One of the most commonly problems in the population analysis are those involving the need to **estimate the population size** for particular geographic area *(Qism, or shiyakhah)* in **one** or **several** future years from the existing census data (Shoukry, N. 2004). Population forecasts and projections are interest to develop tools for extrapolating the logical implications of current demographic forces by using **simple mathematical or statistical equations**. (1)

There are many scenarios can used to estimate the **future population** at particular years. From my reading, many articles and researches support and use the **A**verage **P**opulation **G**rowth **R**ate **(APGR)** method as the best procedure to project the future population growth at particular years, not only in **GCR** but also in the whole country (**C**airo **D**emographic **C**enter **(CDC)** 2009, Shoukry, N. 2004).

Therefore, **Three** alternatives were developed based on using the **APGR** to estimate the population growth in **GCR** in the proposed predictive years, the estimation procedure includes the following **three** steps:

(1) This article available at: http://www.cdc-egypt.org. (last accessed, 08/2009).

1- Calculation of the **Annual Population Growth Rate (APGR)** on the basis of **current** and **previous** census **1996** and **2006** by using equation (6.9). This **APGR** will used as the base to calculate the population growth rate in the first future period *(i.e., from 2006 to 2011).*

$$r_p = \frac{(P_2 - P_1)/t}{(P_2 + P_1)/2} \times 100 \qquad \text{Equ. (6.9)}$$

Where:

- r_p defined as the **A**nnual **P**opulation **G**rowth **R**ate between two successive census *(i.e., 1996 and 2006),*
- P_2 the population size in the **current** or latest census *(i.e. 2006 census),*
- P_1 the population size in the **previous** census *(i.e. 1996 census),*
- t the number of years in the period.

2- The future **APGR** in the next periods from **2006** to **2046** will estimate based on the **UNPD U**nited **N**ations **P**opulation **D**ivision [(1)], estimation assumptions **High**, **Medium**, and **Low** projection variants. The biennial **W**orld **U**rbanization **P**rospects volumes *(the most recent edition being United Nations, 2006)* presents population estimates and projections at regular **5-year** intervals for countries, and all capital cities, as shown on Figure (6-5).

The **U**nited **N**ations **P**opulation **D**ivision **(UNPD)** uses population statistical prediction techniques based on professional judgments about the range of **socio-economic** and **environmental influences** including many variables and assumptions regarding to **future trends in <u>fertility</u>**, **<u>mortality</u>**, **<u>age structure</u>**, **<u>increasing education levels</u>**, **<u>decreasing illiteracy</u>**, and **<u>Family Planning Programs (FPP)</u>**, **as well as the historical population growth rates for cities and counties**.

In preparing **W**orld **U**rbanization **P**rospects **(WUP)**, the **U**nited **N**ations **P**opulation **D**ivision clearly draws its raw materials from population counts that are published in the **Demographic Yearbook** (Mark R. Montgomery, 2003).

[(1)] This article available at: http://www.esa.un.org/unpp/ (last accessed, 06/2009).

3- Then, we can estimate the future population size at particular year on the basis of the following equation:

$$P_{t+1} = -P_t\left(T\,r_p/2\right) + 100 \div \left(T\,r_p/2\right) - 100 \qquad \text{Equ. (6.10)}$$

<u>Where:</u>

- P_{t+1} the projected population size in the next period *(i.e., 2006, 2011,…etc.,)*
- P_t the population size in the **current** or latest census,
- r_p the **A**nnual **P**opulation **G**rowth **R**ate **(APGR)**, *(from previous step)*
- t the number of years in the period.

Period	High variant			Medium variant			Low variant		
	Crude Birth Rate	Crude Death Rate	Total Growth Rate	Crude Birth Rate	Crude Death Rate	Total Growth Rate	Crude Birth Rate	Crude Death Rate	Total Growth Rate
1950-1955	48.6	24.0	2.46%	48.6	24.0	2.46%	48.6	24.0	2.46%
1955-1960	44.8	21.0	2.40%	44.8	21.0	2.40%	44.8	21.0	2.40%
1960-1965	45.4	20.4	2.51%	45.4	20.4	2.51%	45.4	20.4	2.51%
1965-1970	41.5	18.3	2.18%	41.5	18.3	2.18%	41.5	18.3	2.18%
1970-1975	40.4	16.0	2.15%	40.4	16.0	2.15%	40.4	16.0	2.15%
1975-1980	39.8	14.5	2.18%	39.8	14.5	2.18%	39.8	14.5	2.18%
1980-1985	37.9	12.6	2.38%	37.9	12.6	2.38%	37.9	12.6	2.38%
1985-1990	35.0	10.2	2.28%	35.0	10.2	2.28%	35.0	10.2	2.28%
1990-1995	29.1	8.0	1.91%	29.1	8.0	1.91%	29.1	8.0	1.91%
1995-2000	26.8	6.6	1.85%	26.8	6.6	1.85%	26.8	6.6	1.85%
2000-2005	**25.5**	**5.9**	**1.82%**	**25.5**	**5.9**	**1.82%**	**25.5**	**5.9**	**1.82%**
2005-2010	26.2	5.6	**1.95%**	24.2	5.6	**1.76%**	22.2	5.6	**1.56%**
2010-2015	25.5	5.5	**1.91%**	22.6	5.5	**1.61%**	19.5	5.5	**1.31%**
2015-2020	23.8	5.3	**1.76%**	20.6	5.4	**1.42%**	17.0	5.5	**1.06%**
2020-2025	21.7	5.4	**1.56%**	18.8	5.5	**1.24%**	15.6	5.8	**0.90%**
2025-2030	20.5	5.5	**1.43%**	17.5	5.8	**1.10%**	14.3	6.1	**0.74%**
2030-2035	20.0	5.7	**1.36%**	16.6	6.1	**0.97%**	13.0	6.6	**0.56%**
2035-2040	19.5	6.0	**1.29%**	15.6	6.5	**0.84%**	11.6	7.2	**0.36%**
2040-2045	18.7	6.2	**1.20%**	14.5	6.9	**0.70%**	10.4	7.8	**0.18%**
2045-2050	17.6	6.4	**1.07%**	13.5	7.3	**0.55%**	9.3	8.5	**0.00%**

Table (6-5) The Egyptian Crude Birth Rate, Crude Death Rate, and the total population growth rate, for **High**, **Medium**, and **Low** variant assumption from 1950 to 2050

(Source: http://esa.un.org/unpp/)

Table (6-5), summarizes the **UNPD** **P**opulation **G**rowth **R**ates **(PGR)** for **Egypt** based on **High**, **Medium**, and **Low** variant growth rates starting from **2005** to **2050**.

Therefore, **three** scenarios were developed based on the **UNPD** growth variant assumptions to estimated the future Population size in each district, as shown in figures (6-5), (6-6), and (6-7).

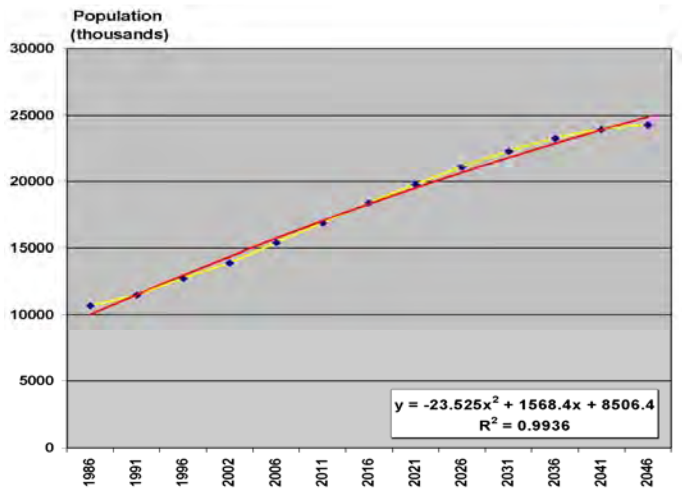


Figure (6-5) The expected **GCR** population size by using **UNPD Low variant**

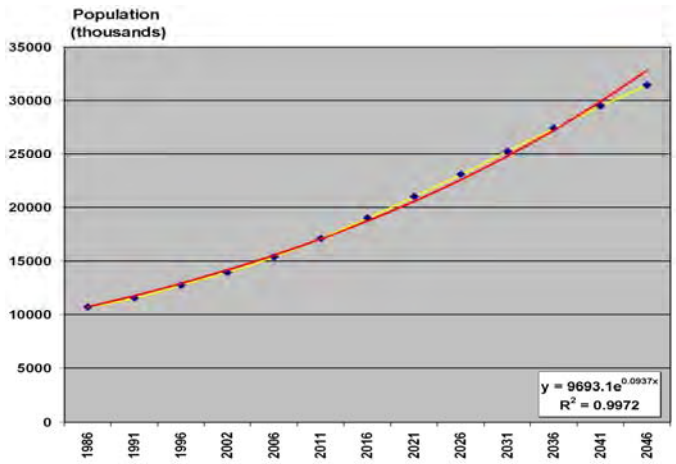


Figure (6-6) The expected **GCR** population size by using **UNPD Medium variant**

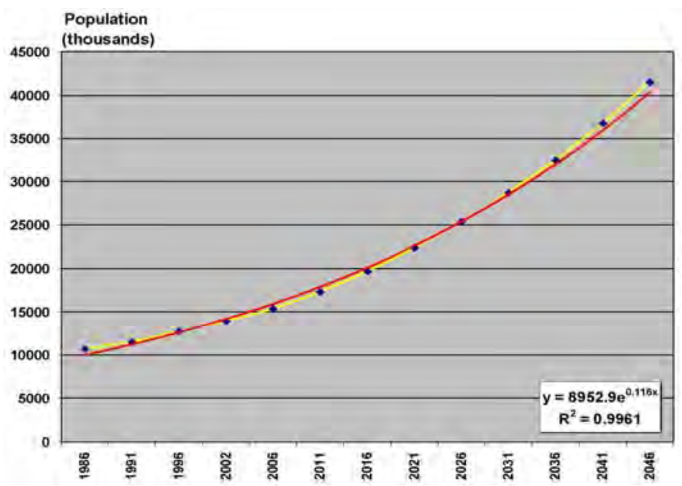


Figure (6-7) The expected **GCR** population size by using **UNPD High variant**

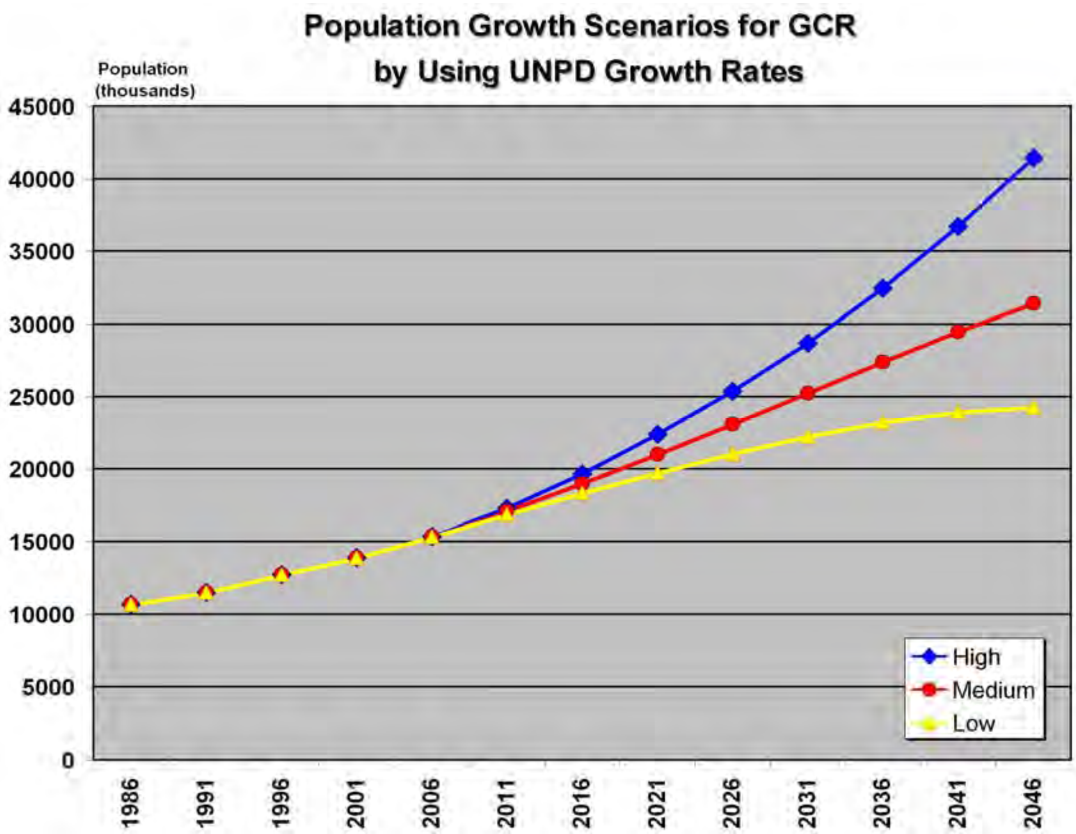


Figure (6-8) Population growth scenarios for **GCR**, by using **UNPD High**, **Medium**, and **Low** variant growth rates from **2011** to **2046**

Year	High variant		Medium variant		Low variant	
	Estimated Population Size	Increment ratio	Estimated Population Size	Increment ratio	Estimated Population Size	Increment ratio
1986	10,678,472		10,678,472		10,678,472	
1996	12,733,338	**19.2%**	12,733,338	**19.2%**	12,733,338	**19.2%**
2006	**15,369,091**	**20.7%**	**15,369,091**	**20.7%**	**15,369,091**	**20.7%**
2011	**17,294,633**	**12.5%**	**17,085,226**	**11.2%**	**16,870,470**	**9.8%**
2016	**19,666,632**	**13.7%**	**18,999,664**	**11.2%**	**18,361,374**	**8.8%**
2021	**22,398,093**	**13.9%**	**21,024,968**	**10.7%**	**19,749,885**	**7.6%**
2026	**25,375,006**	**13.3%**	**23,106,690**	**9.9%**	**21,076,925**	**6.7%**
2031	**28,679,488**	**13%**	**25,244,568**	**9.3%**	**22,283,210**	**5.7%**
2036	**32,454,883**	**13.2%**	**27,395,603**	**8.5%**	**23,272,474**	**4.4%**
2041	**36,734,996**	**13.2%**	**29,489,976**	**7.6%**	**23,945,954**	**2.9%**
2046	**41,459,473**	**12.9%**	**31,420,916**	**6.5%**	**24,294,293**	**1.5%**

Table (6-6) Population growth scenarios for **GCR**, by using **UNPD High**, **Medium**, and **Low** variant growth rates from **2011** to **2046**

According to **UNPD <u>High variant</u>** growth rate, the population size in the study area will be about **41.5** million people **(MP)** in year **2046** with an increase about **26** MP over the population size in year **2006**, *(about **170 %** increase).*

According to **UNPD <u>Medium variant</u>** growth rate, the population size in the study area will be about **31.4** MP in year **2046** with an increase about **16** MP over the population size in year **2006**, i.e., the population size will double in the next **40** years.

According to **UNPD <u>Low variant</u>** growth rate, the population size in the study area will be about **24.3** MP in year **2046** with an increase about **8.9** MP over the population size in year **2006**, *(about **58 %** increase).*
(More details about the UNPD High, Medium, and Low growth rates results are available in Appendix c).

(6-2-4-2) Projection of Built-up Area

In this section, we will estimate the built-up area in each district *(Qism or hay)* by using the relationship between population size and the size of urban areas consumption. **The private agriculture lands in the rural areas around the region represents the fundamental force that drives urban growth and land use change in Greater Cairo Region**.
<u>Growth ratio</u>, sometimes called **sprawl index** or **sprawl scatter index**, is defined as the ratio of <u>urban area growth</u> to <u>urban population growth</u> measured as a percentage (Allen, J. and K. Lu. 2003). It can be calculated using the following equation: [(1)]

$$r = \{(A_1 - A_0)/A_0\} / \{(P_1 - P_0)/P_0\} \qquad \text{Equ. (6.11)}$$

<u>Where</u>:

- r the **growth ratio** between urban area to population size,
- P_0 the **start-year** population size,
- P_1 the **end-year** population size,
- A_0 the **start-year** built-up area,
- A_1 the **end-year** built-up area.

(1) This article available at: http://www.consecol.org/vol8/iss2/art2

Therefore, the built-up area (**A_1**) in any district can calculate on the basis of future population by the equation:

$$A_1 = r\ A_0\ (P_1 - P_0) / P_0\ + A_0 \qquad \text{Equ. (6.12)}$$

<u>Where:</u> The urban area size (**A_1**) depends on the future population size (**P_1**) and the growth ratio (***r***), for both (**A_0**) and (**P_0**).

<u>The process of estimating the future built-up area can summarize as follows :</u>

1- Calculate the **<u>P</u>**<u>opulation to</u> **<u>B</u>**<u>uilt-up area</u> **<u>R</u>**<u>atio</u> **(PBR)** for each population growth scenario *(High, Medium, and Low)* using equation (6.11), for each prediction period.

2- Calculate the predicted **built-up area** based on the projected population size and the calculated **PBR**, using equation (6.12), for each district *(Qism or hay)*. Then we aggregate the projected built-up area to the entire region. (1)

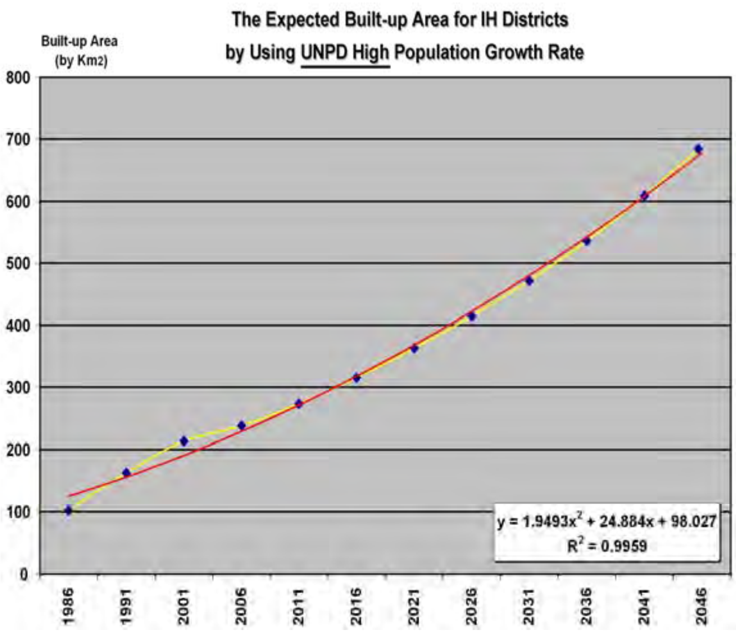


Figure (6-9) The expected built-up area for **IH districts** by using **UNPD High** population growth rate from **2001** to **2046**

Year	Estimated Built-up Area Km²	Increment ratio
1972	56.66	
1986	102.01	80.0 %
1991	162.36	59.2 %
2001	209.23	28.7 %
2006	**237.77**	**13.6 %**
2011	**272.90**	**14.8 %**
2016	**315.11**	**15.5 %**
2021	**362.86**	**15.2 %**
2026	**414.33**	**14.2 %**
2031	**471.05**	**13.7 %**
2036	**535.53**	**13.7 %**
2041	**608.42**	**13.6 %**
2046	**688.82**	**13.2 %**

Table (6-7) The expected built-up area for **IH districts** by using **UNPD High** population growth rate from **2001** to **2046**

(1) More details about built-up area projection results using **PBR** method are available in **Appendix c**.

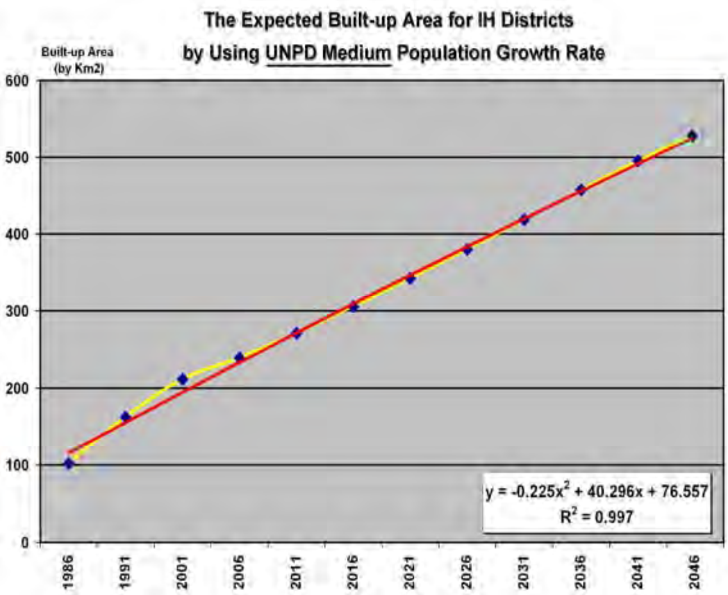


Figure (6-10) The expected built-up area for **IH districts** by using **UNPD Medium** population growth rate from **2001** to **2046**

Year	Estimated Built-up Area Km²	Increment ratio
1972	56.66	
1986	102.01	80.0 %
1991	162.36	59.2 %
2001	209.23	28.9 %
2006	**237.77**	**13.3 %**
2011	**267.96**	**13.0 %**
2016	**301.44**	**12.5 %**
2021	**336.68**	**11.7 %**
2026	**372.66**	**10.7 %**
2031	**409.48**	**9.9 %**
2036	**446.48**	**9.0 %**
2041	**482.53**	**8.1 %**
2046	**515.84**	**6.9 %**

Table (6-8) The expected built-up area for **IH districts** by using **UNPD Medium** population growth rate from **2001** to **2046**

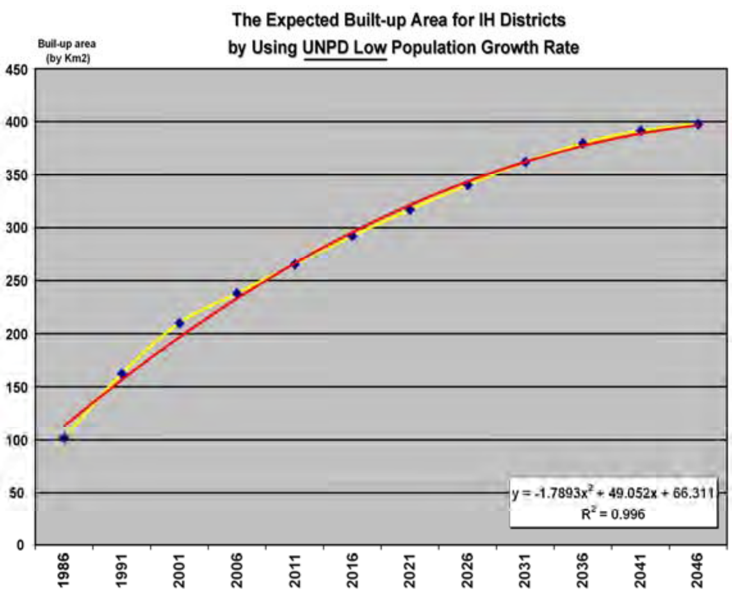


Figure (6-11) The expected built-up area for **IH districts** by using **UNPD Low** population growth rate from **2001** to **2046**

Year	Estimated Built-up Area Km²	Increment ratio
1972	56.66	
1986	102.01	80.0 %
1991	162.36	59.2 %
2001	209.23	28.9 %
2006	**237.77**	13.6 %
2011	**265.31**	11.6 %
2016	**292.22**	10.1 %
2021	**317.06**	8.5 %
2026	**340.67**	7.4 %
2031	**362.09**	6.3 %
2036	**379.65**	4.8 %
2041	**391.63**	3.2 %
2046	**397.84**	1.6 %

Table (6-9) The expected built-up area for **IH districts** by using **UNPD Low** population growth rate from **2001** to **2046**

Using the estimated **PBR** from the projected population according to **UNPD** population growth rate with **High variant** assumption, the built-up area in the study area will reach **688.8 Km^2** in year **2046**, with an increase of **451 Km^2** from year **2006**, *(about **189 %** increase).*

Using the estimated **PBR** from the projected population according to **UNPD** population growth rate with **Medium variant** assumption, the built-up area in the study area will reach **515.8 Km^2** in year **2046**, with an increase of **278 Km^2** from year **2006**, *(about **116 %** increase. i.e., the built-up area in the selected districts will approximately doubled in the next **40** years)*

Using the estimated **PBR** from the projected population according to **UNPD** population growth rate with **Low variant** assumption, the built-up area in the study area will reach **397.8 Km^2** in year **2046**, with an increase of **160 Km^2** from year **2006**, *(about **67 %** increase).*

*(More details about the **GCR** Built-up area projection results using **PBR** method are available in Appendix c).*

(6-2-5) Selection of the Growth Scenario

In summary of the above, Figure (6-12) and Table (6-10) show a comparison between the **six** built-up area projection scenarios for the selected informal housing districts in **GCR** from 2006 to 2046. The highest projected built-up area occurred in the **second** scenario *(Exponential trend),* while the lowest was the **six** one *(UNPD low variant growth rate).*

So far, we have developed **six** built-up projection scenarios from 2006 to 2046, these projection scenarios will evaluated, and then one scenario will selected. The selection procedure based on some factors such as:

- The internal historical growth trend of **GCR**,
- The changes in external driving forces affect on the expansion of **IH**,
- The regional **physical capacity**,
- The national **economic policy**,
- The **socio-development** national policies trends which plan to **decrease** the population growth rate in the near and far future.

By comparing the proposed growth scenarios, we find the **third** and **fifth** scenarios gave very close results that represents a moderate growth during the next **40** years. In the case of **GCR**, we select the **third** scenario **(AABGR)** as the most reasonable one. The selection of this scenario based not only on the **national policy trends** to minimize the centralization in **GCR**, but also on the **population growth trend**, which decreased in the last **10** years.

The period 1986-1991, as was mentioned previously, has a very high built-up growth rate of **6.3%** for the entire study area, which is due to the **national economic transition period** after the ending of the **1973** Egyptian-Israeli war and the beginning of the open market economy policy.
The rate decreased in the **next period 1991-2001** to **3.1%**, which assures a decreasing trend of the built-up growth rate, and indicates that it will continue decreasing in future.

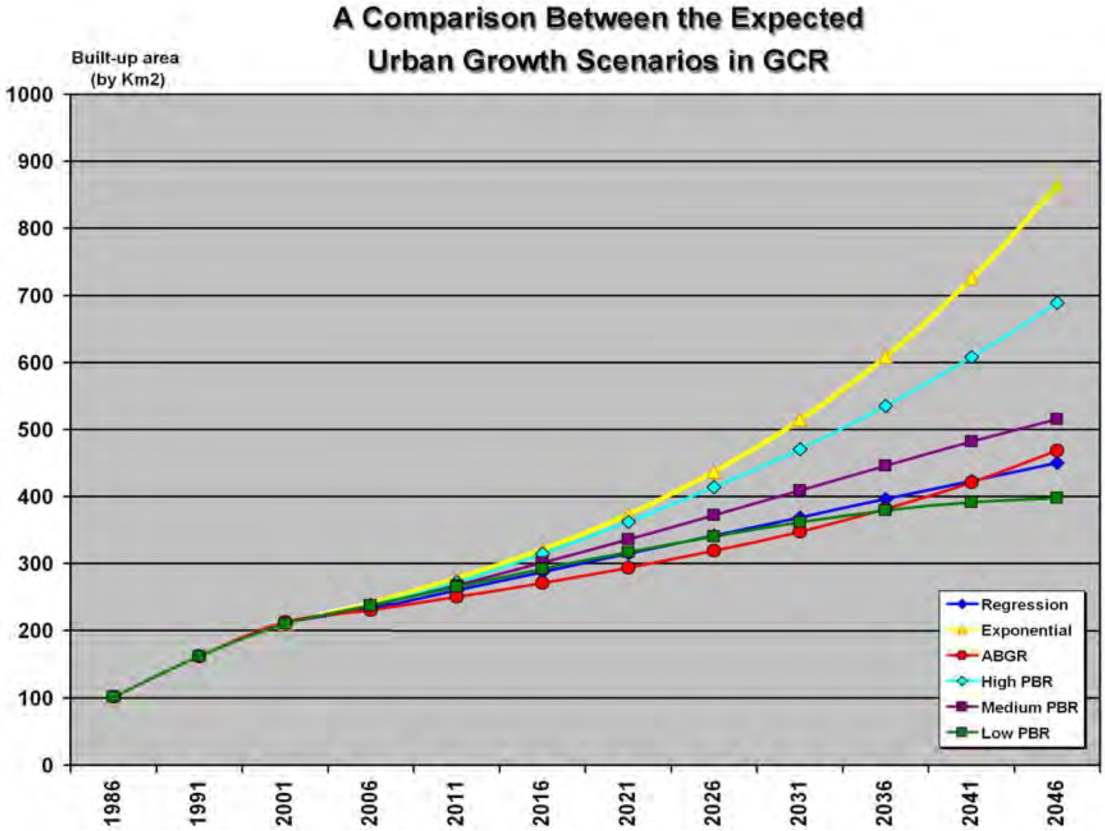


Figure (6-12) A comparison between the expected **SIX** urban growth scenarios in **GCR**

Year	Regression	Exponential	ABGR	Population Projection Scenarios		
				High PBR	Medium PBR	Low PBR
1986	102.01	102.01	102.01	102.01	102.01	102.01
1991	162.36	162.36	162.36	162.36	162.36	162.36
2001	210.18	210.18	210.18	210.18	210.18	210.18
2006	**233.32**	**240.82**	**231.04**	**237.77**	**237.16**	**237.77**
2011	**260.49**	**277.3**	**250.96**	**272.9**	**267.96**	**265.31**
2016	**287.65**	**320.97**	**271.53**	**315.11**	**301.44**	**292.22**
2021	**314.82**	**373.53**	**293.90**	**362.86**	**336.68**	**317.06**
2026	**341.99**	**437.13**	**319.06**	**414.33**	**372.66**	**340.67**
2031	**369.15**	**514.52**	**347.92**	**471.05**	**409.48**	**362.09**
2036	**396.32**	**609.23**	**381.55**	**535.53**	**446.48**	**379.65**
2041	**423.49**	**725.79**	**421.24**	**608.42**	**482.53**	**391.63**
2046	**450.65**	**864.48**	**468.61**	**688.82**	**515.84**	**397.84**

Table (6-10) The expected **built-up area** for **IH districts in GCR**, from **2006** to **2046**

(Area by square km)

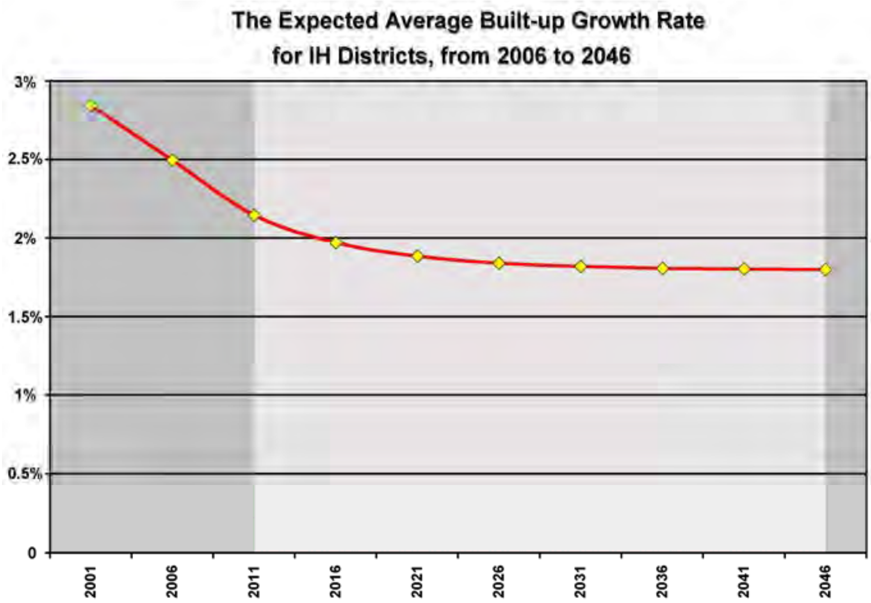


Figure (6-13) The expected average built-up growth rate for **IH** districts from **2006** to **2046** (The researcher work)

When comparing the third scenario with others, we find it supports the declining of population size in the study area, and the population size of this scenario become very close to the sixth scenario *(UNPD Low Variant)*, which represents the lowest population size in future.

In addition, there are other factors indicate the decreasing of population size in **GCR** in near and long future periods including:

- The public awareness of the population problem,
- Increasing education levels, and decreasing illiteracy,
- Increasing number of women in the working force,
- Higher age of marriage,
- Another important indicator is the **T**otal **F**ertility **R**ate **(TFR)** that is decreasing remarkably, Egypt's total fertility rate **(TFR)** has fallen from **7.2** children per woman in the early 1960s to **3.4** in 1998s, to **3** in 2005s. **U**nited **N**ations **P**opulation **D**ivision **(UNPD)** projections suggest that the **TFR** in Egypt will decrease to **two** children by 2020-2025 (Shoukry, N. 2004).

(6-2-6) Future Demand from Residential Lands

In summary of the above, different projection scenarios were developed to project the **built-up area** and future **population size** by using different statistical techniques using different local variables, that are easy to get not only in **Egypt**, but in other **LDC** countries as well.

These scenarios were developed and implemented based on the available published data to produce visions about the expected **built-up area** in GCR.

According to the previous discussion, we will choose the **third** scenario *(**A**verage **A**nnual **B**uilt-up **G**rowth **R**ate)* as the most appropriate scenario that can simulate the future urban growth in **GCR**. Therefore, we can estimate the amount of required lands to meet future demand from housing in the selected informal housing districts *(Qism or hay)* which faced a physical random growth, during last **30** years in **GCR**, *(as shown in figure 6-1).*

(Table 6-11) shows the expected demand from residential lands for each **IH** district in the proposed prediction years from **2006** to **2046** every **5** years.

Qism _Code	Gov.	Qism Name	2006	2011	2016	2021	2026	2031	2036	2041	2046
106	Cairo	**Masr Al-Qadima**	**6.019**	**6.315**	**6.594**	**6.870**	**7.149**	**7.435**	**7.730**	**8.036**	**8.354**
108		**Al-Khalifa**	**5.798**	**6.486**	**7.255**	**8.114**	**9.073**	**10.146**	**11.346**	**12.687**	**14.186**
126		**Nasr City -1**	**19.298**	**19.660**	**19.977**	**20.273**	**20.560**	**20.845**	**21.130**	**21.417**	**21.707**
127		**Nasr City -2**	**2.626**	**2.792**	**2.970**	**3.160**	**3.362**	**3.577**	**3.806**	**4.049**	**4.308**
132		**Al-Salam**	**17.508**	**18.622**	**19.426**	**20.069**	**20.632**	**21.159**	**21.674**	**22.188**	**22.707**
134		**Monshat Naser**	**3.869**	**5.138**	**6.837**	**9.109**	**12.142**	**16.189**	**21.587**	**28.789**	**38.394**
135		**Al-Basatine**	**11.658**	**12.334**	**12.966**	**13.586**	**14.214**	**14.858**	**15.526**	**16.221**	**16.944**
136		**Al-Marg**	**9.314**	**10.199**	**11.052**	**11.914**	**12.810**	**13.756**	**14.762**	**15.836**	**16.986**
901	Helwan	**Al-Tebin**	**2.746**	**3.478**	**4.415**	**5.609**	**7.131**	**9.068**	**11.533**	**14.669**	**18.657**
902		**Helwan**	**15.270**	**16.859**	**18.542**	**20.356**	**22.325**	**24.473**	**26.821**	**29.392**	**32.206**
905		**Tora**	**3.294**	**3.492**	**3.662**	**3.819**	**3.974**	**4.128**	**4.286**	**4.449**	**4.617**
911		**Al-Saf**	**0.974**	**1.311**	**1.769**	**2.388**	**3.227**	**4.361**	**5.896**	**7.970**	**10.775**
1006	October	**Al-Hram**	**4.688**	**5.297**	**5.842**	**6.364**	**6.891**	**7.440**	**8.019**	**8.637**	**9.299**
1008		**Al-Hawamdia**	**3.698**	**3.924**	**4.146**	**4.370**	**4.602**	**4.842**	**5.094**	**5.359**	**5.636**
1009		**Al-Giza**	**6.751**	**7.422**	**8.114**	**8.847**	**9.632**	**10.481**	**11.400**	**12.397**	**13.481**
1010		**Al-Badrashin**	**7.776**	**8.377**	**8.978**	**9.596**	**10.244**	**10.928**	**11.654**	**12.427**	**13.249**
1015		**Madenat Ausim**	**0.684**	**0.741**	**0.801**	**0.862**	**0.927**	**0.997**	**1.072**	**1.151**	**1.237**
1016		**Ausim**	**4.827**	**5.162**	**5.467**	**5.761**	**6.055**	**6.357**	**6.669**	**6.995**	**7.336**
1017		**Waraq Al-Hader**	**0.682**	**0.732**	**0.778**	**0.824**	**0.870**	**0.917**	**0.967**	**1.019**	**1.073**
1018		**Bashteel**	**2.538**	**2.737**	**2.824**	**2.850**	**2.863**	**2.870**	**2.873**	**2.876**	**2.877**
1020		**Markaz Kerdasa**	**8.349**	**9.253**	**10.241**	**11.327**	**12.525**	**13.847**	**15.307**	**16.921**	**18.704**
1021		**Qism Kerdasa**	**4.482**	**5.447**	**6.612**	**8.021**	**9.728**	**11.796**	**14.303**	**17.342**	**21.026**

Table (6-11) The expected demand from residential lands for each **IH** district in **GCR** *(Square km area)*

Qism _Code	Gov.	Qism Name	2006	2011	2016	2021	2026	2031	2036	2041	2046
1403	Kalyoubia	**Al-Khanka**	**9.313**	**10.307**	**11.294**	**12.313**	**13.390**	**14.542**	**15.784**	**17.127**	**18.581**
1404		**Al-Kanater**	**6.884**	**7.567**	**8.163**	**8.722**	**9.276**	**9.842**	**10.431**	**11.048**	**11.698**
1405		**Shbeen Al-Kanater**	**2.021**	**2.717**	**3.661**	**4.940**	**6.668**	**9.003**	**12.158**	**16.420**	**22.176**
1406		**Shubra Al-Khaima-1**	**6.003**	**6.363**	**6.747**	**7.156**	**7.590**	**8.052**	**8.541**	**9.061**	**9.612**
1407		**Shubra Al-Khaima-2**	**5.841**	**6.155**	**6.437**	**6.707**	**6.974**	**7.246**	**7.524**	**7.812**	**8.109**
1409		**Qism Qalyûb**	**2.978**	**3.219**	**3.463**	**3.717**	**3.985**	**4.269**	**4.573**	**4.897**	**5.244**
1410		**Qalyûb**	**6.484**	**7.246**	**7.976**	**8.714**	**9.485**	**10.305**	**11.185**	**12.135**	**13.162**
1412		**Al-Khusûs**	**4.236**	**4.803**	**5.431**	**6.134**	**6.924**	**7.812**	**8.813**	**9.941**	**11.214**
2101	Giza	**Qism Imbaba**	**4.804**	**4.880**	**4.943**	**5.001**	**5.055**	**5.108**	**5.160**	**5.213**	**5.266**
2104		**Qism Al-Giza**	**4.296**	**4.425**	**4.541**	**4.653**	**4.764**	**4.876**	**4.989**	**5.104**	**5.222**
2105		**Bolaq Al-Dakrour**	**6.975**	**7.538**	**8.100**	**8.681**	**9.291**	**9.937**	**10.623**	**11.356**	**12.137**
2106		**Al-Ahram**	**5.534**	**5.824**	**6.088**	**6.341**	**6.593**	**6.850**	**7.114**	**7.386**	**7.668**
2117		**Al-Waraq**	**4.460**	**4.713**	**4.948**	**5.178**	**5.409**	**5.646**	**5.891**	**6.145**	**6.409**
2118		**Al-Omrania**	**11.891**	**12.255**	**12.565**	**12.849**	**13.122**	**13.392**	**13.663**	**13.938**	**14.216**
2120		**Kerdasa**	**6.470**	**7.165**	**7.902**	**8.709**	**9.595**	**10.572**	**11.647**	**12.831**	**14.135**
Total (Square km area)			**231.039**	**250.956**	**271.527**	**293.902**	**319.056**	**347.921**	**381.552**	**421.237**	**468.611**

Table (6-11) The expected demand from residential lands for each **IH** district in **GCR** (Cont.) *(Square km area)*

(Qism_Code Source: **CAPMAS** - 2009)

(6-3) Designing of the Informal Housing Growth Model (IHGM)

This section first presents **the concepts**, **assumptions**, and **rules** that used in the proposed growth model, and then demonstrates the model main components and aspects.

(6-3-1) IHGM Main Concepts and Features

From **Chapter Four**, we can conclude that no existing dynamic models could be **fully adapted** to investigate the rapid expansion of **IH** especially in the context of **LDC**. This point was discussed and proved strongly in **Chapter Five**.

Therefore, the proposed model will be **flexible** and can **adapt** with many types of growth factors, also, it is attempts to simulate the conditions and rules that responsible for **IH** emergence and growth in **LDC**.

There are at least three motivations to develop a growth model to predict the future expansion of IH :

Firstly, the proposed **IHGM** will increase our understanding of the fast-growing **I**nformal **S**ettlements **(IS)** and **I**nformal **H**ousing areas **(IH)** within the growing mega cities in less developed countries, to study and define the urbanization factors, where there are no sufficient formal data.

Secondly, the future expansion of **IH** can be explored on the basis of the historical experiences and knowledge about **IH**, coupled with a group of selected **growth factors** and **growth conditions**, that causing the emergence and expansion of **IH** (UN-Habitat, 2003).

Thirdly, the proposed **IHGM** has many features, especially its ability to generate different scenarios based on different growth factors **weighs** and **ranks**, coupled with the opportunity for the user to produce multiple outputs. Therefore, the propsed model can be useful tool to guide local governments and urban stakeholders in their decision making process.

The proposed **IHGM** draws its origins from the **concepts**, **theories** and **technologies** of both **C**ellular **A**utomata **(CA)** and **G**eographical **I**nformation **S**ystems **(GIS)**. **IHGM** **loosely couples** **CA** and **GIS** technologies to simulate and predict the patterns of **IH** emergence and growth.

Therefore, the **IHGM** takes the approach of incorporating various **GIS** data formats *(point, line, and polygon),* which converted to raster format *(Raster Dataset)* to make the modelling process transparent and flexible.

- The **IHGM** main features follow the concepts of **C**ellular **A**utomata **(CA)** such as: **grid space**, **cells**, **cell state**, **neighboring cells states**, and **transition rules**. Specifically, the **IHGM** takes the same principles of **C**ellular **A**utomata, where the changes operate on a **pixel** *(cell)* which is a unit of regular **two-dimensional lattice**.
- The cell state is synchronously updated in discrete time steps according to generic rules. **Based on this assumption, the previous states of the neighboring cells determine the state of each cell at the next period**.
- The **IHGM** uses extended **Moore's** neighborhood matrix *(e.g., r = 3 to r = 7 see Chapter 3)* and can accommodate unlimited number of rules. Also, the **C**ellular **A**utomata module developed within **IHGM** is innovative in the design, and it is considerably flexile by incorporating many functions such as: **calibration of growth factors**, **probability calculation**, **transition rules**, and **prediction module**.
- On the other hand, **IHGM** uses **GIS** technology in **three** important operations:

Firstly, to prepare the required maps and data to run the model *(see Chapter Five, section 5-3),*

Secondly, the modelling interface to run the **CA Visual Basic** macro,

Thirdly, the displaying interface for the simulation results.

(6-3-2) IHGM Assumptions

The **IHGM** is designed around some general assumptions of **IH growth rules** that can be changed to suit **different urban areas with different conditions**, while maintaining the general conditions that relate to the emergence and growth of **IH**.

For the case of **GCR** simulation and prediction, some assumptions are defined to control the model behavior included:

1- The study area is converted to **two-dimensional grid** of square, equal-sized cells, *(in the case of **GCR** the study area consists of 1777 rows and 1531 columns)*;

2- The proposed model can allow an **unlimited amount of input data** with the same format and properties;

3- **Each layer consists of at least two states** *(e.g., urban and non- urban, road and non-road, water and non-water, …etc.,)*;

4- **Each cell has a unique identifier number (ID)** because changes operate at the cell level; *(e.g., housing: 1, informal housing: 2, roads: 19)*. This allows the **VB** macro to read the value of each land use category, and recognize the land use type for the neighborhood cells in a logical way;

5- **Cell changes operate only on vacant land** on the defined grid;

6- **Cell changes according to predefined and homogeneous transition rules**;

7- During the calibration process, all **IH** cells across the complete grid are chosen and calibrated to test the affected growth factors, and calculate their influence ratio on the emergence of **IH**;

8- During the simulation process, the **CA** macro calculates the **relative probability** to change from **vacant** to **IH** for each cell across the complete grid. Thus, **high probability cells will change its state in the next iteration;**

9- During the simulation process, if a cell's neighborhood does not contain at **least one IH** cell, a new **IH** cell cannot emerge. This condition prevents **IH** emerging in an isolated area;

10- **All new IH cells occur only on vacant land**. Existing land use classes do not change within the model as currently designed;

11- **No IH cell "*dies*" after emerging**. This condition suggests that an **IH** cell cannot return to its previous state or change to another land use type once it created. This rule consistent with the spread of **IH** patterns in **CGR**, especially in the western part *(rural districts in Giza governorate)*;

12- **The proposed model adopt the experimental approach**, To get the most suitable neighborhood matrix size for **land use** and **network** growth factors, we will test many alternatives for both land use search matrix $\mathbf{L_{(s)}}$ and network search matrix $\mathbf{N_{(s)}}$, starting from **matrix size = (3 x 3) pixels** *(r =1 pixel, i.e., matrix size = 90 m)* **to matrix size = (7 x 7) pixels** *(r =3 pixels, i.e., matrix size = 210 m)*;

The developed **CA** macro within the **IHGM** model will simulate these aspects, through multiple functions that simulate the conditions and cases under which the cell should behave in the defined matrix at each time step.

(6-3-3) IHGM Main Rules

The developed **CA** macro within the **IHGM** simulates some rules and conditions that affect on **IH** emergence and growth. These general rules control the **Visual Basic** macro operation, apart from the growth parameter values that are calibrated by comparing two historical urban data.

The model provides various possibilities for **fine-tuning** the growth rules; also, **the growth parameter values** *(weights, ranks)* **can be adapted to specific conditions to improve the prediction accuracy**.

The cell probability to change depends on three main conditions:

- **First**, the stages of growth the model is in,
- **Second**, the number and states of the surrounding land use cells,
- **Third**, the cell accessibility according to nearness or remoteness from physical network features *(roads, railways, metro …etc,)*.

According to the conditions under which the cell can changes from vacant to IH, we can estimate the probability value as follows :

1- If a **vacant cell** is located in a **high slope area**, then its probability of becoming an **IH** cell at the next iteration decreases *(low probability)*;

2- If a **vacant cell** is located close to *(e.g., less than four extended neighbors away from)* a **road**, **canal**, **market place**, **workshop place** or **low slope cell**, then its probability of becoming an **IH** cell increases by a user-defined value *(medium probability)*;

3- If a **vacant cell** is close to both **IH** cell and **workshop place** or one or more **roads**, its probability of becoming an **IH** cell becomes even greater *(high probability)*;

The **GIS** and **CA** concepts, along with these assumptions and rules serve to define the proposed model framework. To be operational, the model passes through several instances of **refinement** and **modification** to increase its prediction capacity and test the validity of its assumptions.

(6-4) The IHGM Visual Basic Macro

A range of programming languages including **C**, **Java**, and **Microsoft Visual Basic** could have been used to write the proposed **CA** macro, for this model the **Microsoft Visual Basic (VB)** programming language was found easier to learn, write and modify. Moreover, **VB** has the ability to integrate with wider mapping and **GIS** software such as **ESRI-ArcGIS (9.x)**

Microsoft Visual Basic is also described as a cross platform language, appropriate for prototyping *(e.g., using macro)* by **adopting compact codes** that have multiple functions, and can be supported by almost any **GIS** environment. In addition, the **VB** macro uses **less computing space** and **runs faster**. These functionalities and abilities of **VB** will thus enhance the **usefulness**, **flexibility**, **portability** and **cost** of the proposed **IHGM**. These characteristic and features were considered when choosing the modeling environment of the proposed model.

Another advantage of using **VB** macro is that the user can **enter** and **change** the program assumption *(the growth variables weight and rates)* to implement an unlimited number of probabilities and rules, so the model can produces a range of results and different simulated growth maps.

The **IHGM** program is *transparent* or a ***"white box"***, that one can access and modify the line commands, or adding new conditions or growth factors, and check the consistency of the **IHGM** codes. **This capability helps to adapt the model with other development regions**.

The **IHGM** program is a standalone program consists of **CA** macro, which was written and implemented by using **Microsoft Visual Basic** programming language, and uses **ESRI-ArcGIS (9.x)** as a **G**raphical **U**ser **I**nterface **(GUI)** because of its ability to preserve the properties of the **input** and **output** files. Similarly, **ArcGIS** offers the possibility of calibrating, validating and statistically comparing the simulation results.

The developed **CA** macro for the **IHGM program is my original work towards this PhD thesis**, a full copy of the **IHGM VB** macro is available by contact the researcher, and on the attached **CD** at the back of this thesis.

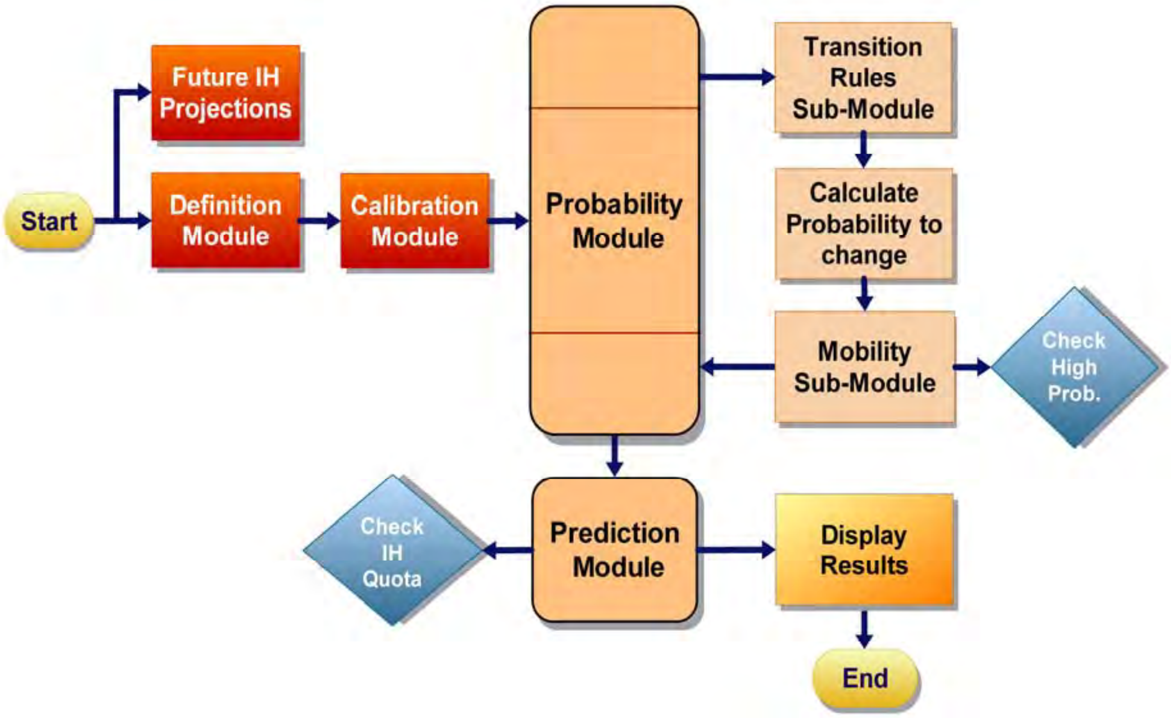


Figure (6-14) Simplified representation of the **IHGM** main modules

Based on the previous discussion, the following sections explain step by step how the **IHGM CA** macro works and the execution of its modules. The **IHGM** is divided into **five** main Modules as follows:

- **Definition module**,
- **Growth factors calibration module**,
- **Probability to change module**,
- **Prediction module**,
- **Display simulation results**.

(6-4-1) Definition Module

The definition module defines and declares the required parameters and variables to run the proposed model. This module **lists** the files and maps that will use in the **calibration** and **prediction** phases, and **describes** the data type for each file, as well as the **identification number (ID)** for each **land use** and **network growth factor** that is necessary to know the growth factor type.

In the definition module, the user must define the following **five** parameters:

a) The image map:

In this step, the user defines the image parameter of the study area. i.e., sets the dimensions of the image map in a number of **columns** and **rows**.

b) The base and target year

The user defines the **starting** and **final year** for the **calibration phase** *(i.e., 1991 and 2001 respectively)*, as well as, the **base** and **target year** for the **prediction phase** *(i.e., 2006 and 2046 respectively).*

c) The number of iterations

The user defines the **number of iterations** between the **base** and **target** year for the prediction phase. The number of iterations refers to the number of periods *(in years)* between the **base year** *(2006)* and the **target prediction year** *(2046).* This number refers to the number of simulated output maps, *(in the case of **GCR**, every period = 5 years, i.e., the number of iterations = 8).*

d) The size of neighborhood matrix *(Kernel size)*

The user defines the size of neighborhood search matrix for land use ($L_{(s)}$) and network features ($N_{(s)}$), which required to count the number of surrounding pixels from each growth factor *(e.g.,* $L_{(s)} = 3$ *for land use ,* $N_{(s)} = 5$ *for network factors).*

e) The annual_target and nett_pixel_gain

The **IHGM** definition module requires the user to specify the number of **annual_target_pixel_gain** for each district *(Qism or hay)* in each prediction period, as well as, the **nett_pixel_gain** for the entire study area in the whole prediction period.

- The **annual_target_pixel_gain** is the expected number of additional **IH** pixels for each prediction period *(every 5 years)* classified by districts. The

annual_target_pixel_gain can be estimated by studying the historical urban development of **IH** districts and predict the required land for housing **every prediction period** for each district by statistical means. *(see table 6-11)*

- The **nett_pixel_gain** is the estimated number of additional **IH** pixels between the **base** and **target** prediction year <u>for the entire study area</u>. The **nett_pixel_gain** is the summation of the **annual_target_pixel_gain** for all districts, which represents the required land for housing for the entire study area *(see section 6-3).* However, the **nett_pixel_gain** can be modified to simulate different growth scenarios.

  Therefore, the prediction module allows the user to **decrease** or **increase** the **annual_target_pixel_gain** for specific periods *(iterations),* or specific districts, or set the **annual_target** according to the historical growth rate in specific stage.

For GCR growth model, the annual_target_pixel_gain was estimated based on the <u>Average Annual Built-up Growth Rate (AABGR)</u>, which estimated based on historical urban maps from 1952 to 2001, **this approach was used to estimate the future required lands for urban expansion in GCR**. *(see table 6-11)*

When the definition parameters have been declared and verified, the macro can now proceed to perform the following two steps:

<u>The first step</u>, consists of locating the user-defined **GIS** environment, which used to display the output prediction maps, *(in this case ArcGIS 9.x will use as the GIS environment)*. **It is recommended that all files and layers are located in the same directory**.

<u>The next step</u>, the macro displays the **starting** and **final** calibration maps on the **GIS** interface, with **user defined color** palette. *It is recommended that a color palette be created to clearly define and focus on the important aspects of the map.*

When all the required maps are successfully verified, **set**, **displayed**, **converted to the same data type and format**, **then the procedure moves to run the growth factors calibration module.**

(6-4-2) Growth Factors Calibration Module

The second module of the **IHGM** estimates the physical growth factors **weights** and **rates**, which are best fit the historical urban development. Unfortunately, there is no universal applicable method of calibration due to the nature complexity.

The calibration module calculates the **influence ratio** for each **growth factor**, and the **relative calibration score** for each **IH pixel** according to the **multi-contribution** of these factors to emerge informal housing areas.
Figure (6-15) shows **the calibration module flow-chart**.

The calibration module passes through the following actions :

1- The calibration procedure uses **two sets of historical land use data to calculate the influence ratio for the selected growth factors**, the first represents the land use map at the **starting calibration year** *(1991)* and the second is the land use map at the **final calibration year** *(2001)*;

2- Intersect the **starting** and **final** land use maps to generate the informal housing distribution between the starting and final calibration years, and count the **IH Quota**;

3- Then, the procedure **loops through all the generated IH pixels** that created in the calibration period, to capture the **neighboring** land use and network features, then the procedure examines the affected factors on the created **IH** cell.
The calibration procedure uses **Lu(s)** and **N(s)** which represent the **size of neighborhood matrix** for land use and network features respectively;

4- Then, the user assigns calibration weights for land use and transportation network factors, according to the **closeness** or **remoteness** from the examine **IH cell**;

5- For each **IH cell** the macro calculates the land use calibration value ($Lu\,P_i$) for each land use type, and the network calibration value ($N\,P_i$) for each network type, using the following **two** equations:

$$Lu\,P_i = a\,Lu_i\,W_1 + b\,Lu_i\,W_2 + c\,Lu_i\,W_3 + \dots\dots\dots + n\,Lu_i\,W_n \quad \text{Equ. (6.13)}$$

Where:

$Lu\,P_i$	the calibration value for **land use** *(i)*,
a, b, c, ….., n	the number of neighboring pixels from **land use type** *(i)* at levels 1, 2 , 3, ..., and n respectively,

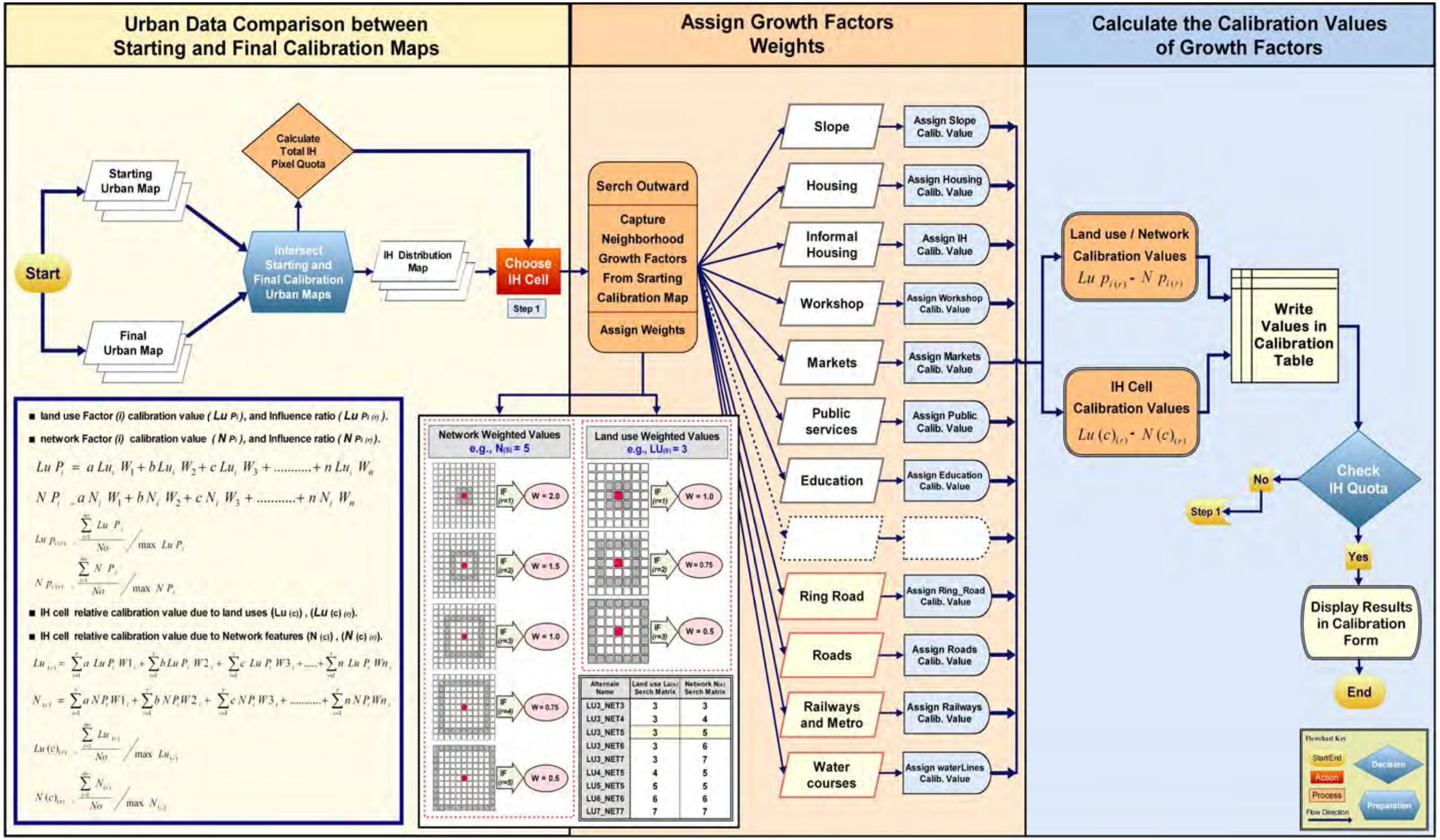


Figure (6-15) The calibration module flow-chart

$W_1, W_2, W_3, \ldots, W_n$	user defined weights for **land use** factors at levels 1, 2 , 3, ..., and n respectively.

$$N\,P_i = a\,N_i\,W_1 + b\,N_i\,W_2 + c\,N_i\,W_3 + \ldots\ldots\ldots.+ n\,N_i\,W_n \qquad \text{Equ. (6.14)}$$

Where:

$N\,P_i$	the calibration value for **network** *(i)*,
a, b, c, …..., n	the number of neighboring pixels from **network type** *(i)* at levels 1, 2 , 3, …, and n, respectively,
$W_1, W_2, W_3, \ldots, W_n$	user defined weights *(attractions)* for **network** factors at levels 1, 2, 3, …, and n, respectively.

6- The macro calculates the calibration values for each **IH cell** according to all neighboring land uses and transportation network types as follows:

$$Lu_{(c)} = \sum_{i=1}^{x} a\,LuP_i\,W1_i + \sum_{i=1}^{x} b\,LuP_i\,W2_i + \sum_{i=1}^{x} c\,LuP_i\,W3_i + \ldots.. + \sum_{i=1}^{x} n\,LuP_i\,Wn_i \qquad \text{Equ. (6.15)}$$

Where:

$Lu_{(c)}$	the **IH cell** calibration value due to the neighboring **land uses**,
x	the total number of **land use** factors,
a, b, c, …..., n	the number of neighboring pixels from **land use type** *(i)* at level 1, 2, 3, …, and n, respectively,
$W_1, W_2, W_3, \ldots., W_n$	user defined weights for **land use** factors at levels 1, 2, 3, …., and n, respectively.

$$N_{(c)} = \sum_{i=1}^{y} a\,NP_i\,W1_i + \sum_{i=1}^{y} b\,NP_i\,W2_i + \sum_{i=1}^{y} c\,NP_i\,W3_i + \ldots\ldots\ldots. + \sum_{i=1}^{y} n\,NP_i\,Wn_i \qquad \text{Equ. (6.16)}$$

Where:

$N\,P_i$	the **IH cell** calibration value *(attraction)* due to the neighboring **network factors**,
Y	the total number of **network** factors,
a, b, c, …..., n	the number of neighboring pixels from **network type** *(i)* at levels 1, 2 , 3, …., and n, respectively,
$W_1, W_2, W_3, \ldots., W_n$	user defined weights *(attraction)* for **network** factors at levels 1, 2 , 3, …., and n, respectively.

7- Then the procedure moves to write the **calibrated influence ratio** for each land use and network factor in the results calibration table. In addition, it writes the **cell calibration value** due to all neighboring land uses and network factors in the same table.

8- Then, the calibration procedure check the total **IH Quota** *(step 2)*, if **IH** Quota not reached, the procedure go back to **step 3** to choose another **IH** cell.

9- If the **IH Quota** was reached, *(i.e., all IH cells were examined)* then, the calibration procedure calculate the **relative influence ratio** for each **land use** factor $Lu\ P_{i\,(r)}$, and **transportation network** factor $NP_{i\,(r)}$. Also, the **IH cell relative calibration value** $Lu(c)_{(r)}$, $N(c)_{(r)}$ as follows:

$$Lu\,p_{i\,(r)} = \frac{\sum_{i=1}^{no} Lu\ P_i}{No} \Big/ \max LuP_i \qquad \text{Equ. (6.17)}$$

$$N\ p_{i\,(r)} = \frac{\sum_{i=1}^{no} N\ P_i}{No} \Big/ \max\ N\ P_i \qquad \text{Equ. (6.18)}$$

$$Lu(c)_{(r)} = \frac{\sum_{i=1}^{no} Lu_{(c)}}{No} \Big/ \max\ Lu_{(c)} \qquad \text{Equ. (6.19)}$$

$$N\ (c)_{(r)} = \frac{\sum_{i=1}^{no} N_{(c)}}{No} \Big/ \max\ N_{(c)} \qquad \text{Equ. (6.20)}$$

<u>Where</u>:

$Lu\ P_{i\,(r)}$	the relative influence ratio for **land use** factor *(i)*,
$NP_{i\,(r)}$	the relative influence ratio for **network** factor *(i)*,
$Lu\ (c)_{(r)}$	the relative calibration value for <u>**IH cell**</u> due to all neighboring **land use** factors,
$N\ (c)_{(r)}$	the relative calibration value *(attraction)* for <u>**IH cell**</u> due to all neighboring **transportation networks** and **watercourses** factors,
No	the number of examine **IH cells**.

10- Then, the calibration procedure displays the calibration results for all <u>land uses</u>, <u>networks</u> and <u>watercourses factors</u> in the **IHGM** calibration form, as shown in Figure (6-16).

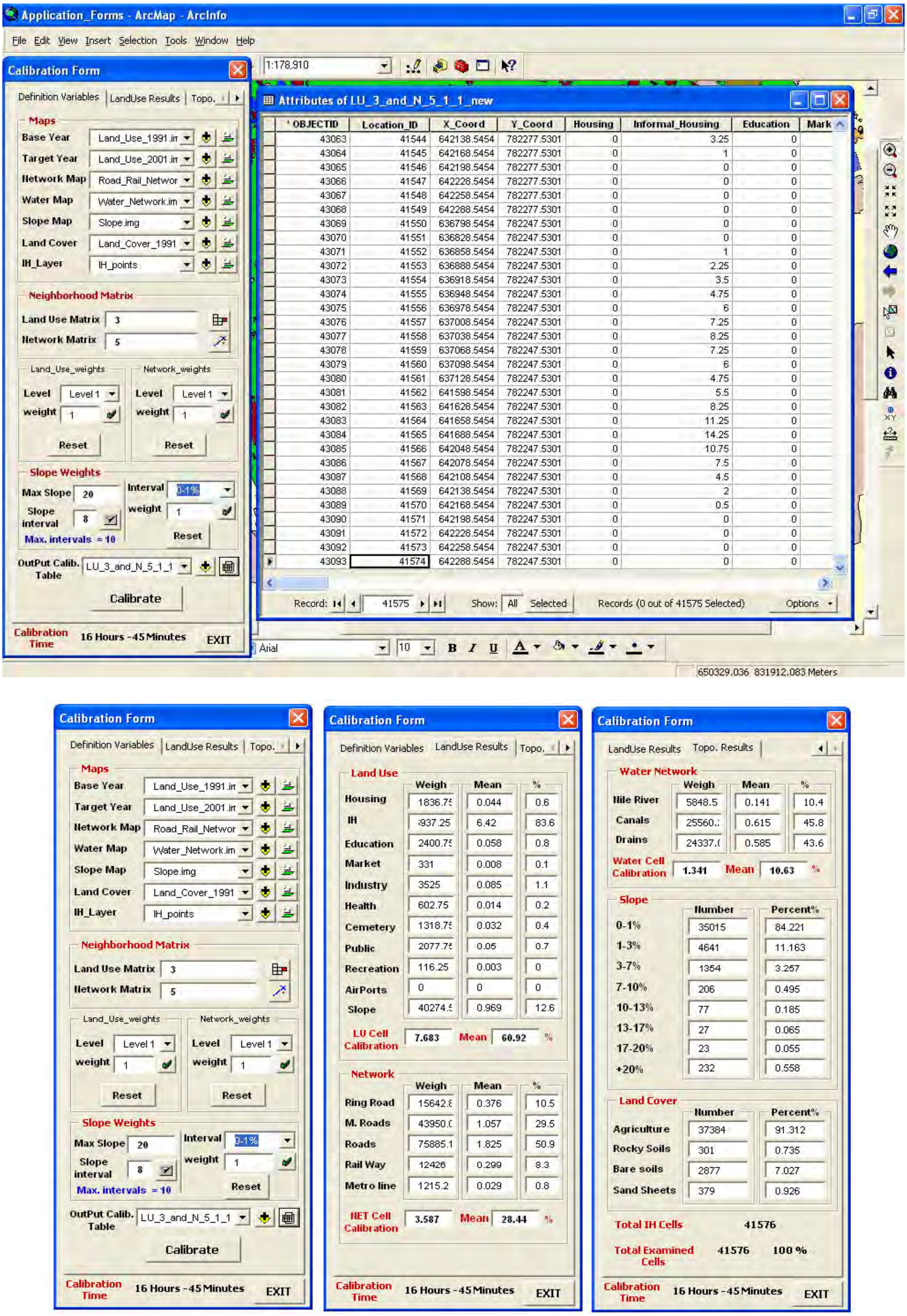


Figure (6-16) Sample of **IHGM** calibration module results

(where Lu(s) = 3 , N(s) = 5)

(6-4-3) The Probability Module

The Probability module was developed to derive the most suitable areas for **IH** expansion, the concept of **<u>weighting</u>** and **<u>rating</u>** growth factors was used to calculate the probability to change based on **four** main assumptions:

a) User defined transition rules, *(experiences gained from the calibration phase).*

b) The **influence ratio** of growth factors relative to others, that derived from the calibration phase.

c) The degree of **closeness** or **remoteness** of the examined <u>vacant cell</u> from all **land use types**.

d) The degree of **closeness** or **remoteness** of the examined <u>vacant cell</u> from all **transportation network types** *(Accessibility).*

This module consists of **three** sub-modules: **Transition rules module**, **calculate probability to change** and the **mobility module**. Figure (6-17) shows the probability module flow-chart.

(6-4-3-1) Transition Rules Sub-Module

The **IHGM** based on multiple criteria and assumptions, which define the cases and conditions under which an **IH pixel** can be created.

In this section, the user defines many assumptions and rules that control the <u>land mobility</u> from **vacant** to **built-up state**, this rules will considered when calculating the <u>vacant cell probability to change</u> in the next step. This sub-module contains **five** categories as follows:

a) **<u>Physical suitability rules:</u>** reflect the **on-site** relationships between different land uses and **IH** expansion. Although human factors play other roles in urban development, **physical features are the fundamental force** that control the **IH** spread and emergence, especially in **LDC**.

b) **<u>Accessibility rules:</u>** reflect the **off-site** effects of **transportation means** *(e.g., roads, railways, and metro lines)*, **watercourses** *(e.g., canals and drains)* and **utilities**, which represent a <u>reverse function</u> of distance with urbanization and often generate urban expansion with linear characteristics.

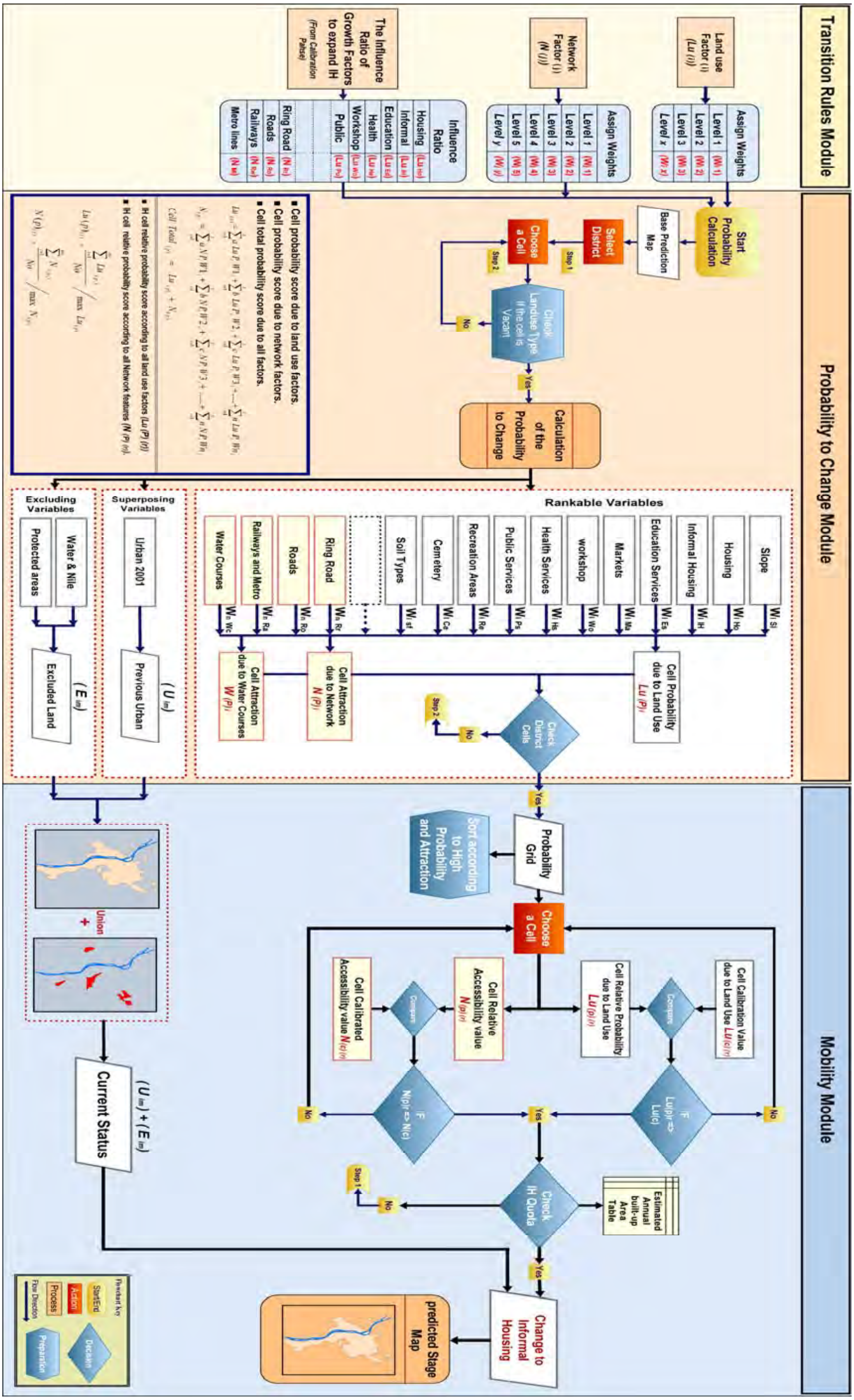


Figure (6-17) The Probability module flow-chart

c) **Market rules:** these rules concern with **where urbanization will grow faster**, when the housing demand is relatively high and land price is relatively low, *(e.g., high population, low availability of vacant land, and the availability of employment opportunities).*

d) **The urban-to-urban rules:** these rules assume that the initial urban will remain urban in future and land use change from **non-urban** *(agriculture natural, desert …etc.,)* to **urban** is allowable.

e) **Policy constraint rules:** these rules define the environmental and military important areas that protected from urban development.

The transition rule sub-module is very flexible to include many other assumptions and rules, the proposed **CA** macro allows the user to define the following rules:

- The **size of neighborhood matrix** for land use **$Lu_{(s)}$** and network **$N_{(s)}$** factors,
- The **weights** of growth factor at the neighborhood search matrix levels *(W_1, W_2, W_3,…., W_n)*,
- The growth factors **influence ratios**.

1- Definition of the neighborhood matrix size

In this section the user defines the **size of the neighborhood search matrix** for both land use, network, and watercourses factors, we must notice that the higher the matrix size the higher of the produced cells that able to convert to **IH** cells in the next step, also the higher of the program run time.

In the case of **GCR** future prediction, we use **5** sizes of neighborhood matrix *($Lu_{(s)}, N_{(s)} = 3$ - $Lu_{(s)}, N_{(s)} = 4$ - $Lu_{(s)}, N_{(s)} = 5$ - $Lu_{(s)}, N_{(s)} = 6$ - $Lu_{(s)}, N_{(s)} = 7$)* to test many matrices sizes and chosse the most suitable size that simulate the behavior of **IH** expansion in the region.

2- Definition of the levels weighs of neighborhood matrix

a) Land uses weights:

In this section, the user defines different scores *(weights)* for land uses factors according to the level of nearest or remoteness from the vacant cell.

b) Transportation networks weights:

In this section, the user defines different scores *(attraction weight or accessibility value)* for transportation networks and watercourses factors according to the level of nearest or remoteness from the vacant cell.

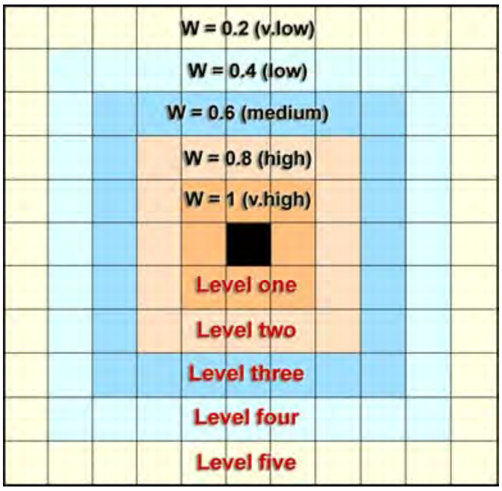


Figure (6-18) Example of neighborhood matrix for network factors *($N_{(s)}$ = 5)*

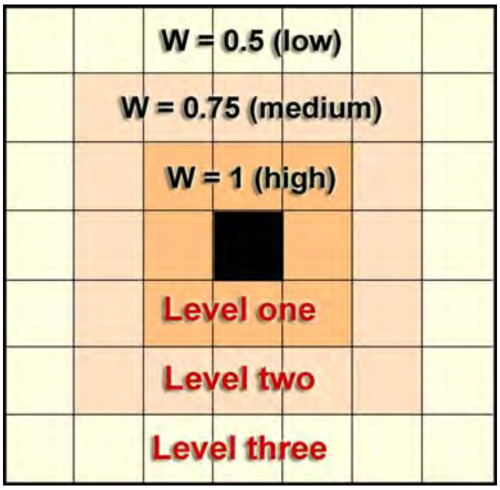


Figure (6-19) Example of neighborhood matrix for land use factors *($Lu_{(s)}$ = 3)*

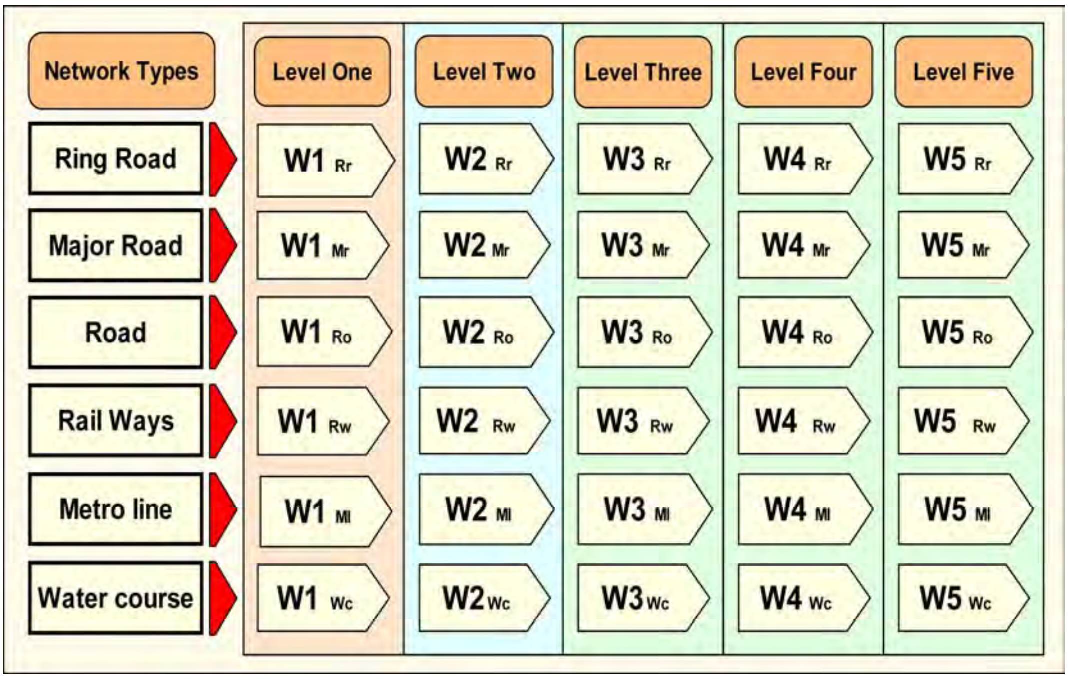


Figure (6-20) Example of the proposed weights for network factors, where the neighborhoods matrix size **N(s)** = **5**

3- Definition of the growth factors influence ratios

In this step, the user assigns an **influence ratio** for each land use growth factor relative to other factors and its contribution to emerge **IH**, as well as, the degree of **attraction** to spread **IH** due to network and watercourses factors relative to others.

These values are based on the acquired knowledge from the study of historical urban development, and the obtained results from calibration module.

For instance, the **road** affect on the emergence of **IH**, the weight **boost** for roads is increased to the **maximum**, whereas the weight of other factors *(markets, education, health services,…etc.,)* is significantly reduced or ignored.

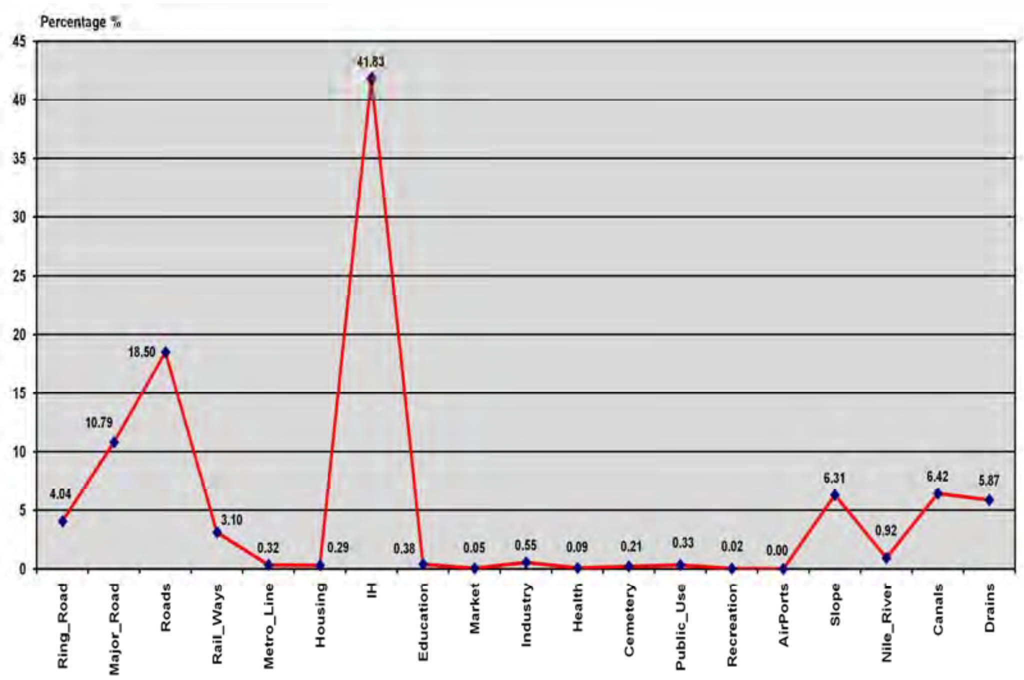


Figure (6-21) Example of the influence ratios of land use and network factors to emerge informal housing, *(where $Lu_{(s)} = 3$, $N_{(s)} = 5$)*

(6-4-3-2) Calculation of the Probability to Change

The **Probability to change** sub-module was developed to derive land suitability for **IH** expansion by taking the contribution of all growth factor, the concept of **rating**, and **weighting** growth factors was used to calculate the vacant cell probability.

The cell **probability to change** depends on, the states of the surrounding cells *(land uses, network, and watercourses features)*, for example:

- **a)** If a **vacant cell** is located in a **high slope**, then its probability of becoming an **IH** cell at the next iteration decreases *(low probability)*;
- **b)** If a **vacant cell** is located close to *(e.g., less than four extended neighbors away from)* a **road**, **river**, **market place**, i**ndustry area** or **low slope cell**, then its probability of becoming an **IH** cell increases by a user-defined value *(high probability)*;
- **c)** If a **vacant cell** is close to both **IH** cell and **workshop place** or one or more **roads**, its probability of becoming an **IH** cell becomes even greater *(high probability)*;

Based on the above rules, the probability to change of any vacant cell depends on the nearest or remoteness from the existing informal housing. i.e., the location of expected new **IH cell** must be near to existing **IH** cells created in previous periods, this rule ***prevents emerging IH cells near to other land use classes; unless they are surrounded by at least one IH cell.***

These general rules control the **Visual Basic** program operations. Apart from the growth coefficient values that are calibrated by comparing two historical urban data. the model provides various possibilities for **fine-tuning** these rules, and **the growth coefficients values can be adapted to a specific condition to improve the prediction accuracy**.

The **probability to change sub-module** calculates a **probability score for each vacant cell** according to the **types** and **No of neighboring pixels** from land uses and network features *(Equ. 6.21 and 6.22)*. Then the **mobility module** classifies and sorts all the predicted cells by districts to change the high probability cells that satisfy the mobility rules to **IH** cells in the next period.

The **probability to change procedure** starts by defining the **land use**, **road network**, **watercourses**, **slope**, and **land cover maps** in the base prediction year, as well as **the districts map** *(el_ahyaa)* which contains the statistical expected annual **built-up area** for each prediction period *(as discussed in section 6-2)*. The procedure contains the following steps:

1) Choose the first cell in the entire grid *(study area)*.
2) Check the selected cell **land use type**, if the cell is **not vacant** *(occupied)* then the macro moves to choose the next cell, else if the cell **is vacant** then the macro proceed to **calculate the cell probability to change**.
3) Then the macro search outward to identify the neighboring land use and network types to calculate the probability to change score.
4) The macro calculates:

   First: cell probability score due to all neighboring **land use types** ($Lu_{(p)}$) by using neighborhood matrix (**Lu (s)**), which defined in the transition sub-module, using (Equ. 6.21)

   Second: cell probability score due to all neighboring **transportation and watercourse types** ($N_{(p)}$) by using neighborhood matrix (**N(s)**), which defined in the transition sub-module, using (Equ. 6.22).

$$Lu_{(p)} = \sum_{i=1}^{x} a\ Lu\ P_i\ W1_i + \sum_{i=1}^{x} b\ Lu\ P_i\ W2_i + \sum_{i=1}^{x} c\ Lu\ P_i\ W3_i + \ldots + \sum_{i=1}^{x} n\ Lu\ P_i\ Wn_i \qquad \text{Equ. (6.21)}$$

Where:

$Lu_{(p)}$	the **cell** probability score due to all neighboring land uses,
$Lu\ P_i$	the influence ratio of **land use** *(i)* relative to other land use factors *(the calibrated value for land use factor (i))*,
x	the total number of **land use** factors,
a, b, c, ….., n	the number of neighboring pixels from **land use** *(i)* at levels 1, 2, 3, …. and n, respectively,
$W_1, W_2, W_3, \ldots, W_n$	user defined weights for **land use** factors at levels 1, 2, 3,… and n, respectively.

$$N_{(p)} = \sum_{i=1}^{y} a\ NP_i\ W1_i + \sum_{i=1}^{y} b\ NP_i\ W2_i + \sum_{i=1}^{y} c\ NP_i\ W3_i + \ldots + \sum_{i=1}^{y} n\ NP_i\ Wn_i \qquad \text{Equ. (6.22)}$$

Where:

$N_{(p)}$	the **cell** probability score due to all neighboring **network** types,
$N\ P_i$	the influence ratio of **network factor** *(i)* relative to other factors *(the calibrated value for network factor (i))*,

y	the total number of **network** factors,
a, b, c, ….., n	the number of neighboring pixels from **network** *(i)* at levels 1, 2 , 3, … and n, respectively,
$W_1, W_2, W_3,…,W_n$	user defined weights fro **network** factors at levels 1, 2 , 3, … and n, respectively.

5) Then the macro calculates the vacant cell **total probability score** by summing the probability due to all land uses ($Lu_{(p)}$) plus the probability due to all transportation and watercourses factors ($N_{(p)}$).

6) Then the macro writes the calculated values ($Lu_{(p)}$), ($N_{(p)}$), and ($Total_{(p)}$) in the probability to change layer *(point layer)*.

$$Cell\ Total_{(p)} = Lu_{(p)} + N_{(p)} \quad \text{Equ. (6.23)}$$

7) Then the macro go back to **step 2** to select the next vacant cell and calculate its probability to change score.

8) After examining all cells in the entire grid and calculate the probability to change for all **vacant cells** *(in the case of GCR, the number of rows = 1777 and the number of columns = 1531)*, then the **mobility sub-module** starts.

(6-4-3-3) The Mobility Sub-Module

The mobility sub-module converts the **vacant cells** that satisfy the user defined mobility rules into new **IH** cells. The created **IH** cell in any district added to the **annual_pixel_gain** count, which will use to update the **nett_pixel_gain** value.

The mobility module executes **three** main functions :

(a) Classify the probability to change layer that generated from the previous step according to district name, and sort the estimated **IH** points according to their total probability score.

(b) Compare the probability to change score for the estimated **IH** points with the calibration score for both **land use** and **network** factors.

(c) Check the stock of new **IH** cells that created in any district with the required statistical quota. If the **nett_pixel_gain** quota reached, then the macro proceeds to record the highest probability **IH** points in the output map.

The mobility module passes through the following steps :

1- Choose the first district from the districts map *(el_ahyaa)*,

2- Sort all the estimated **IH** cells in the selected district according to land use probability ($Lu_{(p_i)}$) and network probability ($N_{(p_i)}$) value , and get ($\max Lu_{(p)}$) and ($\max N_{(p)}$) .

3- Then the macro loops through all the estimated **IH** cells in the selected district, and calculates the **relative probability score** for **land use** factors ($Lu(p)_{(r)}$), and the **relative probability score** for **network** factors ($N(p)_{(r)}$), as follows:

$$Lu(p)_{(r)} = \frac{\sum_{i=1}^{no} Lu_{(p_i)}}{No} \Big/ \max Lu_{(p)}$$ Equ. (6.24)

$$N(p)_{(r)} = \frac{\sum_{i=1}^{no} N_{(p_i)}}{No} \Big/ \max N_{(p)}$$ Equ. (6.25)

4- Then the macro, loops through all the estimated **IH** cells in the selected district to test the following **two** cases :

- **Compare** the relative calibration value ($Lu(c)_{(r)}$) with the relative probability score ($Lu(p)_{(r)}$) for land use types.
- **Compare** the relative calibration value ($N(c)_{(r)}$) with the relative probability score (*accessibility)* ($N(p)_{(r)}$) for network types.

5- **If** $Lu(p)_{(r)} + N(p)_{(r)} < Lu(c)_{(r)} + N(c)_{(r)}$ **,** then the macro moves to **step (4)** and select the next **IH** cell in the same district.

Else if $Lu(p)_{(r)} + N(p)_{(r)} => Lu(c)_{(r)} + N(c)_{(r)}$ **,** then the macro changes the state of the selected cell to informal housing.

6- The mobility sub-module verifies the number of generated **IH** cells, which created in any district and update the **annual_pixel_gain** count.

- If the required **IH** quota not reached, the macro runs over to locate the next **IH** cell *(step 4)*.
- Alternatively, if the required **IH** quota reached, then the macro moves to **step (4)** and select the next district from the districts map *(el_ahyaa)*,

7- When the macro examines all the districts, then it starts to write the converted **IH** cells in the **predicted map** for this period.
8- **Finally**, the mobility sub-module registers the total values of changes during the iterations into the output file. The output file updated after each iteration period, then the **prediction module** can starts to display the simulation results.

(6-4-4) Displaying and Visualization of IHGM Results

This module sets the overall outcome and displays the results of the simulation. More specifically, when the simulated maps produced under the previous described conditions, the output is recorded and ready to be displayed. Then, the generated maps will display to the default **GIS** environment *(ArcGIS 9.x)* and store in the specified working directory.

The **IHGM** is very flexible to display the simulated output maps in different formats, such as the default **GIS** environment that was in **raster data_grid**. As well as, the simulated maps can be displayed on a **user-defined color palette**. Additionally, the user has the option to define which prediction period will be displayed *(for instance, all results, every period, and so on).*

The model also has a provision to adjust the **IH** quota if the program is encountering difficulties. An additional command line adds a **user-defined period** *(in this case annual change)* and the map title on bottom of each simulated map.

The final command automatically displays the simulated maps onto the specified **GIS** interface.

(6-5) Preparing GCR Data to Run the Model

This section outlines the case study of applying and testing the proposed **I**nformal **H**ousing **G**rowth **M**odel **(IHGM)** presented in the previous sections, and applies it to a real situation.

The first part discusses the case study area of **G**reater **C**airo **R**egion, and briefly describes the rapid expansion and growth of **IH**.

The second part outlines the selected growth variables and presents the required data to run the proposed growth model, as well as, the steps of data preparation.

(6-5-1) Location and Urbanization Processes in GCR

Greater **C**airo **R**egion (**GCR**), the first largest city and capital city of **Egypt** in North East of Africa continent was chosen to test the proposed growth model.

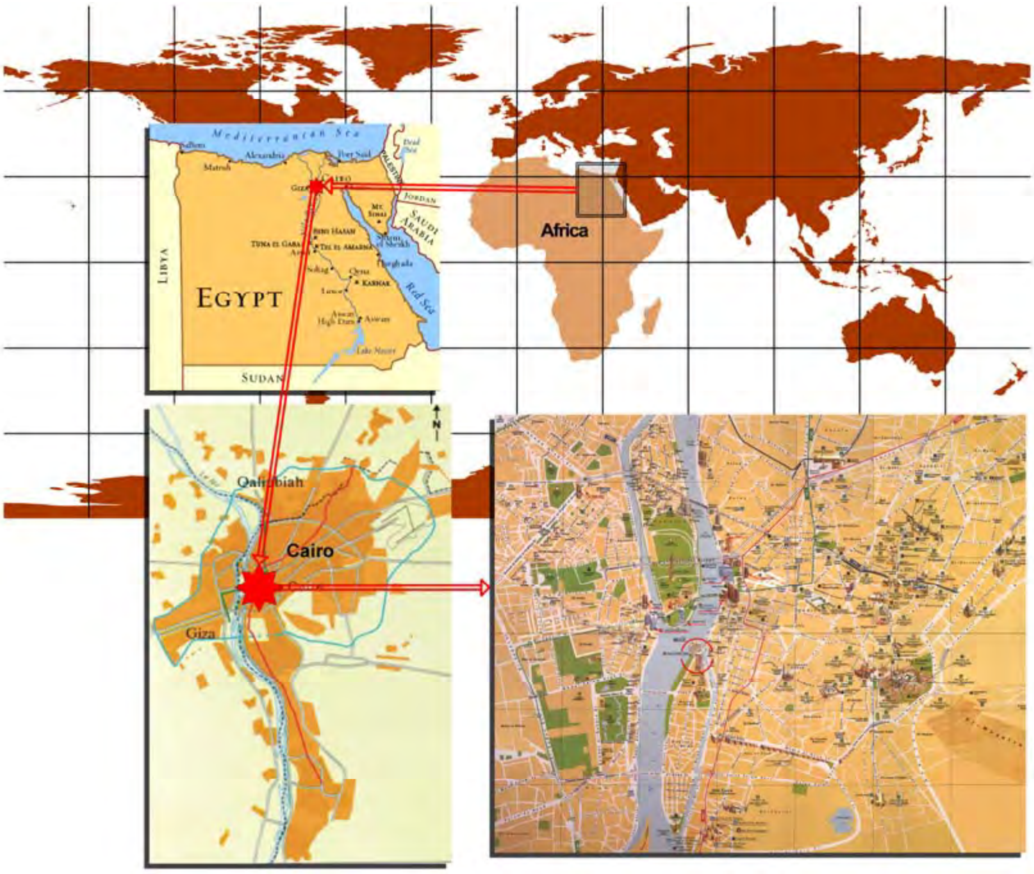


Figure (6-22) The study area: **G**reater **C**airo **R**egion, Egypt

Egypt, with its strategic location in the centre of the **old world**, has become the second most **populous country in Africa after Nigeria**. Throughout the long history of **Egypt**, urbanization has occurred, great cities and major villages have grown up along the banks of **Nile River** and **Delta**, which represent only **4%** of the country total area. Therefore, **population** and **economic activities** concentrated in this narrow and limited area (Yousry, M and Aboul atta, T. 1998).[(1)]

Cairo is the capital of **Egypt**, has grown rapidly to reach more than **15.4 million inhabitants in 2006** (CAPMAS, 2006). It has become the largest urban centre not only in **Africa**, but also in **Middle East**.

Section	Population (2006)	Area: Square Km (app.)	Density per Km²
City	7,740,000	215	36,000
Suburbs	7,705,000	1210	6,368
Total	15,445,000	1425	10,838

Table (6-12) **GCR** urban area: central city and suburbs population & density [(2)]

Greater Cairo Region was selected to test the proposed **IHGM** for **two** main reasons:

- **Firstly**, the population of **GCR** has dramatically increased during the last thirty years, after the **1973** war. The population of **GCR** rapidly grew, especially due to rural migration and the Egyptian government policy that moved to centrally planned and the domination of public sector on economy *(open door policy), (see chapter 2).*

  Figure (6-23) shows how the population of **GCR**, grew from **8.09 MP** in 1976 to **10.860 MP** in 1986 to **15.445 MP** in 2006 and expected to be about **17 MP** by 2010 (Alkitkat, H., 2008). Hence, the **A**verage **P**opulation **G**rowth **R**ate (**APGR**) of **GCR** was above **(2.99%)** from 1976 to 1986, and about **(1.93%)** from 1986 to 1996, and about **(1.63%)** from 1996 to 2006.

  Therefore, the **APGR** of the region has been one of the highest found in **Africa continent** and **Middle East** in the past **thirty years**.

(1) This article available at: http://www.unu.edu/unupress/unupbooks/uu26ue/uu26ue0d.htm
(2) This article available at: http://www.demographia.com/db-worldua.pdf

Many studies have been expected the population growth rate of the region has continued with a **slight tendency to decrease in the near future**. *(For more details see section 6-2).*

- **Secondly**, the urban space of **GCR** has become the largest urban center in **Africa**, and **Middle East**. The **GCR** built-up area has increased almost **eight times** in less than **five** decades, the region built-up area was gradually grow from **58** Km^2 in **1952**, to about **315** Km^2 in **1984**, to about **366** Km^2 in **1991**, and in **2001** the built-up area of **GCR** was estimated about **465** Km^2, as shown in Figure (6-24).

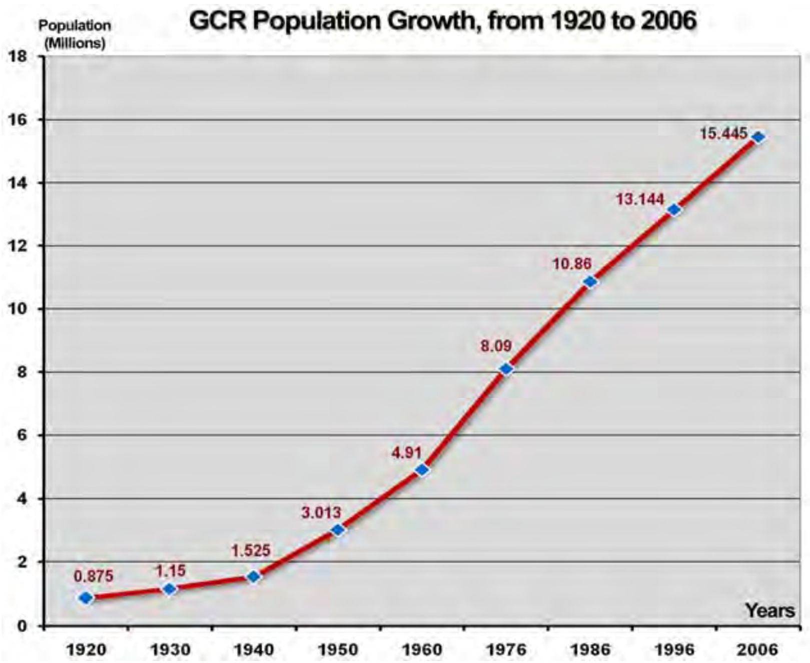


Figure (6-23) **GCR** Population growth, from 1920 to 2006 (**CAPMAS**, 2006)

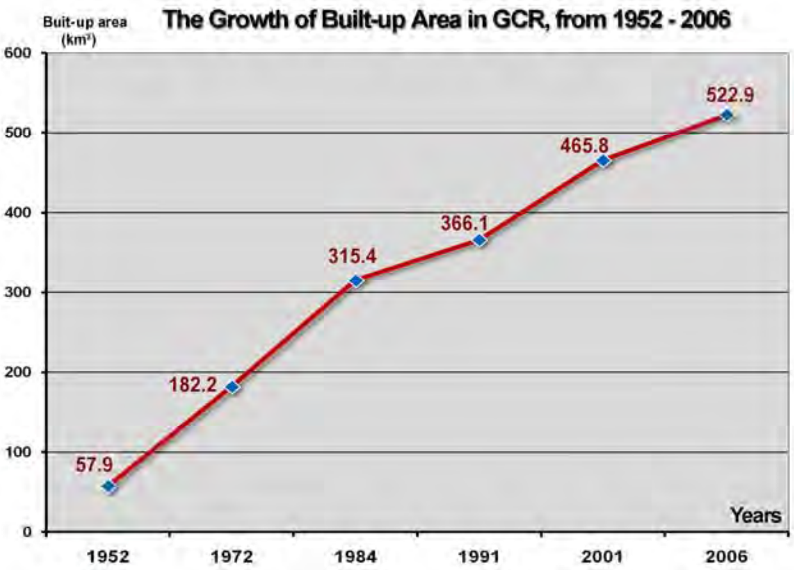


Figure (6-24) The growth of Built-up area in **GCR**, from 1952 to 2006 (the researcher work)

The rapid urbanization of **GCR** has been the result of many factors, of which some are applicable to most **large urban centers** in Egypt and some are specific to the **region**. Some of the leading factors are **demographic**, **economic**, **centralization**, and **political**, while the **accessibility** is also important factor.

It therefore clear that the urbanization process in **GCR** is dominated by **three main factors**:

- **High population growth**,
- **The centralization of economic and public activities in GCR**,
- **The *informalization* of urban space** (Yousry, M and Aboul atta, T. 1998). [1]

year	Formal Housing (area Km²)	Percentage	Informal Housing (area Km²)	Percentage	Total Housing (area Km²)
1972	65.374	52.8 %	58.422	**47.2 %**	123.796
1984	81.767	41.2 %	116.784	**58.8 %**	198.551
1991	103.298	44.0 %	131.386	**56.0 %**	234.684
2001	132.255	44.2 %	166.767	**56.8 %**	299.022
2006	129.33	39.7 %	196.794	**60.3 %**	326.124

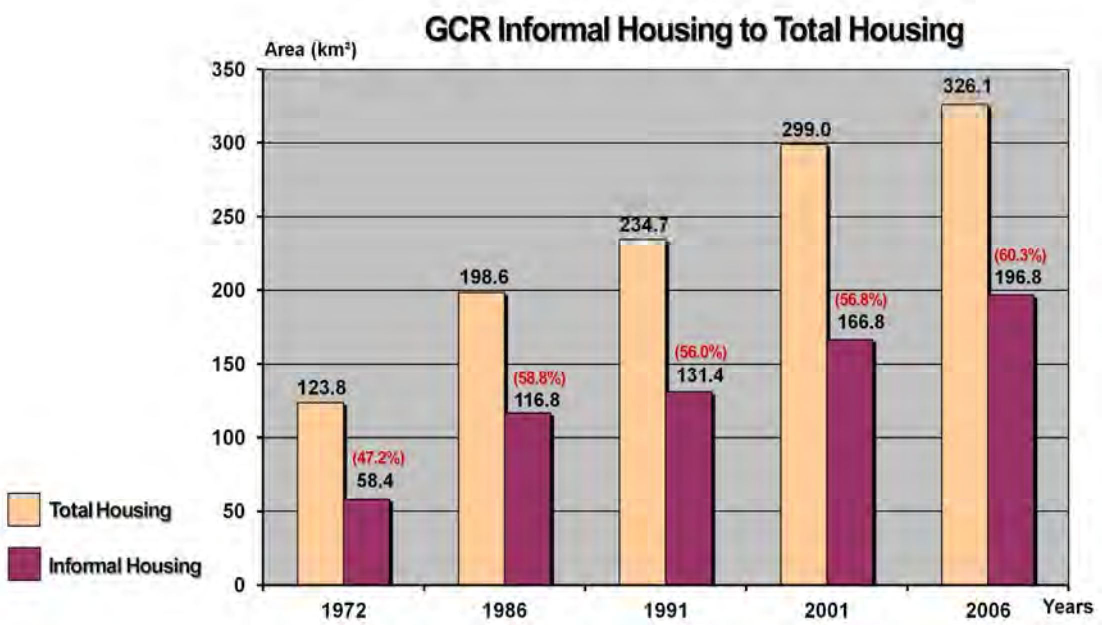


Figure (6-25) A comparison between **informal housing** with **total housing** in **GCR** from 1972 to 2006 (the researcher work)

(1) This article available at: http://www.unu.edu/unupress/unupbooks/uu26ue/uu26ue0d.htm

Recent studies show that about **81** slums and informal areas spread inside and around the **GCR**, represents about **58%** of the region housing area in year 2002 and accommodate about **65%** of the region dwellers (Madbouly, M., 2005).

One of the most noticeable features of GCR urban space is the long tradition of the predominance of IH.

Similarly, the **informal market** represents more than **70** % of housing stock (Woodrow Wilson International Center for Scholars, 2006) [(1)], which means that new future demand from housing is more likely to expand through the informal mechanism *(provision, finance, construction, allocation,… etc.,).*

In **GCR** there are **two** main classes of informal housing can be identified based on the type of occupied land, *(agriculture or desert land).*

- **The first** type is **IH on agriculture land**, this type spreads in the **northern part** of the region, especially in *Shubra Al-Khaima, Bahtem, Al-Marg, Al-Khusûs,* and *Al-Khanka,* also the **western part** in *Al-Waraq, Bashteel, Al-Ahram, Imbaba, Bolaq Al-Dakrour,* and *Al-Omrania,* and the **southern part** in *Al-Tebin* and *Tora.*
- **The second** type is **IH on desert land**, this type spreads in the **eastern part** from Nile River especially at the foot of Mokattam mountain, for example, *Monshat Naser, Al-Basatine, Al-Dewika,* and *Al-Jabal Al-Asfar,* as well as in the **northern part** *Azbit El-Hagana* in nasr city.

Figures (6-26 to 6-29) show the evolution of informal housing in **GCR** from 1972 to 2001, this study focuses on the expansion mechanisms of the **IH** category, which represents the most dynamic land use category in **GCR** in terms of **land acquisition**, **spatial identification** and **numbers of actors** (Sims, D.2003).

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(1) Comparative Urban Studies Project, Urban Studies in Cairo, Egypt , From Cairo to Greater Cairo Region, this article available at: http://www.wilsoncenter.org/cusp

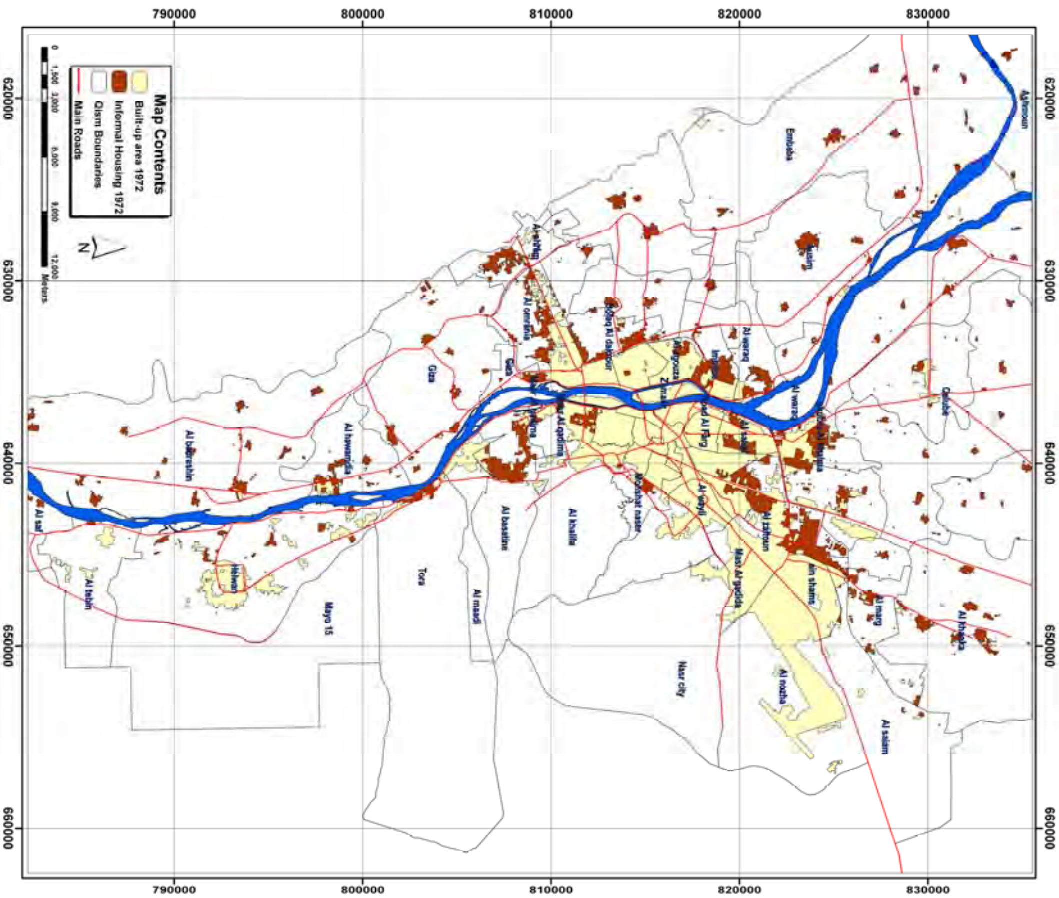


Figure (6-26) Comparison of **GCR** formal and informal growth in year **1972**

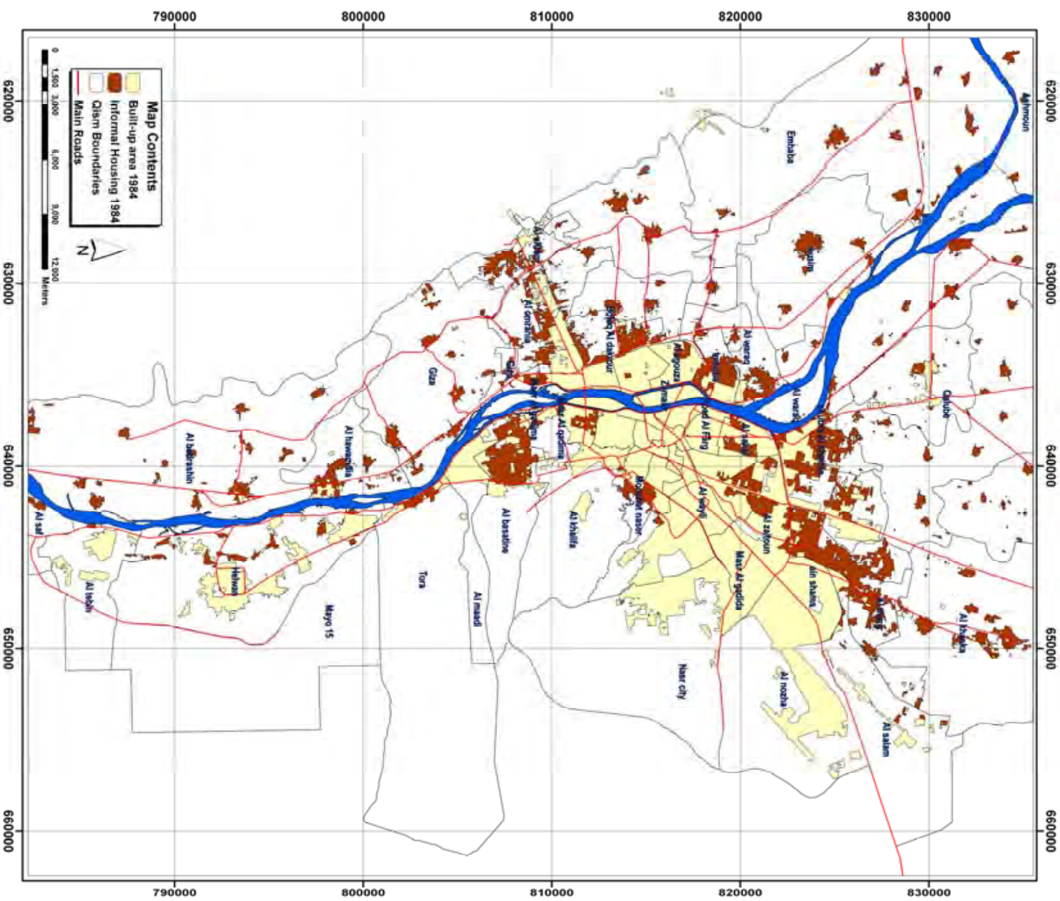


Figure (6-27) Comparison of **GCR** formal and informal growth in year **1984**

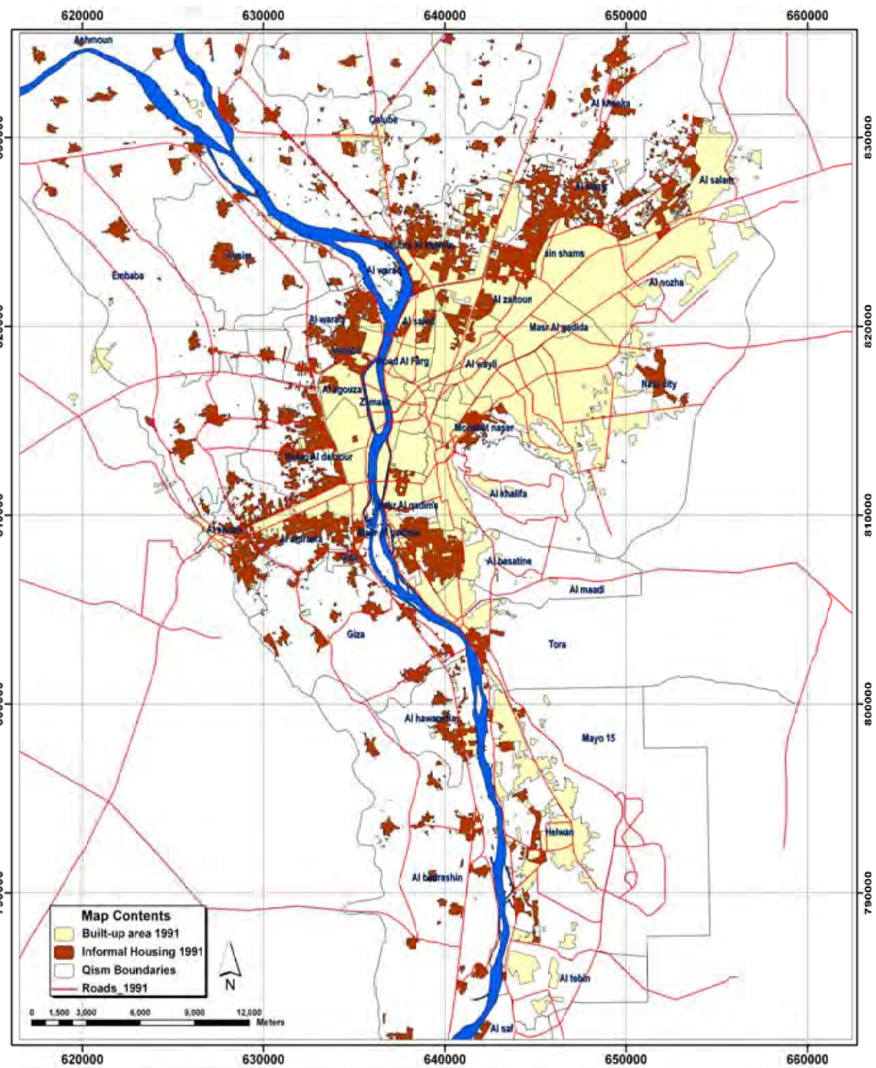


Figure (6-28) Comparison of **GCR** formal and informal growth in year **1991**

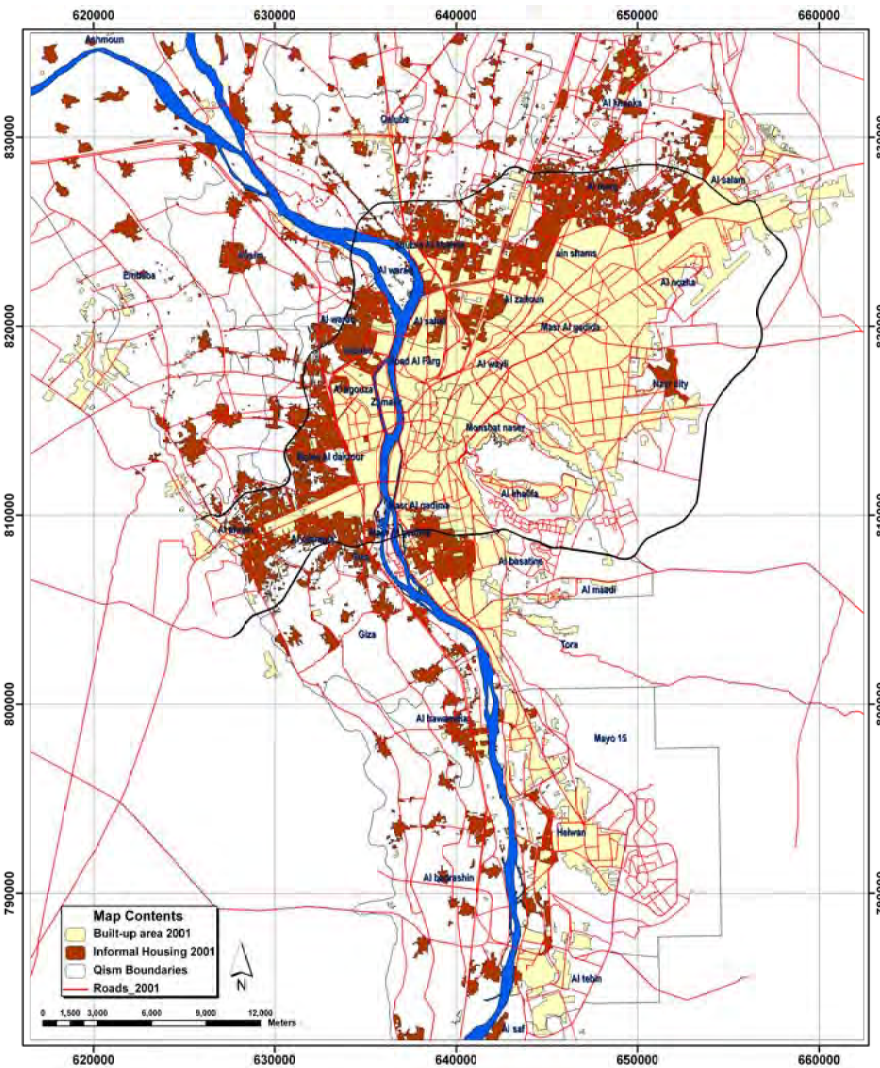


Figure (6-29) Comparison of **GCR** formal and informal growth in year **2001**

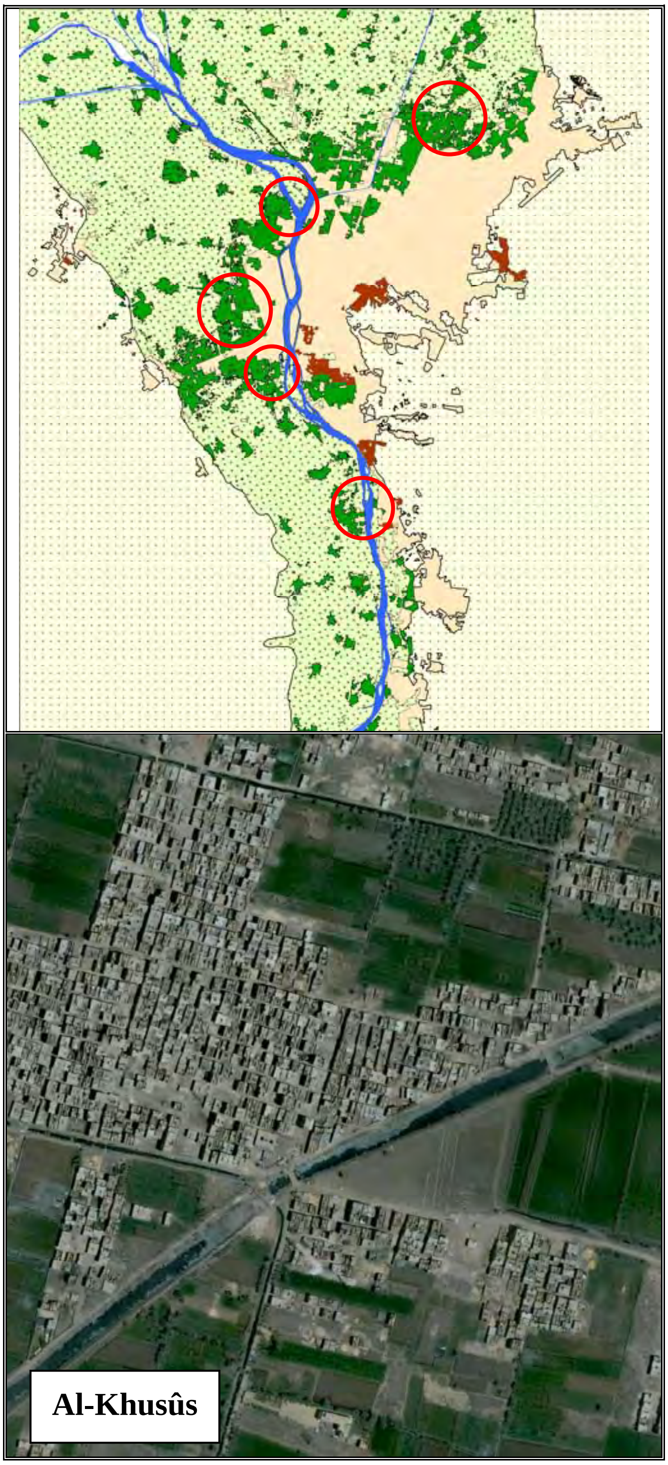


Figure (6-30)

IH on agriculture land, this type spreads in the <u>northern</u> and <u>western</u> part of the region, especially *Imbaba, Bolaq Al-Dakrour, Al-Ahram, Bashteel, Al-waraq, Shubra Al-Khaima, Al-Khusûs, Bahtem, and Al-Marg.*

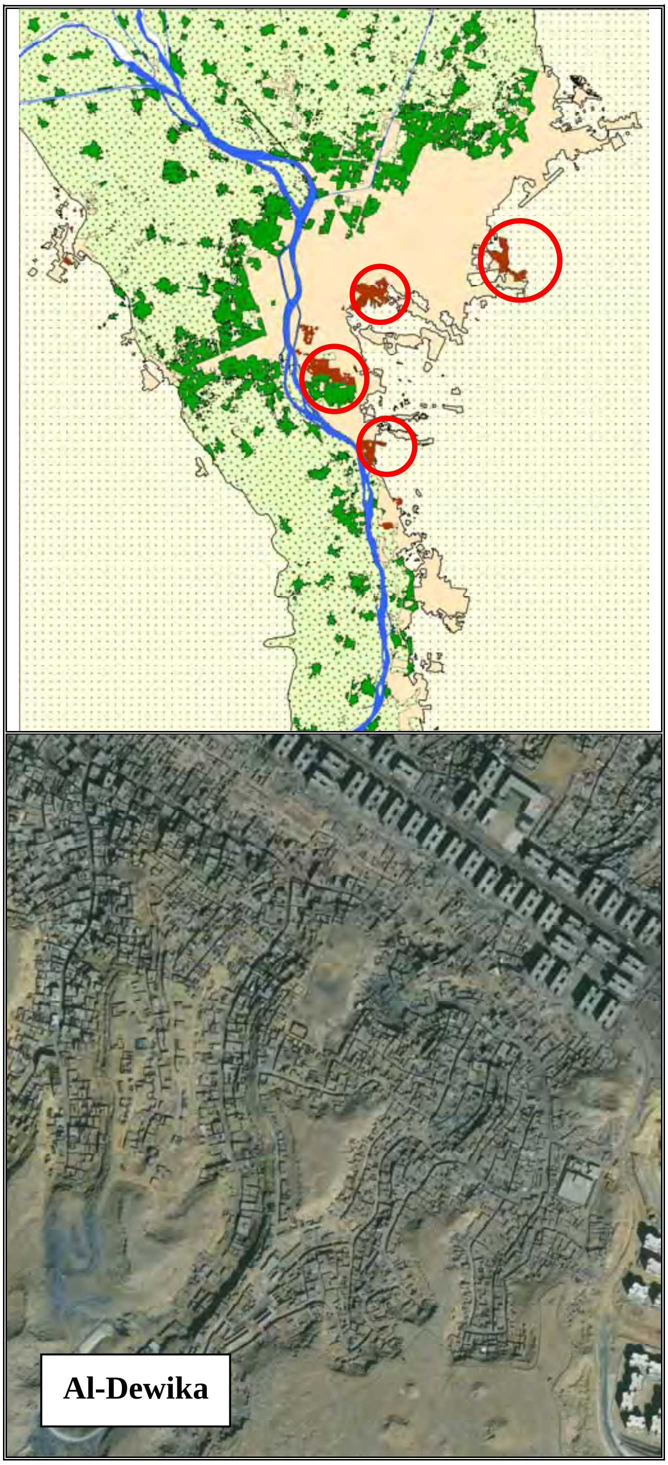


Figure (6-31)

IH on desert land, this type spreads in the eastern part from the Nile River especially at the foot of Mokattam mountain, for example, *Monshat Naser*, *Al-Basatine, and Al-Dewika*.

(6-5-2) Selection of Growth Factors and Data Preparation

The selection of growth factors to be incorporated into the application of **IHGM** is based upon their respective influence on the emergence and growth of **IH**. The following section discusses the choice of **33** different growth factors. The selected growth factors, that will considered in the application of the proposed growth model can be classified into **5** categories as follows:

a) **Land use category**

The ***starting calibration*** map represents the **GCR** land use in **1991**; it is used in the proposed model as the **"seed"** for the simulation of **IH** patterns. While, the ***final calibration*** map presents the **GCR** land use in **2001**; it is used in the model to calibrate the growth factors and validate the simulation outputs.

The **starting_year** and **final_year** maps have the following land use types:

1- Vacant land *(cultivated and desert lands)*,

2- Planned housing ***(Ho)***,

3- Unplanned housing or Informal Housing ***(IH)***,

4- Education services ***(Es)***,

5- Market places ***(Mp)***,

6- Workshop and industrial places ***(Wo)***,

7- Health services ***(Hs)***,

8- Cemetery ***(Ce)***,

9- Public and administrative domain ***(Ps)***,

10- Excluded areas ***(Ex)***, *(areas where IH cannot occur, especially known planning schemes such as: planned new cities around the region and military areas)*,

11- Recreation areas ***(Re)***,

12- Airports ***(Ai)***,

13- Nile River and main lakes ***(Nr)***.

An attempt was made to **identify market places** as points, this approach caused the macro to run too slowly because the points were too remotely scattered. Similarly, increasing the **neighborhood matrix size** caused the macro to slow down significantly. To resolve this problem, **the market places were represented**

as an area using its importance and its impact within the surrounding urban environment, taking into account the presence of **IH** in the neighboring areas.

In addition, the **place of workshop and industry** map was used to determine the role of working places in the emergence and spread of **IH**.

b) Transportation network category

The transportation network growth factors represent the main driving forces behind the expansion of **IH**, this category have the following transportation types:

1- Ring road ***(Rr)***,

2- Major roads ***(Mr)***,

3- Roads ***(Ro)***,

4- Rail ways ***(Rw)***,

5- Under ground Metro line ***(Ml)***.

These factors used to capture the essential relationship between **IH** patterns and transportation network. The existing **ring road** incorporated into the growth factors to show its influence ratio on the **urban planning delimitation**, especially on the expansion and distribution of **IH**.

c) Watercourses category

The watercourses factors used to determine their influence on the expansion and spatial distribution of **IH**, this category have the following types:

1- Lacks and canals ***(Ca)***,

2- Drains ***(Dr)***.

d) Topography category

The **slope and geography aspects** map used to test the influence of the topography on the expansion and spatial distribution of **IH**.

In this study the slope values were classified into **8** categories:

1- form 0 to 1% ;	**2- from 1 to 3%;**	**3- from 3 to 7%;**
4- from 7 to 10%;	**5- from 10 to 13%;**	**6- from 13 to 17%;**
7- from 17 to 20%;	**8- greater than 20%;**	

e) Land cover category

The land cover factors used to test the influence of land cover and soil types on the expansion of **IH**.

1- Agricultural cultivated areas ***(Agri)***,

2- Medium density cultivated areas ***(Me_Agri)***,

3- Rocky areas ***(Ra)***,

4- Bare soils ***(Ba)***,

5- Sand sheet areas ***(Sa)***.

These growth factors are prepared as a **GIS** map layers to easily consider in the model. However, **each category of these layers is merged into single file**, in order to speed up the calibration and prediction procedures, and cut down the macro running time.

All these layers are digitized and geo-referenced by using **ArcGIS** *(Arcinfo software)* [(1)]. All layers have the same **configuration**, **structure**, **spatial extents**, **cell size**, and **projection**, *(in case of **GCR**, the cell size is **30 x 30** meters, and number of rows = 1777, number of columns = 1531, i.e., 2720587 square cells).*

After all input files was prepared and named, then the **IHGM** can now be tested on a **"real-world"** situation. Figures (6-32 to 6-37) show the individual maps, which considered in the calibration phase.

[(1)] The data preparation for **IHGM** is identical with the data preparation procedure for **SLEUTH** program, which discussed in **Chapter 5**, **section** (**5-3**).

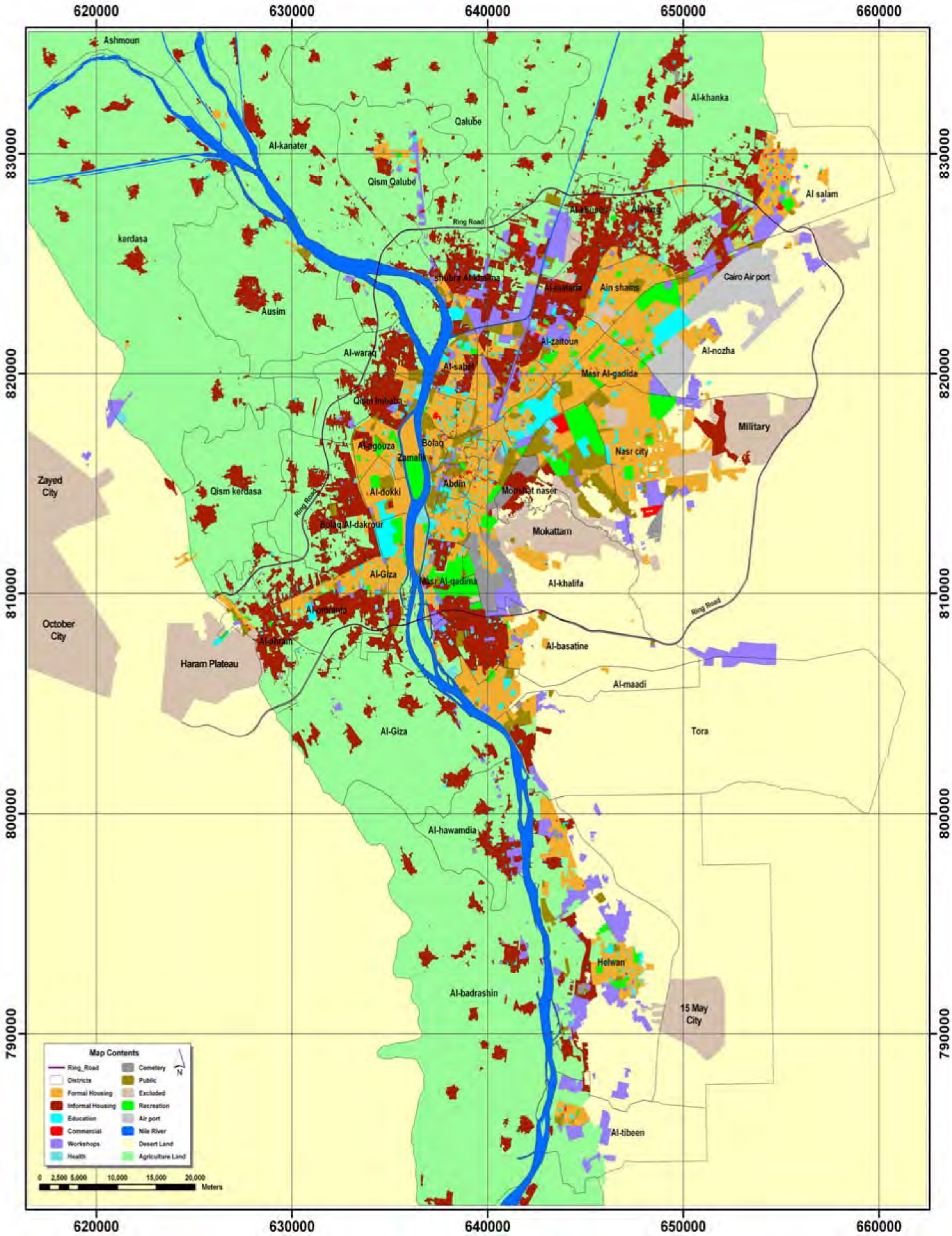


Figure (6-32) **G**reater **C**airo **R**egion land use map in the starting calibration year *(1991)*

(The seed of calibration phase)

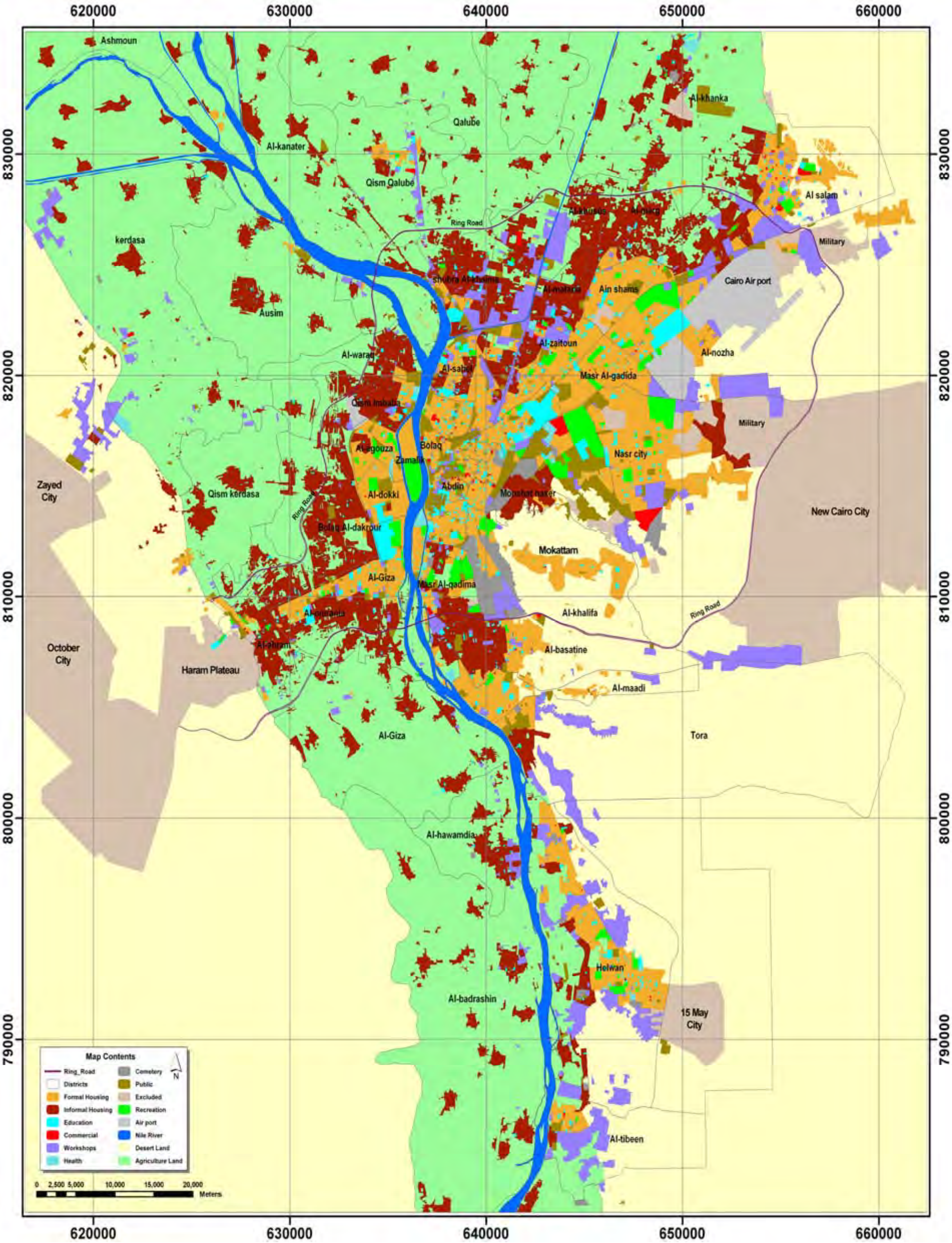


Figure (6-33) **G**reater **C**airo **R**egion land use map in the final calibration year *(2001)*

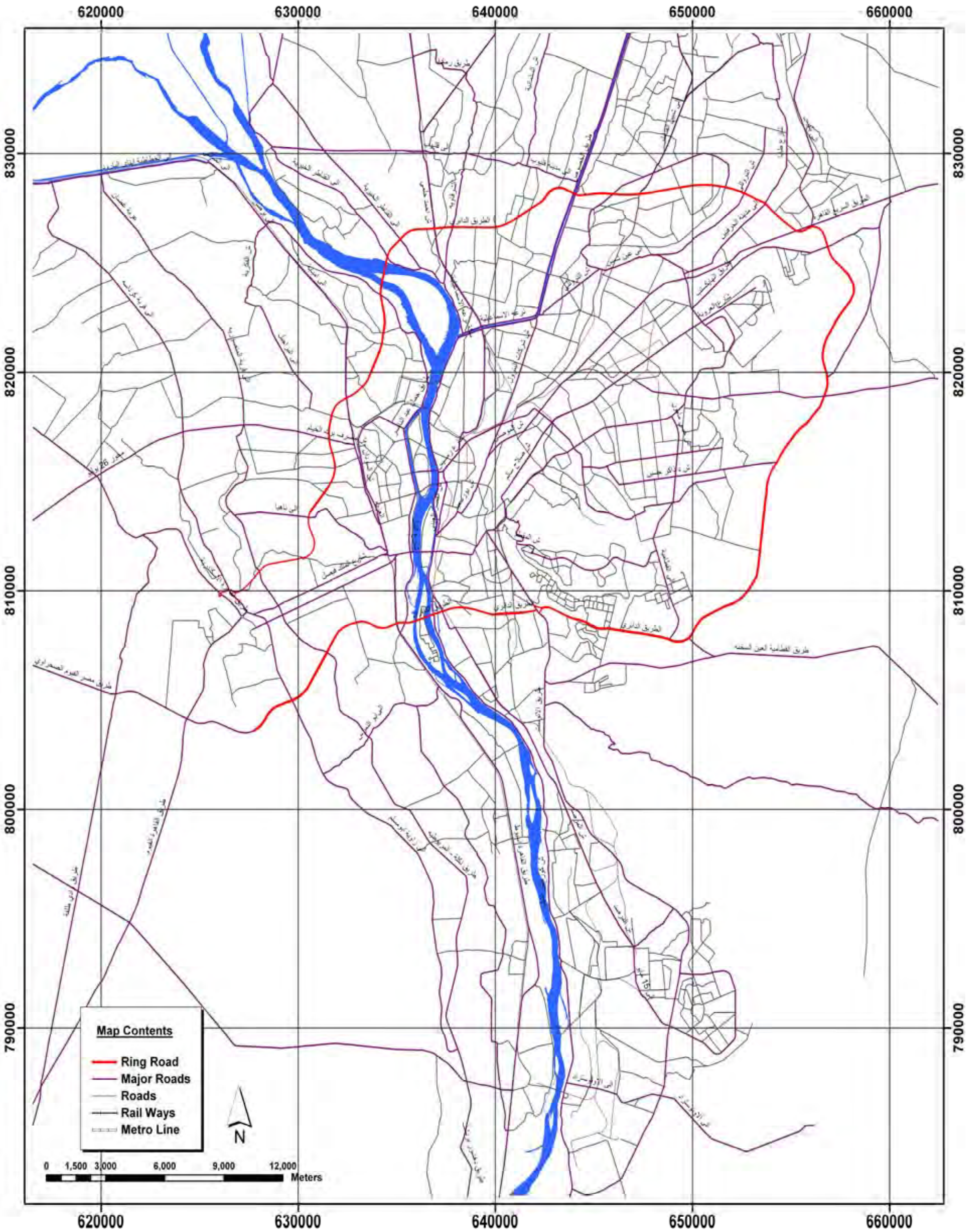


Figure (6-34) **G**reater **C**airo **R**egion transportation networks map

in the starting calibration year *(1991)*

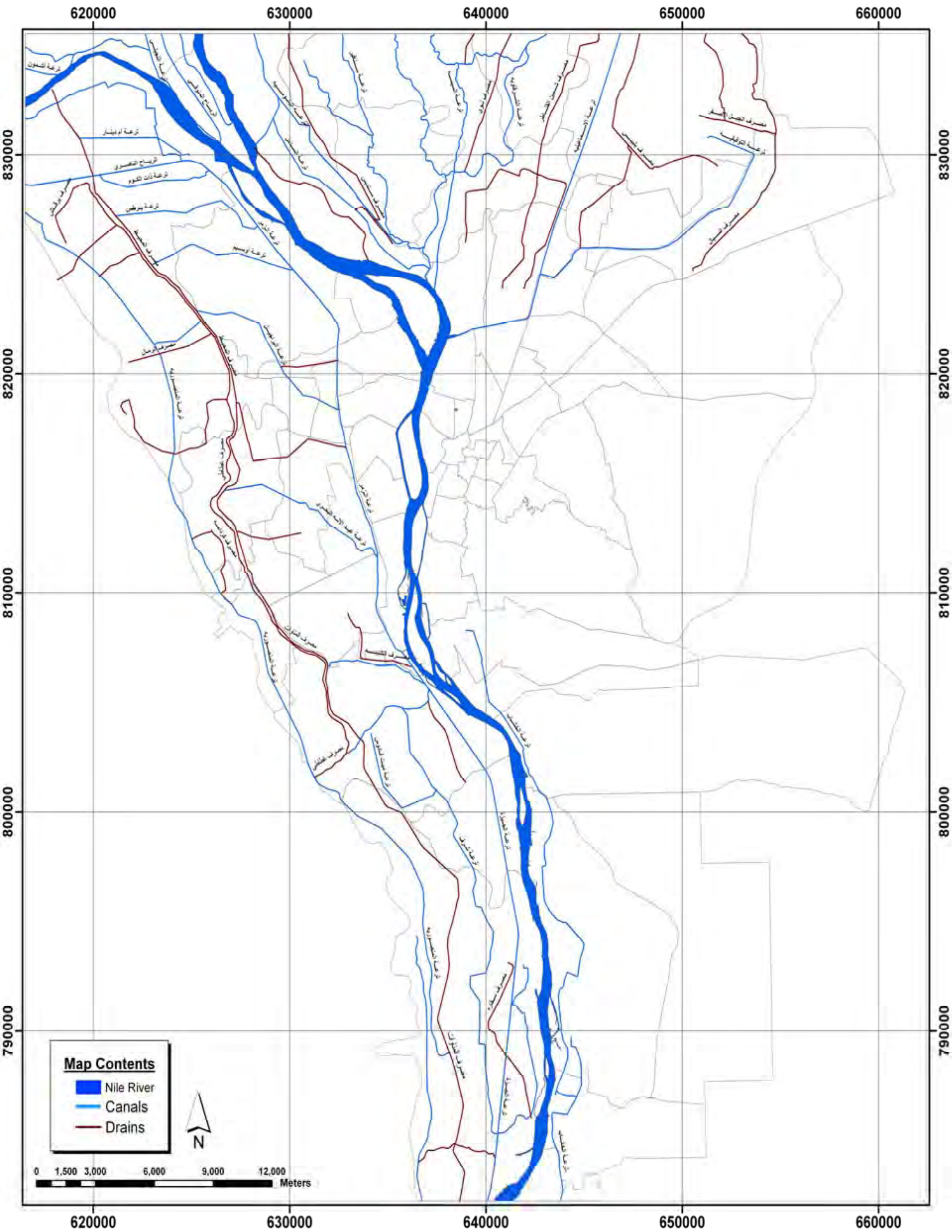


Figure (6-35) **G**reater **C**airo **R**egion watercourses map in the starting calibration year *(1991)*

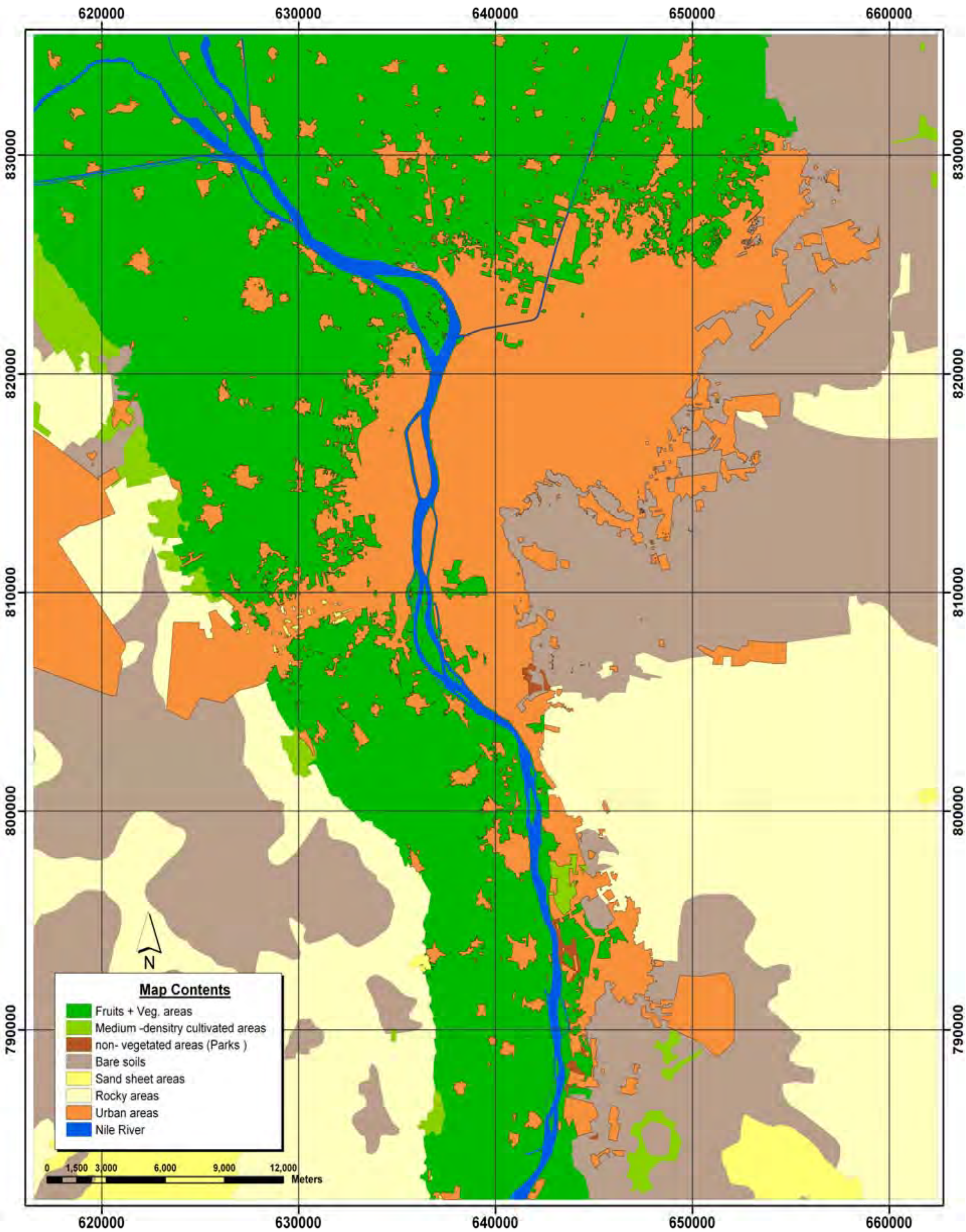


Figure (6-36) **G**reater **C**airo **R**egion land cover map in the starting calibration year *(1991)*

(Source: **S**oil, **W**ater, and **E**nvironment **R**esearch **I**nstitute - **SWERI**)

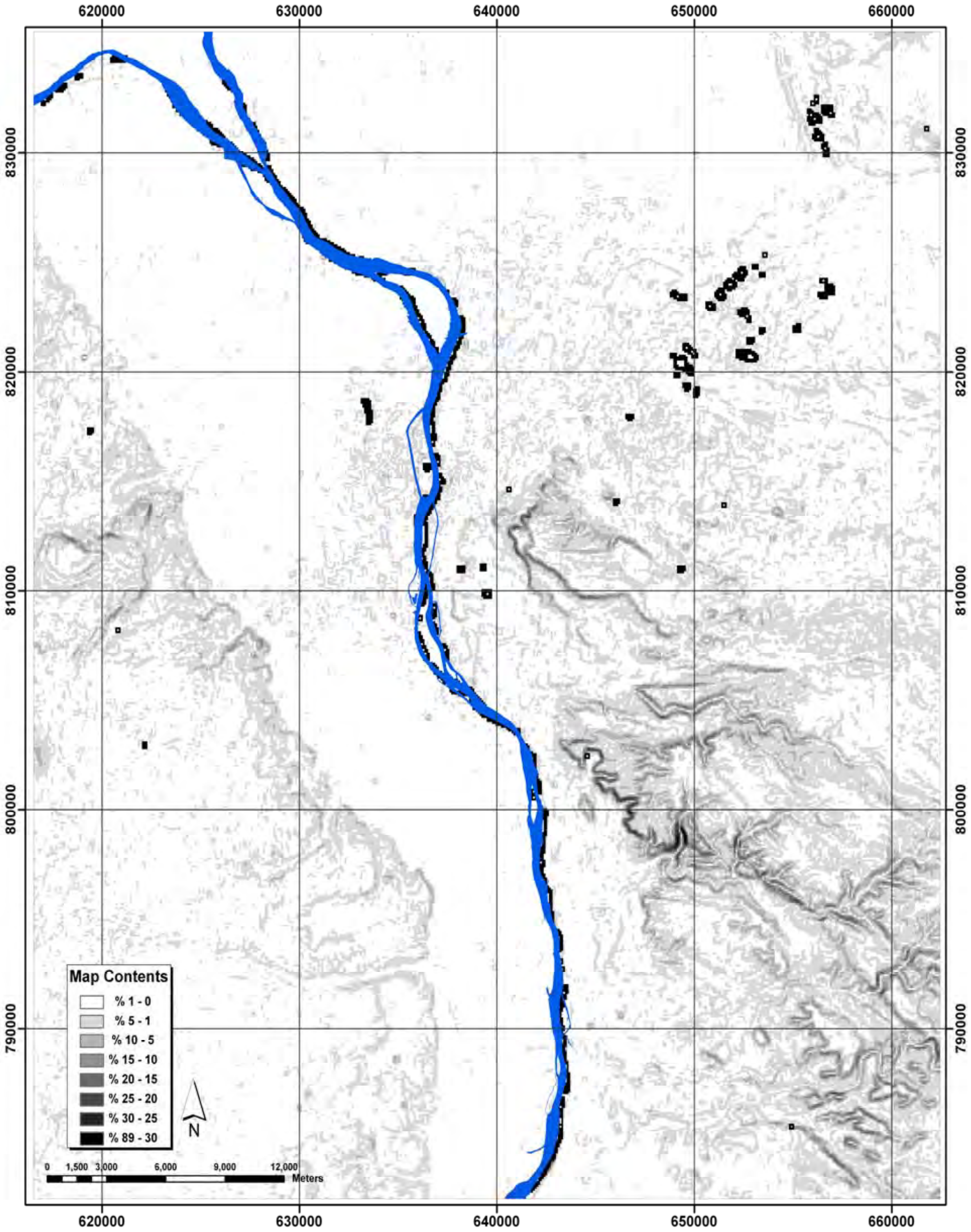


Figure (6-37) **G**reater **C**airo **R**egion Slope map

(Source: http://www.glcfapp.umiacs.umd.edu)

(6-6) Running the IHGM

In this section, we will discuss the stages of running the proposed **IHGM** on the case of **G**reater **C**airo **R**egion, the proposed model include the following stages:

1) Definition of the model parameters,
2) Calibration of the growth factors *(many alternatives)*,
3) Testing of the growth factors calibration results *(influence ratio)*,
   a) Estimation of the probability map in year **2006** *(many alternatives)*,
   b) Prediction and allocation of the **IH** expansion in year **2006** *(many alternatives),*
   c) Choosing of the best allocation alternative,
   d) Choose the most suitable **influence ratios** of growth factors and the **size of neighborhood matrix** for both land use and network factors, which have high allocation rate to predict the **IH** expansion in **GCR**,
4) Prediction of the future **IH** expansion in **GCR** from **2011** to **2046**.

(6-6-1) Definition of the IHGM Parameters

To run the proposed model, we must first assign the parameters and coefficients that are required in both **calibration** and **prediction** phases. These parameters include the following:

- The **GCR** map properties: the study area was converted to raster **data_grid**, the produced image have **1777** rows and **1531** columns *(i.e., 2720587 square cells)*,
- The **starting** calibration land use map is **1991**,
- The **final** calibration land use map is **2001**,
- The **base** prediction land use map is **2006**,
- The number of iterations = **8**,
- The iteration time period = **5** years, *(i.e., the prediction years are: 2011, 2016, 2021, 2026, 2031, 2036, 2041, and 2046),*
- The **annual_pixel_gain** for **IH** districts in each prediction period, and the **net_pixel_gain** for the entire region in each prediction period, as shown in table (6-13).[1]

[1] For more details, see section (6-2).

Qism _Code	Gov.	Qism Name	2011	2016	2021	2026	2031	2036	2041	2046
106	Cairo	**Masr Al qadima**	329	311	306	310	318	328	340	353
108		**Al khalifa**	765	854	954	1066	1192	1333	1490	1666
126		**Nasr city -1**	402	352	329	319	316	317	319	322
127		**Nasr city-2**	185	198	211	224	239	254	271	288
132		**Al salam**	1238	893	714	626	586	572	571	577
134		**Monshat naser**	1410	1888	2524	3370	4497	5999	8002	10672
135		**Al basatine**	751	702	690	697	716	742	772	804
136		**Al marg**	983	948	958	996	1051	1118	1194	1277
901	Helwan	**Al tebin**	813	1041	1327	1691	2152	2739	3484	4432
902		**Helwan**	1765	1871	2015	2188	2387	2609	2856	3128
905		**Tora**	219	189	175	171	172	176	181	187
911		**Al saf**	374	508	689	932	1261	1705	2305	3116
1006	October	**Al-hram**	677	605	581	586	609	644	687	736
1008		**Al hawamdia**	252	246	249	257	268	280	294	308
1009		**Al-Giza**	745	769	814	873	942	1021	1108	1204
1010		**Al badrashin**	668	667	687	720	760	807	858	914
1015		**Madenat Ausim**	64	66	68	73	77	83	89	95
1016		**Ausim**	373	338	326	327	335	347	362	378
1017		**Al-waraq Al-hader**	55	51	50	51	53	55	58	61
1018		**Bashteel**	221	96	29	15	8	4	2	1
1020		**Markaz kerdasa**	1004	1098	1207	1331	1469	1623	1793	1982
1021		**Qism kerdasa**	1072	1294	1566	1896	2298	2785	3377	4094

Table (6-13) The **annual** demand from housing by **pixels** for **IH districts** at each prediction period *[Pixel size = 30 x 30 m]*

Qism _Code	Gov.	Qism Name	2011	2016	2021	2026	2031	2036	2041	2046
1403	Kalyoubia	**Al khanka**	1105	1096	1132	1197	1281	1380	1492	1616
1404		**Al kanater**	759	661	622	616	629	654	686	722
1405		**Shbeen Al kanater**	773	1049	1420	1920	2595	3506	4735	6396
1406		**Shubra Al khaima-1**	400	427	454	483	513	544	577	612
1407		**Shubra Al khaima-2**	349	313	300	297	302	309	319	330
1409		**Qism Qalyûb**	268	271	282	298	316	337	360	386
1410		**Qalyûb**	846	812	820	857	911	978	1055	1141
1412		**Al Khusûs**	630	698	781	877	987	1112	1254	1414
2101	Giza	**Qism Imbaba**	84	70	63	60	59	58	59	59
2104		**Qism Al-Giza**	142	130	125	123	124	126	128	131
2105		**Bolaq Al dakrour**	625	625	645	677	717	763	814	869
2106		**Al ahram**	322	293	281	281	285	293	302	313
2117		**Al-waraq**	282	261	255	257	263	272	282	294
2118		**Al omrania**	405	344	315	303	300	301	305	310
2120		**kerdasa**	772	819	896	985	1085	1194	1316	1449
Total IH Quota *(net_pixel_gain)*			**22127**	**22854**	**24860**	**27950**	**32073**	**37368**	**44097**	**52637**

Table (6-13) The **annual** demand from housing by **pixels** for **IH districts** at each prediction period (Cont.) *[Pixel size = 30 x 30 m]*

(Qism_Code Source : **CAPMAS-** 2009)

(6-6-2) Calibration of Growth Factors

The objective of this section is to estimate the **influence ratios** for the selected growth factors *(land use, transportation networks, watercourses and geography)* with respect to the assumed **neighborhood matrix size** for both land use and network factors, and the assumed **weights** at its levels.

In the calibration phase, we will test many **alternatives** for the **neighborhood matrix size** to get the most suitable neighborhood matrix size and its levels weights, **which simulate the behavior of IH expansion between the starting and final calibration years**.

To do this, we will suggest many alternatives for the **neighborhood matrix size** that will use to capture **land use factors** and their relative weights at each matrix level. Also, we suggest many other alternatives for the **neighborhood matrix size** that will use to capture **transportation networks and watercourses factors** and their relative weights at each matrix level, in order to estimate the calibration scores of land use and transportation networks factors on the emergence of **IH**. *(for more details see section 6-4)*

The calibration procedure choose each **IH** cell, which created between the **starting** *(1991)* and **final** calibration year *(2001)*, and test the affect factors on it to change from **vacant** to **IH** cell, the procedure calculates the following calibration values:

- The calibration value for each **land use** and **network** growth factor *[Equ. (6.13) and Equ. (6.14)]*, and write the results in the calibration table.
- The **IH cell** calibration value due to all neighboring **land uses** and **network** factors *[Equ. (6.15) and Equ. (6.16)]*, and write the results in the calibration table.
- The **relative influence ratio** for each **land use** and **network** growth factor. Also, the **IH cell relative calibration value** for all neighboring **land uses** and **network** factors *[Equ. (6.17) to Equ. (6.20)]*, and write the results in the calibration table.

The calibration module starts by identifying the following variables:

a) The land use map in starting calibration year *(1991)*,

b) The land use map in final calibration year *(2001)*,

c) The roads and transportation networks map in starting calibration year,

d) The watercourses map in starting calibration year,

e) The land cover map in starting calibration year,

f) The study area slope map,

g) The **IH** areas which emerged between starting and final calibration years,

h) The assumed **neighborhood matrixes sizes** for both land use and network factors, and its levels weights, as shown in table (6-14),

i) The output table that contains the growth factors calibration results.

Figures (6-38 and 6-39) show and illustrate the dialog boxes of calibration module, and brief description of their components.

To be operational, the model passes through several instances of **refinement** and **modification** to increase its simulation capacity and test the validity of its assumptions. In the case of **GCR**, we run the calibration macro many times *(18 alternatives)*; in each attempt, we use one of the **assumed neighborhood matrix size** and **its levels weights**, and save the growth factors calibration values in the output calibration table.

In fact, the proposed calibration module explained that, the influence ratios of growth factors are varies depending on the **size of the neighborhood matrix** *[$Lu_{(s)}$, $N_{(s)}$]* and **the assumed levels weights** *[W_1,W_2,W_3,…]*.

After running the calibration module for all the proposed alternatives *(table 6-14)*, the **Microsoft EXCEL®** was used to analyze and determine the influence ratio *(degree of contribution)* for each growth factor to affect on the **vacant cell** to change into **IH cell**.

These results will use in the next step to estimate the areas that have high probability to change from vacant to IH in year 2006 *(test year)*,

Figures (6-40 to 6-57) show the growth factors influence ratios for all the proposed calibration scenarios.

No.	Matrix Name	Land use Matrix	Network Matrix	Land use weights							Roads network and watercourses weights						
		L(s)	N(s)	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_1	W_2	W_3	W_4	W_5	W_6	W_7
1	Lu3_Net3_1	3	3	1.0	0.75	0.50					1.0	0.75	0.50				
2	Lu3_Net3_2	3	3	1.0	0.75	0.50					2.0	1.50	1.0				
3	Lu3_Net4_1	3	4	1.0	0.75	0.50					1.0	0.75	0.50	0.25			
4	Lu3_Net4_2	3	4	1.0	0.75	0.50					2.0	1.75	1.50	1.25			
5	Lu3_Net5_1	3	5	1.0	0.75	0.50					1.0	0.80	0.60	0.40	0.20		
6	Lu3_Net5_2	3	5	1.0	0.75	0.50					2.0	1.75	1.50	1.25	1.0		
7	Lu3_Net6_1	3	6	1.0	0.75	0.50					1.0	0.90	0.80	0.70	0.60	0.50	
8	Lu3_Net6_2	3	6	1.0	0.75	0.50					2.0	1.75	1.50	1.25	1.0	0.75	
9	Lu3_Net7_1	3	7	1.0	0.75	0.50					1.0	0.90	0.80	0.70	0.60	0.50	0.40
10	Lu3_Net7_2	3	7	1.0	0.75	0.50					2.0	1.75	1.50	1.25	1.0	0.75	0.50
11	Lu4_Net5_1	4	5	1.0	0.75	0.50	0.25				1.0	0.80	0.60	0.40	0.20		
12	Lu4_Net5_2	4	5	1.0	0.75	0.50	0.25				2.0	1.50	1.0	0.75	0.50		
13	Lu5_Net5_1	5	5	1.0	0.80	0.60	0.40	0.20			1.0	0.80	0.60	0.40	0.20		
14	Lu5_Net5_2	5	5	1.0	0.80	0.60	0.40	0.20			2.0	1.50	1.0	0.75	0.50		
15	Lu6_Net6_1	6	6	1.0	0.90	0.70	0.50	0.30	0.20		1.0	0.90	0.70	0.50	0.30	0.20	
16	Lu6_Net6_2	6	6	1.0	0.90	0.70	0.50	0.30	0.20		2.0	1.75	1.50	1.25	1.0	0.75	
17	Lu7_Net7_1	7	7	1.0	0.90	0.75	0.60	0.45	0.30	0.15	1.0	0.90	0.75	0.60	0.45	0.30	0.15
18	Lu7_Net7_2	7	7	1.0	0.90	0.75	0.60	0.45	0.30	0.15	2.0	1.75	1.50	1.25	1.0	0.75	0.50

Table (6-14) The alternatives assumptions of neighborhood matrix sizes and the growth factors weights

1 The land use map in **starting** calibration year,

2 The land use map in **final** calibration year,

3 The **roads** and **transportation networks map** in starting calibration year,

4 The **watercourses map** in starting calibration year,

5 The study area **slope map**,

6 The **land cover map** in starting calibration year,

7 The **IH** areas, which emerged between starting and final calibration years,

8 The neighborhood **matrix size** for **land use** factors,

9 The neighborhood **matrix size** for **network** factors, *(roads and watercourses)*

10 Definition of the **land use weights** at each matrix level,

11 Definition of the **networks weights** at each matrix level,

12 Definition of the **maximum slope** which suitable for urban development,

13 The number of **slope categories**, *(between 0 and maximum slope)*

14 Definition of the **weight** for each slope category,

15 The output table that contains the **growth factors calibration results**,

16 The **calibration button**, *(that run the calibration macro)*

17 The **Exit** button.

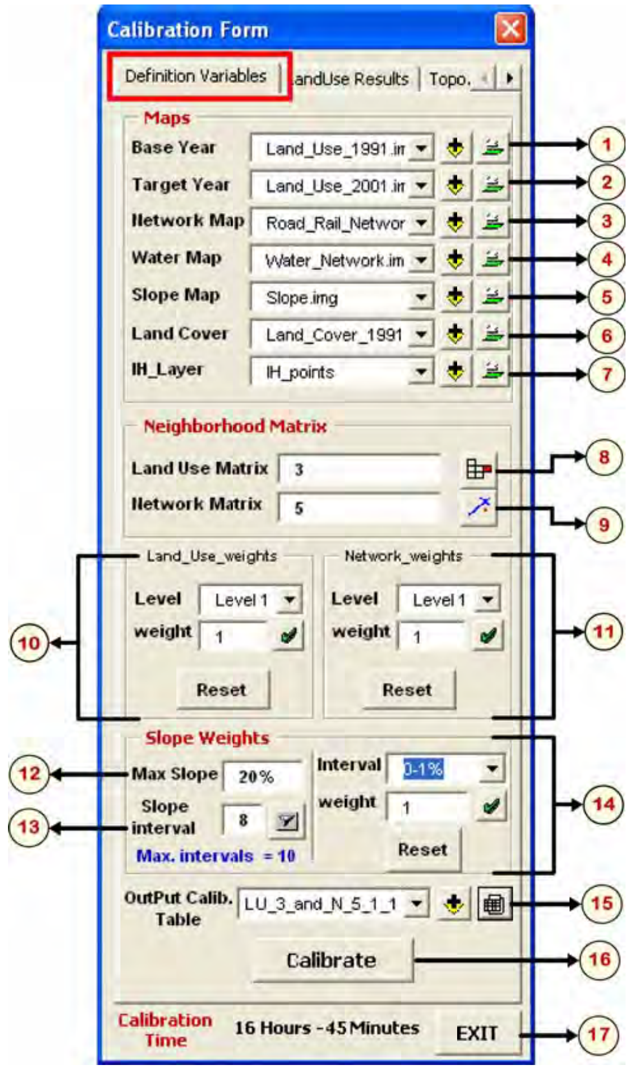


Figure (6-38) Variables definition in the calibration form dialog box

1 The **relative influence ratio** for land use factors,

2 The **relative calibration value** for **IH cell** due to all neighboring land use factors,

3 The **relative influence ratio** for roads and transportation factors,

4 The **relative calibration value** for **IH cell** due to all neighboring roads and transportation factors,

5 The **relative influence ratio** for watercourses factors,

6 The **relative calibration value for IH cell** due to all neighboring watercourses factors,

7 The **relative influence ratio** for slope categories,

8 The **relative influence ratio** for land cover types,

9 The **Exit** button.

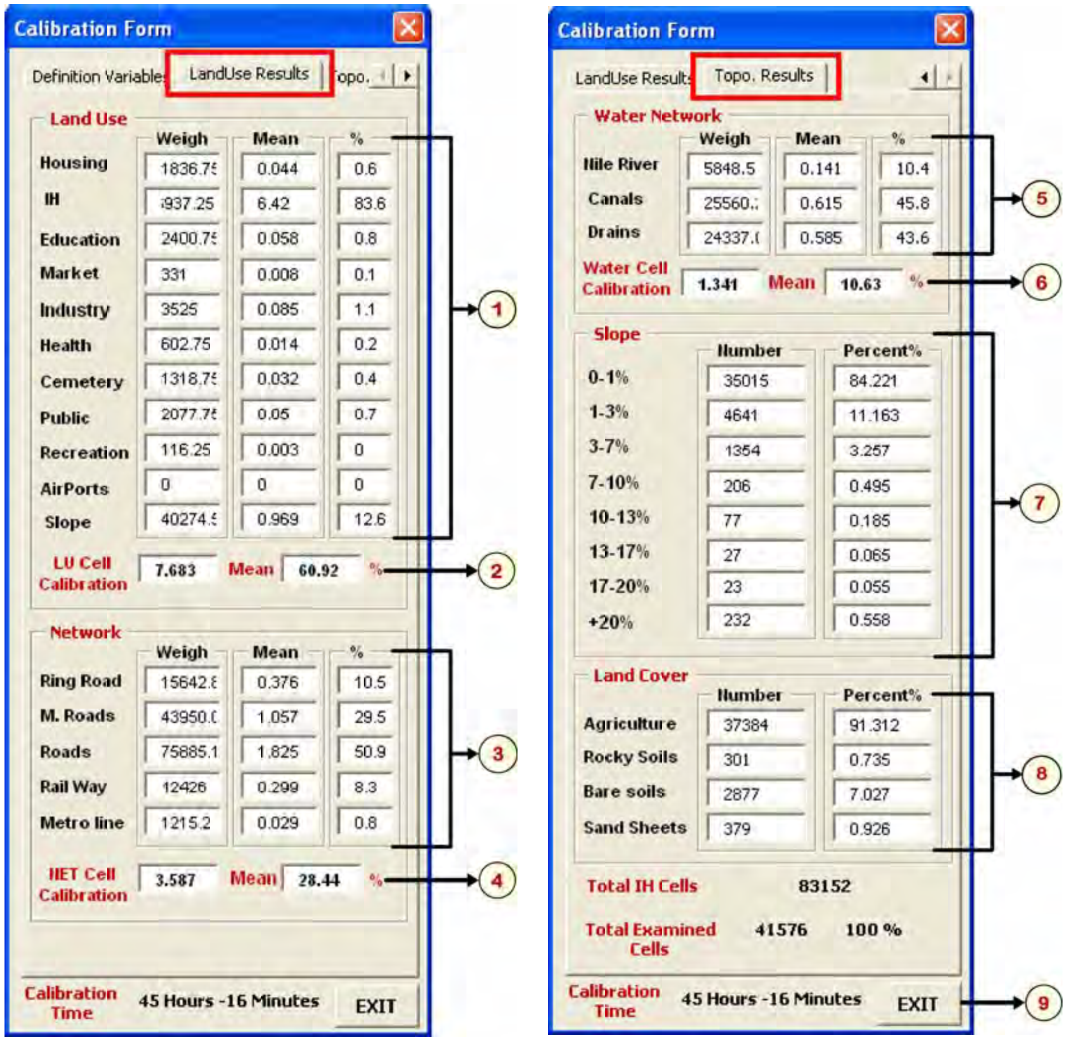


Figure (6-39) The calibration results for **land use**, **roads network**, **watercourses**, **land cover**, and **topographic** factors

Level	Land use weights	Roads & Water weights
level 1	**1**	**1**
Level 2	**0.75**	**0.75**
Level 3	**0.50**	**0.50**

	Factor Name	Percentage %
Network	**Ring Road**	**1.92 %**
	Major Road	**6.03 %**
	Roads	**10.53 %**
	Rail Ways	**1.64 %**
	Metro Line	0.15 %
Land Use	Housing	0.44 %
	Informal Housing	**63.57 %**
	Education	0.57 %
	Market	0.08 %
	Industry	0.84 %
	Health	0.14 %
	Cemetery	0.31 %
	Public Use	0.49 %
	Recreation	0.03 %
	Air Ports	0.00
	Slope	**9.59 %**
Water	**Nile River**	**2.54 %**
	Canals	0.60 %
	Drains	0.53 %

Results

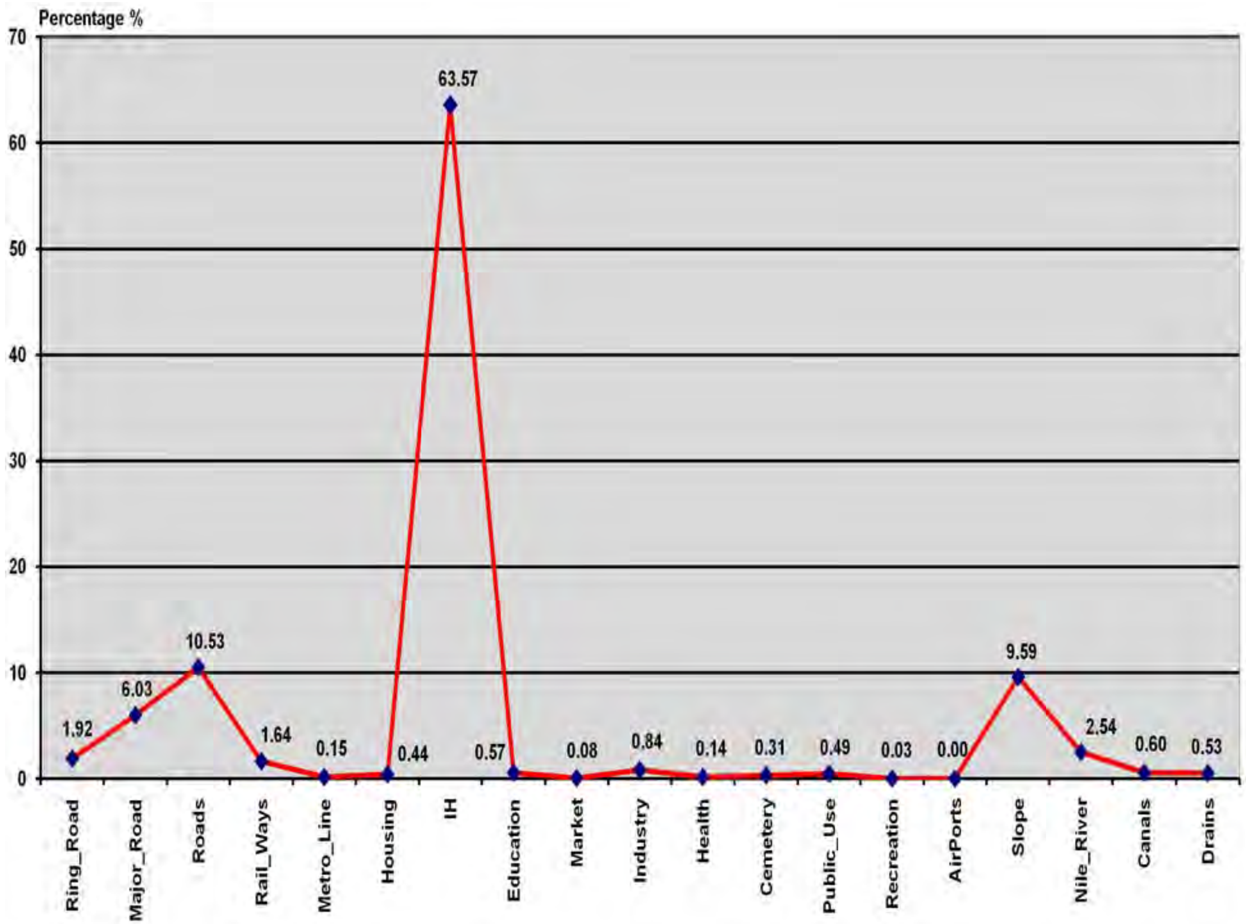


Figure (6 – 40) The calibration results of Matrix : **LU3_Net3_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.75**	**1.50**
Level 3	**0.50**	**1**

	Factor Name	Percentage %
Network	**Ring Road**	**2.91 %**
	Major Road	**9.17 %**
	Roads	**16.01 %**
	Rail Ways	**2.50 %**
	Metro Line	0.22 %
Land Use	Housing	0.33 %
	Informal Housing	**48.32 %**
	Education	0.43 %
	Market	0.06 %
	Industry	0.64 %
	Health	0.11 %
	Cemetery	0.24 %
	Public Use	0.38 %
	Recreation	0.02 %
	Air Ports	0.00
	Slope	**7.29 %**
Water	Nile River	1.06 %
	Canals	**5.04 %**
	Drains	**5.26 %**

Results

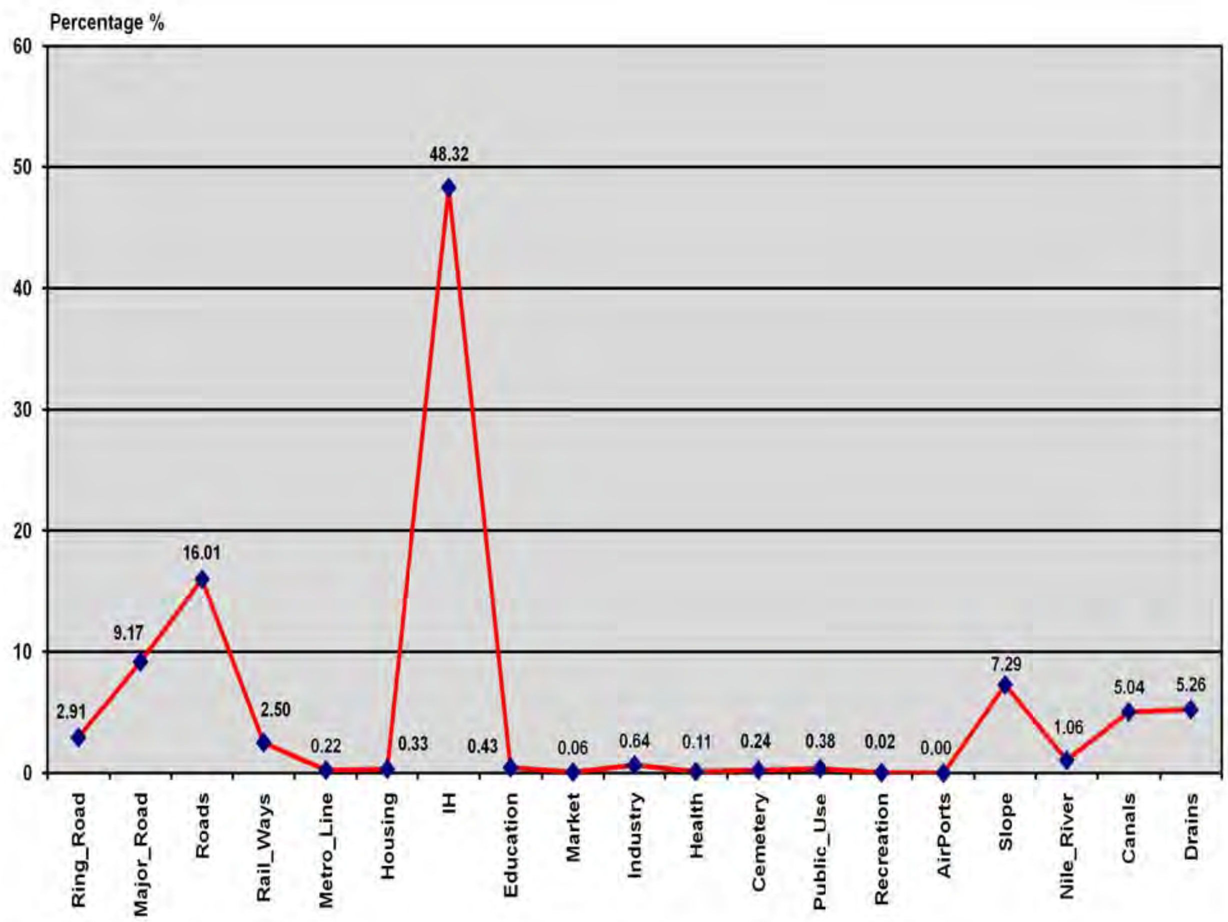


Figure (6 – 41) The calibration results of Matrix: **LU3_Net3_2**

Level	Land use weights	Roads & Water weights
level 1	**1**	**1**
Level 2	**0.75**	**0.75**
Level 3	**0.50**	**0.50**
Level 4	**--**	**0.25**

	Factor Name	Percentage %
Network	**Ring Road**	**2.26 %**
	Major Road	**6.74 %**
	Roads	**11.73 %**
	Rail Ways	**1.87 %**
	Metro Line	0.17 %
Land Use	Housing	0.39 %
	Informal Housing	**57.12 %**
	Education	0.51 %
	Market	0.07 %
	Industry	0.75 %
	Health	0.13 %
	Cemetery	0.28 %
	Public Use	0.44 %
	Recreation	0.02 %
	Air Ports	0.00
	Slope	**8.62 %**
Water	Nile River	1.25 %
	Canals	**3.82 %**
	Drains	**3.81 %**

Results

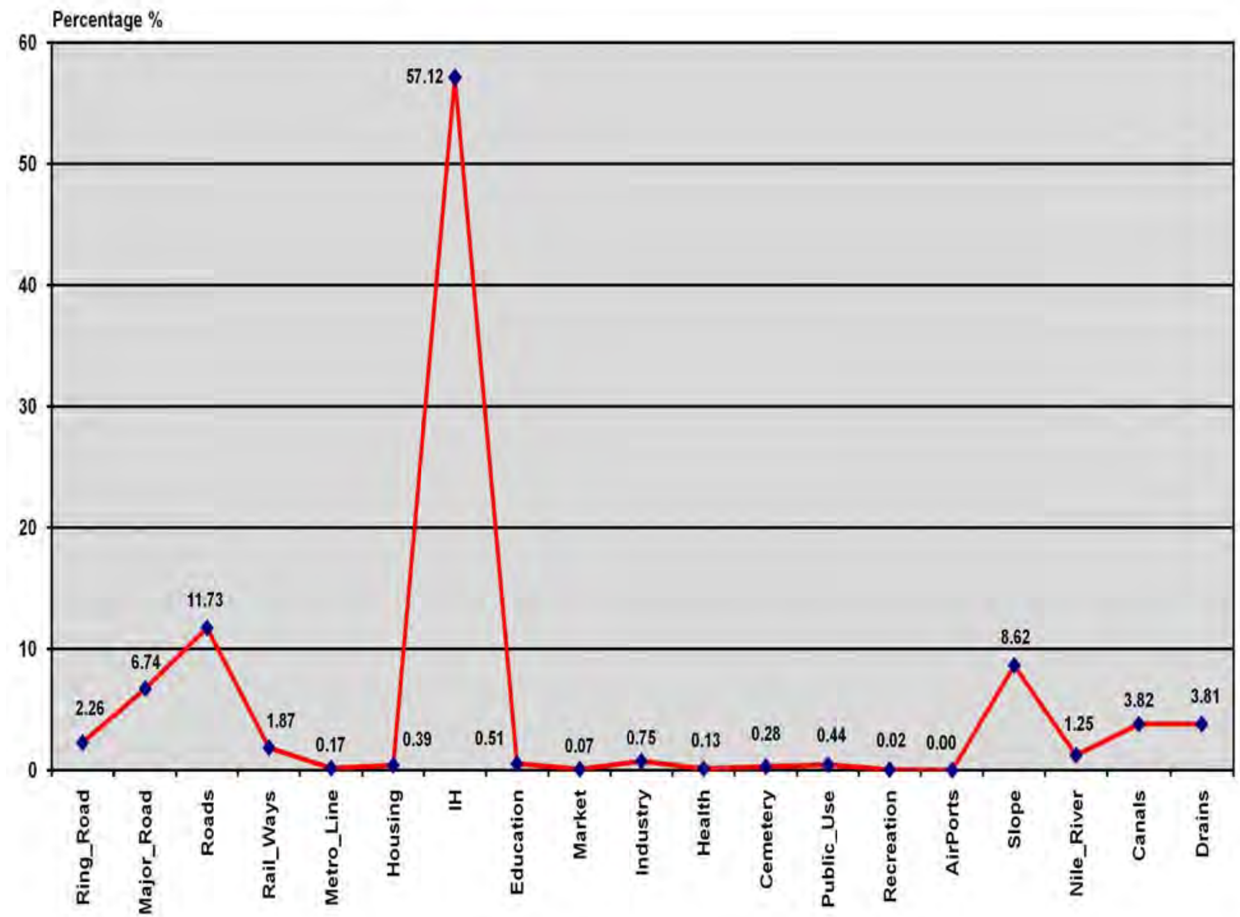


Figure (6 – 42) The calibration results of Matrix : **LU3_Net4_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.75**	**1.75**
Level 3	**0.50**	**1.50**
Level 4	**--**	**1.25**

	Factor Name	Percentage %
Network	**Ring Road**	**4.41 %**
	Major Road	**12.51 %**
	Roads	**21.69 %**
	Rail Ways	**3.53 %**
	Metro Line	0.34 %
Land Use	Housing	0. 24 %
	Informal Housing	**35.51 %**
	Education	0.32 %
	Market	0.04 %
	Industry	0.47 %
	Health	0.08 %
	Cemetery	0.18 %
	Public Use	0.28 %
	Recreation	0.02 %
	Air Ports	0.00
	Slope	**5.36 %**
Water	Nile River	0.78 %
	Canals	**7.29 %**
	Drains	**6.96 %**

Results

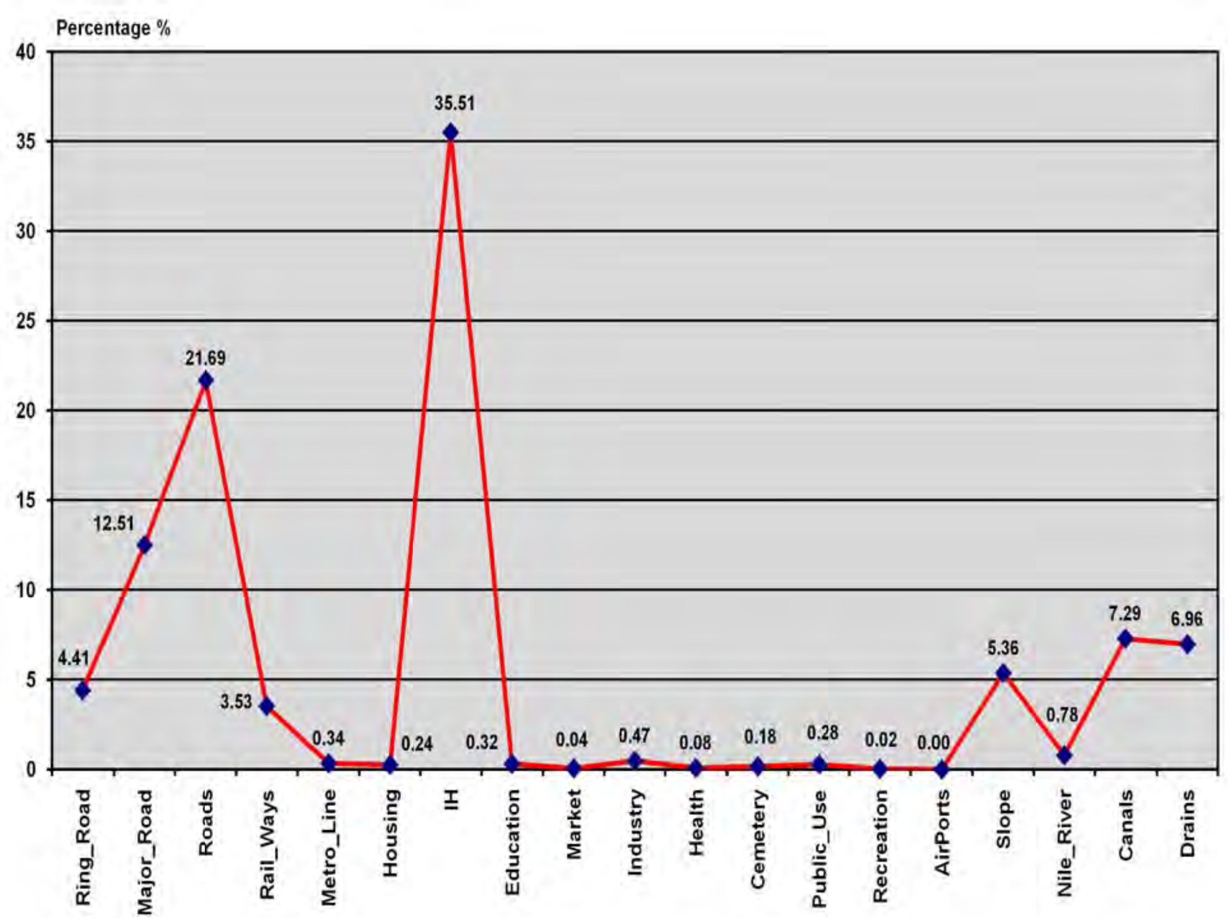


Figure (6 – 43) The calibration results of Matrix : **LU3_Net4_2**

Level	Land use weights	Roads & Water weights
level 1	1	1
Level 2	0.75	0.80
Level 3	0.50	0.60
Level 4	--	0.40
Level 5	--	0.20

	Factor Name	Percentage %
Network	**Ring Road**	**2.98 %**
	Major Road	**8.38 %**
	Roads	**14.47 %**
	Rail Ways	**2.37 %**
	Metro Line	0.23 %
Land Use	Housing	0.35 %
	Informal Housing	**50.91 %**
	Education	0.46 %
	Market	0.06 %
	Industry	0.67 %
	Health	0.11 %
	Cemetery	0.25 %
	Public Use	0.40 %
	Recreation	0.02 %
	Air Ports	0.00
	Slope	**7.68 %**
Water	**Nile River**	**1.12 %**
	Canals	**4.88 %**
	Drains	**4.64 %**

Results

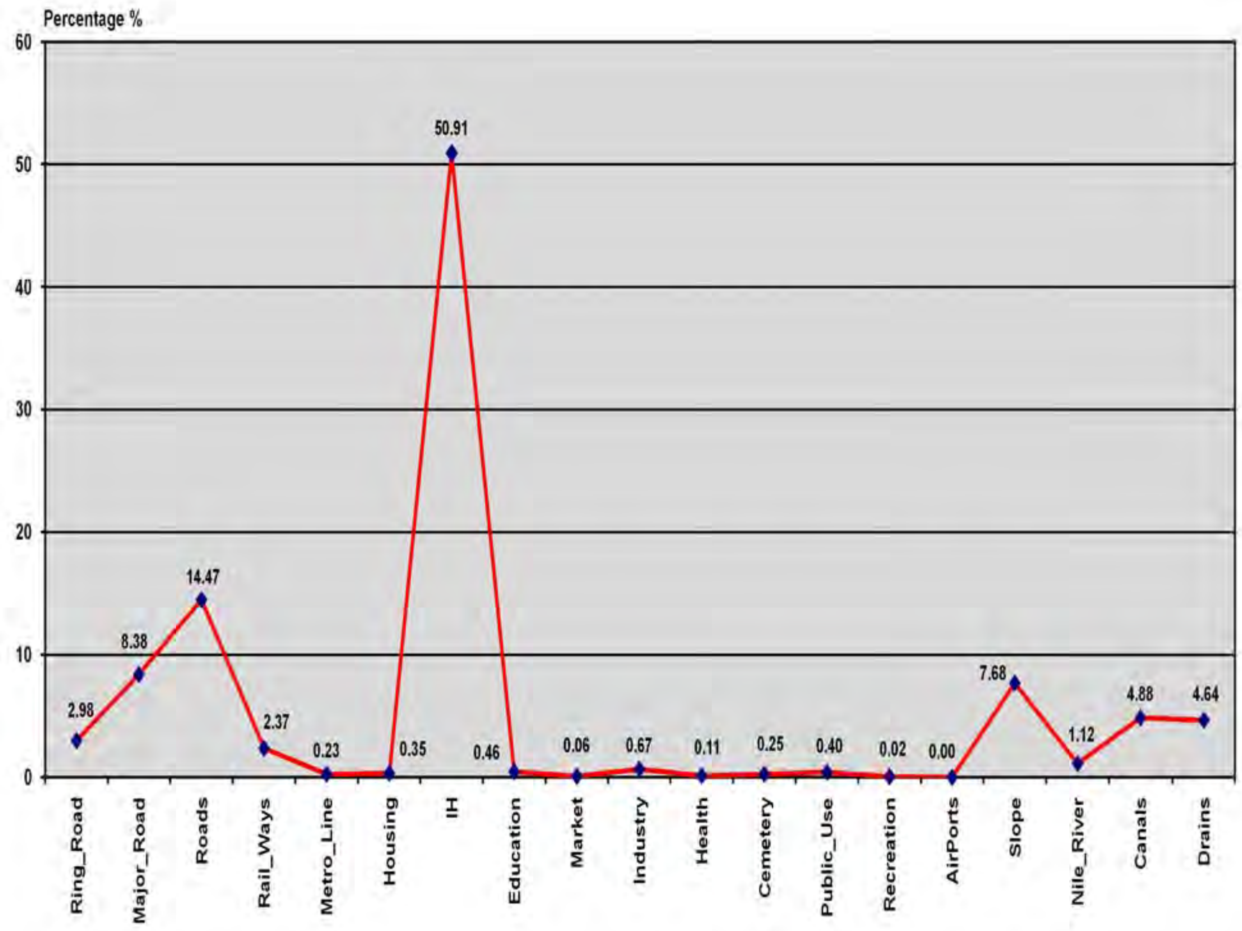


Figure (6 – 44) The calibration results of Matrix: **LU3_Net5_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.75**	**1.75**
Level 3	**0.50**	**1.50**
Level 4	**--**	**1.25**
Level 5	**--**	**1**

	Factor Name	Percentage %
Network	**Ring Road**	**5.20 %**
	Major Road	**14.01 %**
	Roads	**24.05 %**
	Rail Ways	**4.01 %**
	Metro Line	0.41 %
Land Use	Housing	0.21 %
	Informal Housing	**29.85 %**
	Education	0.27 %
	Market	0.04 %
	Industry	0.39 %
	Health	0.07 %
	Cemetery	0.15 %
	Public Use	0.23 %
	Recreation	0.01 %
	Air Ports	0.00
	Slope	**4.50 %**
Water	**Nile River**	0.65 %
	Canals	**8.31 %**
	Drains	**7.64 %**

Results

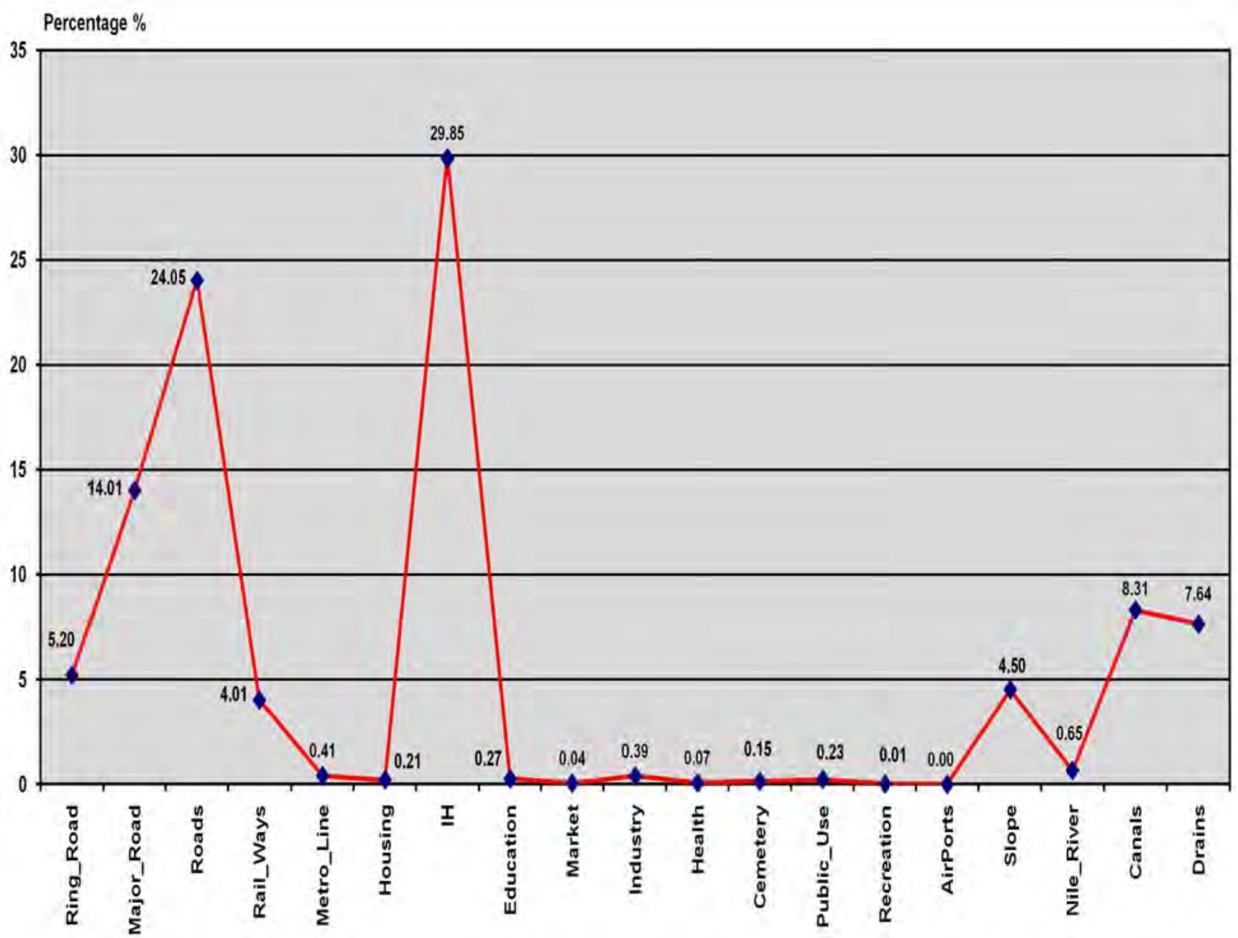


Figure (6 – 45) The calibration results of Matrix: **LU3_Net5_2**

Level	Land use weights	Roads & Water weights
level 1	**1**	**1**
Level 2	**0.75**	**0.90**
Level 3	**0.50**	**0.80**
Level 4	---	**0.70**
Level 5	---	**0.60**
Level 6	---	**0.50**

	Factor Name	Percentage %
Network	**Ring Road**	**4.75 %**
	Major Road	**12.14 %**
	Roads	**20.70 %**
	Rail Ways	**3.52 %**
	Metro Line	0.38 %
Land Use	Housing	0.25 %
	Informal Housing	**37.02 %**
	Education	0.33 %
	Market	0.05 %
	Industry	0.49 %
	Health	0.08 %
	Cemetery	0.18 %
	Public Use	0.29 %
	Recreation	0.02 %
	Air Ports	0.00
	Slope	**5.59 %**
Water	Nile River	0.41 %
	Canals	**7.32 %**
	Drains	**6.49 %**

Results

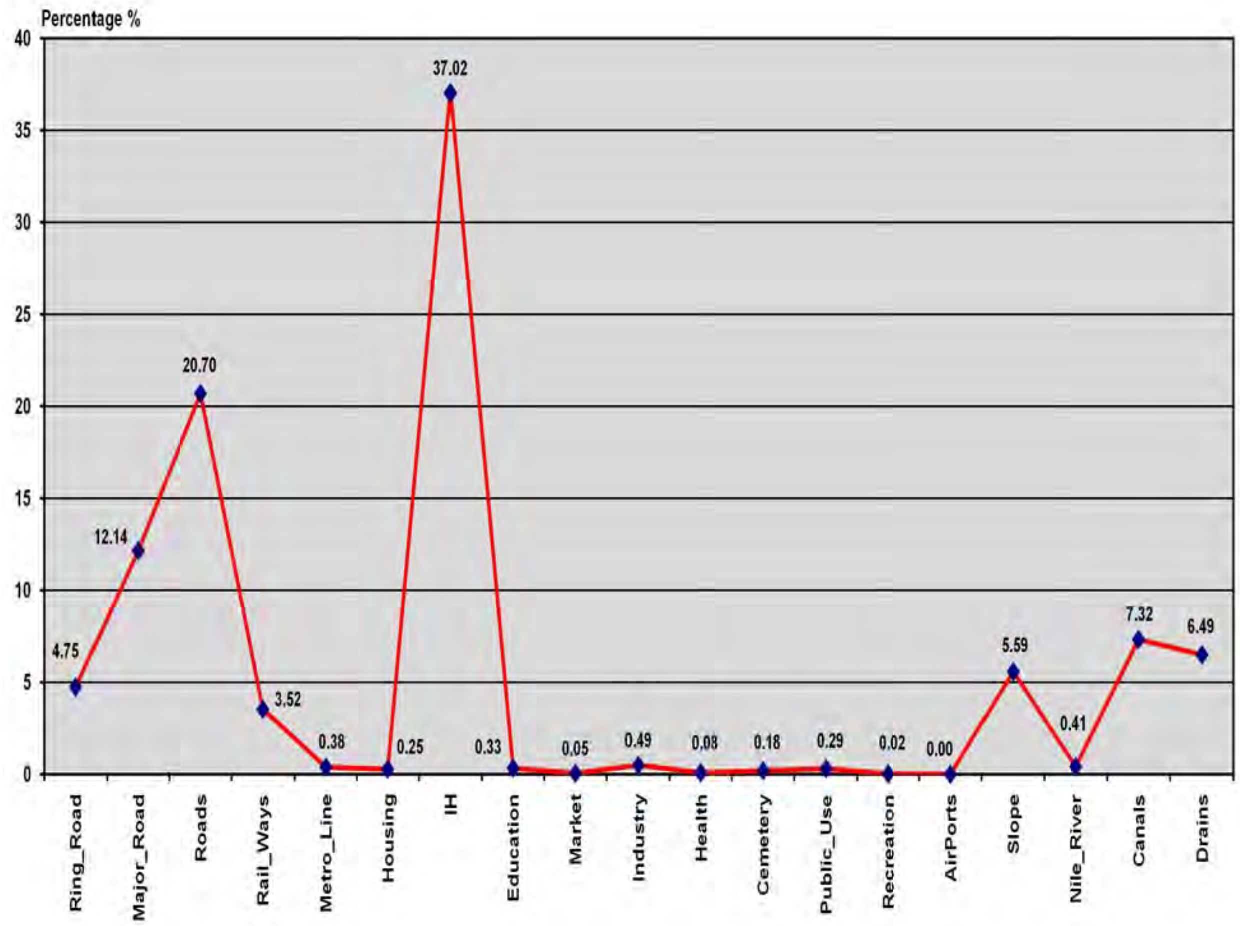


Figure (6 – 46) The calibration results of Matrix: **LU3_Net6_1**

Level	Land use weights	Roads & Water weights
level 1	1	2
Level 2	0.75	1.75
Level 3	0.50	1.50
Level 4	---	1.25
Level 5	---	1
Level 6	---	0.75

	Factor Name	Percentage %
Network	**Ring Road**	**5.78 %**
	Major Road	**14.98 %**
	Roads	**25.59 %**
	Rail Ways	**4.33 %**
	Metro Line	0.46 %
Land Use	Housing	0.18 %
	Informal Housing	**26.10 %**
	Education	0.23 %
	Market	0.03 %
	Industry	0.34 %
	Health	0.06 %
	Cemetery	0.13 %
	Public Use	0.20 %
	Recreation	0.01 %
	Air Ports	0.00
	Slope	**3.94 %**
Water	Nile River	0.57 %
	Canals	**8.99 %**
	Drains	**8.06 %**

Results

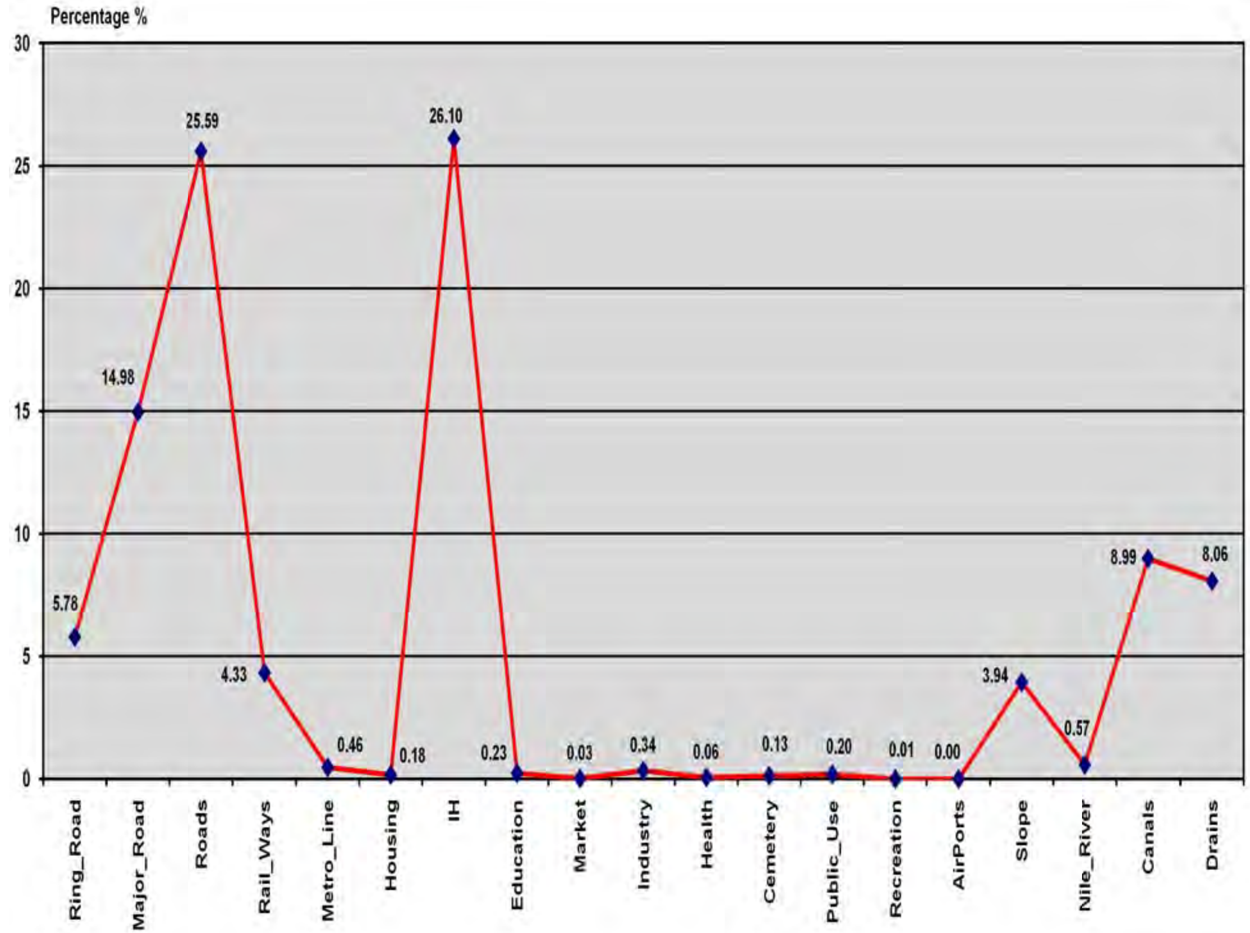


Figure (6 – 47) The calibration results of Matrix: **LU3_Net6_2**

Level	Land use weights	Roads & Water weights
level 1	1	1
Level 2	0.75	0.90
Level 3	0.50	0.80
Level 4	---	0.70
Level 5	---	0.60
Level 6	---	0.50
Level 7	---	0.40

	Factor Name	Percentage %
Network	**Ring Road**	**5.28 %**
	Major Road	**13.09 %**
	Roads	**22.27 %**
	Rail Ways	**3.82 %**
	Metro Line	0.44 %
Land Use	Housing	0.23 %
	Informal Housing	**33.31 %**
	Education	0.30 %
	Market	0.04 %
	Industry	0.44 %
	Health	0.08 %
	Cemetery	0.16 %
	Public Use	0.26 %
	Recreation	0.01 %
	Air Ports	0.00
	Slope	**5.03 %**
Water	Nile River	0.36 %
	Canals	**7.94 %**
	Drains	**6.94 %**

Results

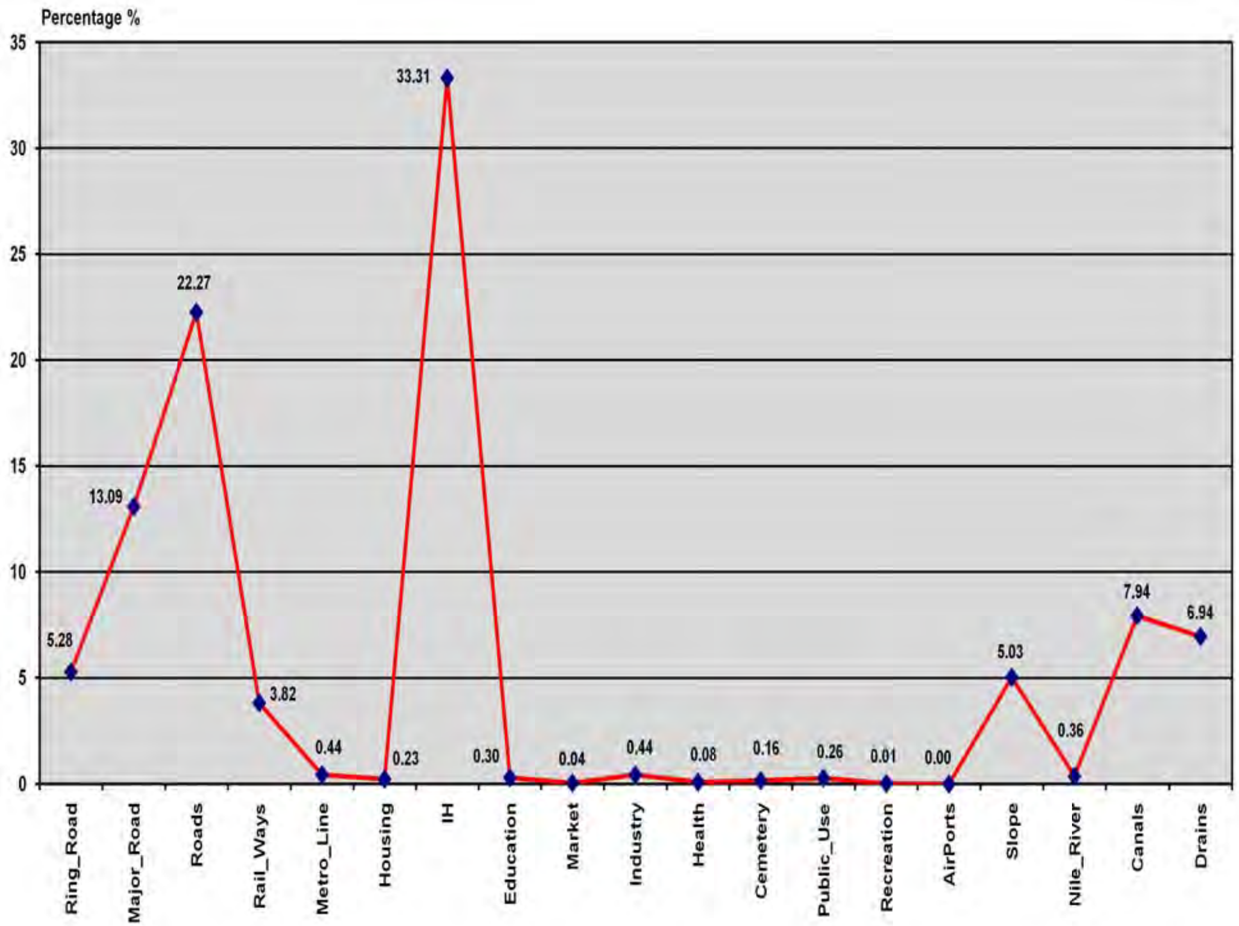


Figure (6 – 48) The calibration results of Matrix : **LU3_Net7_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.75**	**1.75**
Level 3	**0.50**	**1.50**
Level 4	**---**	**1.25**
Level 5	**---**	**1**
Level 6	**---**	**0.75**
Level 7	**---**	**0.50**

	Factor Name	Percentage %
Network	**Ring Road**	**6.18 %**
	Major Road	**15.62 %**
	Roads	**26.63 %**
	Rail Ways	**4.54 %**
	Metro Line	0.51 %
Land Use	Housing	0.16 %
	Informal Housing	**23.83 %**
	Education	0.21 %
	Market	0.03 %
	Industry	0.31 %
	Health	0.05 %
	Cemetery	0.12 %
	Public Use	0.19 %
	Recreation	0.01 %
	Air Ports	0.00
	Slope	**3.60 %**
Water	Nile River	0.26 %
	Canals	**9.42 %**
	Drains	**8.34 %**

Results

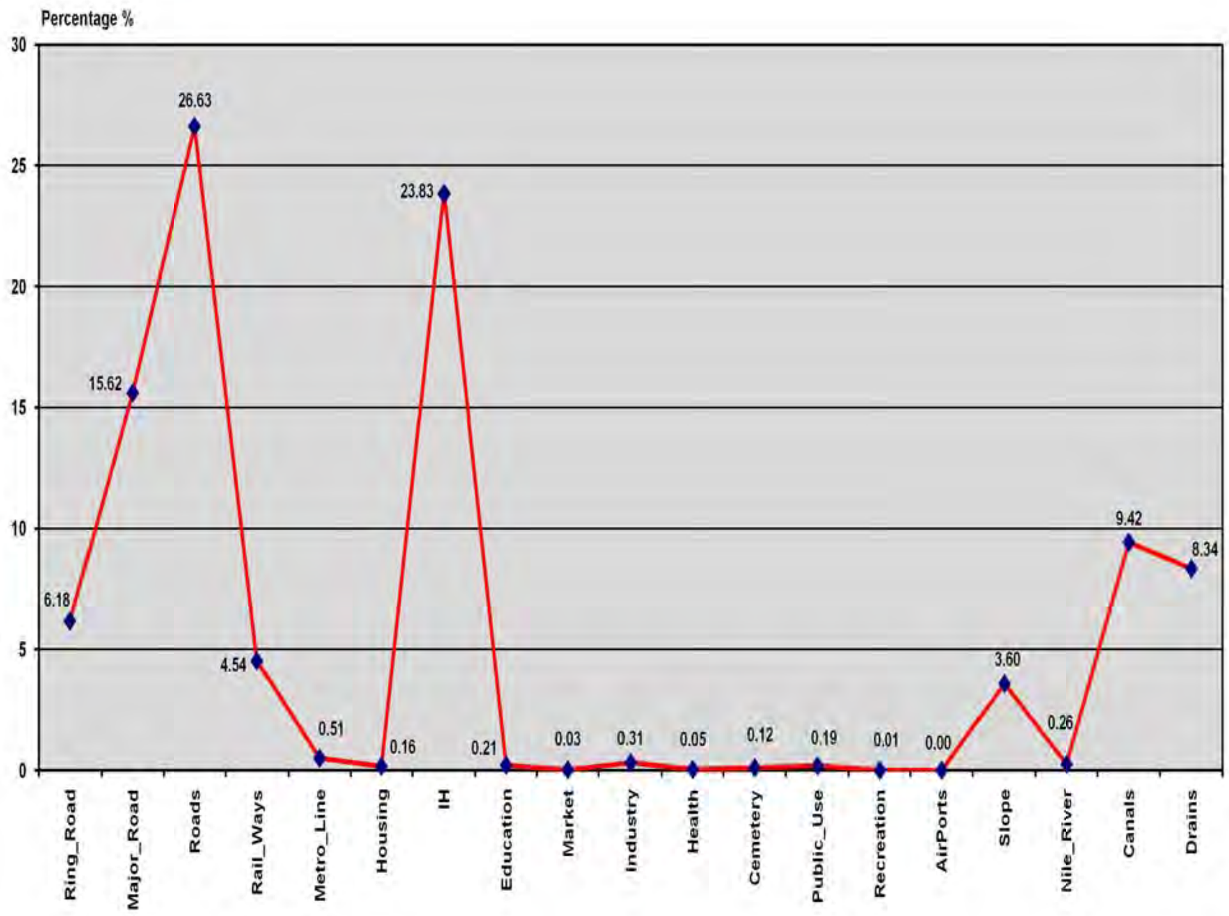


Figure (6 – 49) The calibration results of Matrix: **LU3_Net7_2**

Level	Land use weights	Roads & Water weights
level 1	**1**	**1**
Level 2	**0.75**	**0.80**
Level 3	**0.50**	**0.60**
Level 4	**0.25**	**0.40**
Level 5	**--**	**0.20**

	Factor Name	Percentage %
Network	**Ring Road**	**2.54 %**
	Major Road	**7.15 %**
	Roads	**12.34 %**
	Rail Ways	**2.02 %**
	Metro Line	0.20 %
Land Use	Housing	0.47 %
	Informal Housing	**57.39 %**
	Education	0.56 %
	Market	0.08 %
	Industry	0.86 %
	Health	0.15 %
	Cemetery	0.32 %
	Public Use	0.53 %
	Recreation	0.03 %
	Air Ports	0.00
	Slope	**6.55 %**
Water	**Nile River**	0.71 %
	Canals	**4.16 %**
	Drains	**3.96 %**

Results

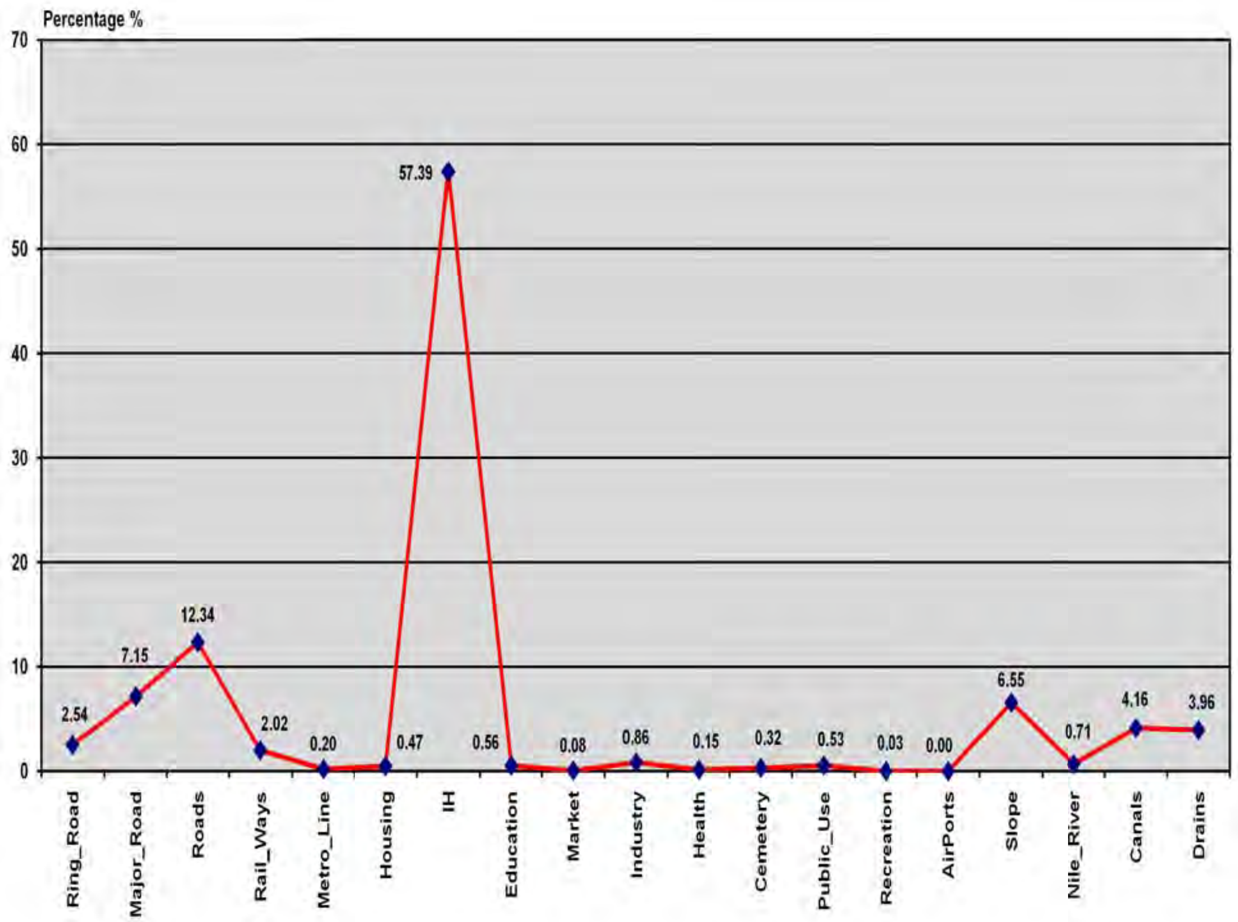


Figure (6 – 50) The calibration results of Matrix: **LU4_Net5_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.75**	**1.50**
Level 3	**0.50**	**1**
Level 4	**0.25**	**0.75**
Level 5	**--**	**0.50**

	Factor Name	Percentage %
Network	**Ring Road**	**3.77 %**
	Major Road	**10.55 %**
	Roads	**18.18 %**
	Rail Ways	**2.98 %**
	Metro Line	0.29 %
Land Use	Housing	0.36 %
	Informal Housing	**43.89 %**
	Education	0.43 %
	Market	0.06 %
	Industry	0.66 %
	Health	0.11 %
	Cemetery	0.24 %
	Public Use	0.40 %
	Recreation	0.02 %
	Air Ports	0.00
	Slope	**5.01 %**
Water	**Nile River**	**1.08 %**
	Canals	**6.13 %**
	Drains	**5.82 %**

Results

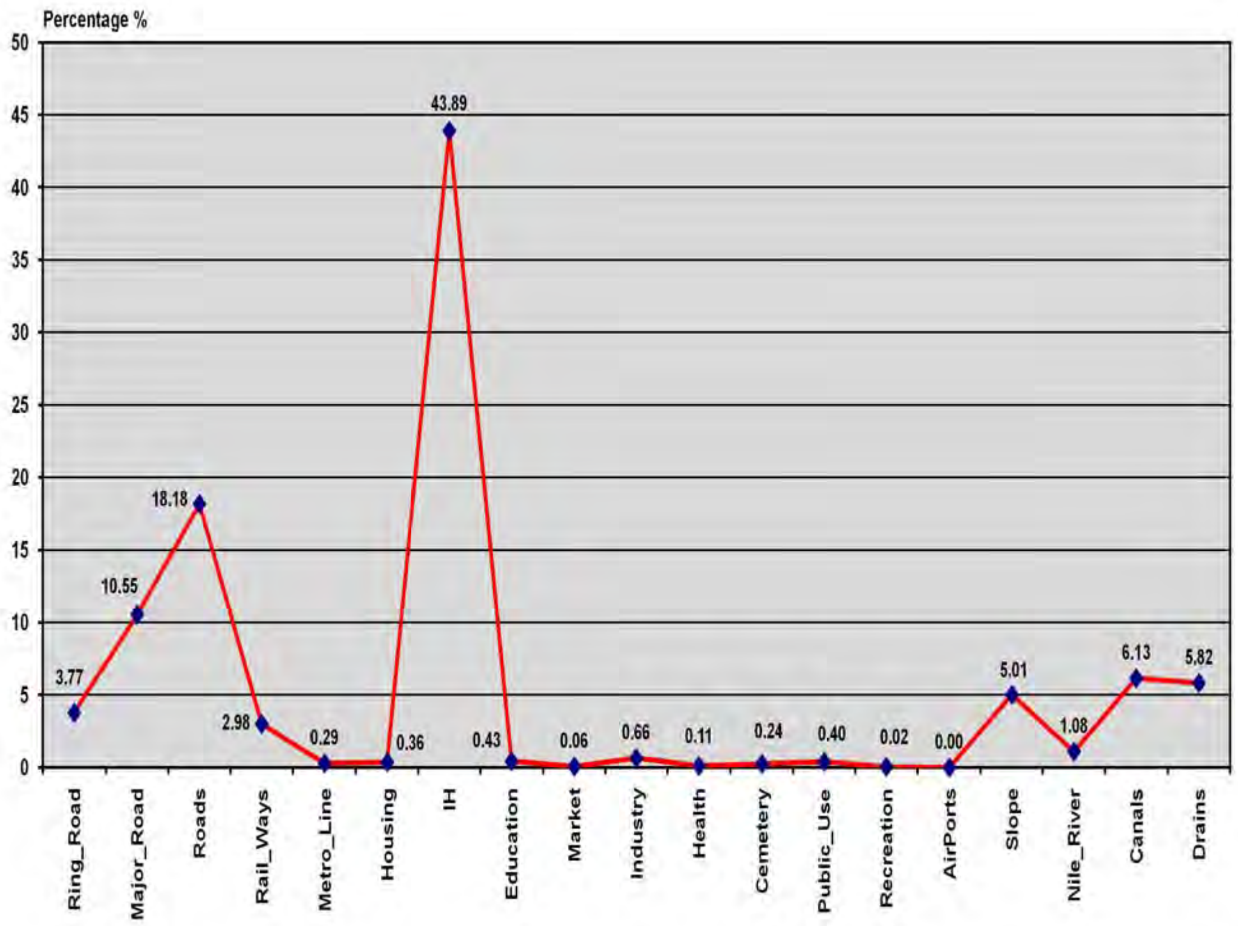


Figure (6 – 51) The calibration results of Matrix: **LU4_Net5_2**

Level		Land use weights	Roads & Water weights
level 1		1	1
Level 2		0.80	0.80
Level 3		0.60	0.60
Level 4		0.40	0.40
Level 5		0.20	0.20
Factor Name			Percentage %
Network	**Ring Road**		**1.93 %**
	Major Road		**5.43 %**
	Roads		**9.37 %**
	Rail Ways		**1.53 %**
	Metro Line		0.15 %
Land Use	Housing		0.65 %
	Informal Housing		**64.77 %**
	Education		0.67 %
	Market		0.09 %
	Industry		**1.11 %**
	Health		0.18 %
	Cemetery		0.40 %
	Public Use		0.70 %
	Recreation		0.05 %
	Air Ports		0.00
	Slope		**4.97 %**
Water	**Nile River**		**1.83 %**
	Canals		**3.16 %**
	Drains		**3.00 %**

Results

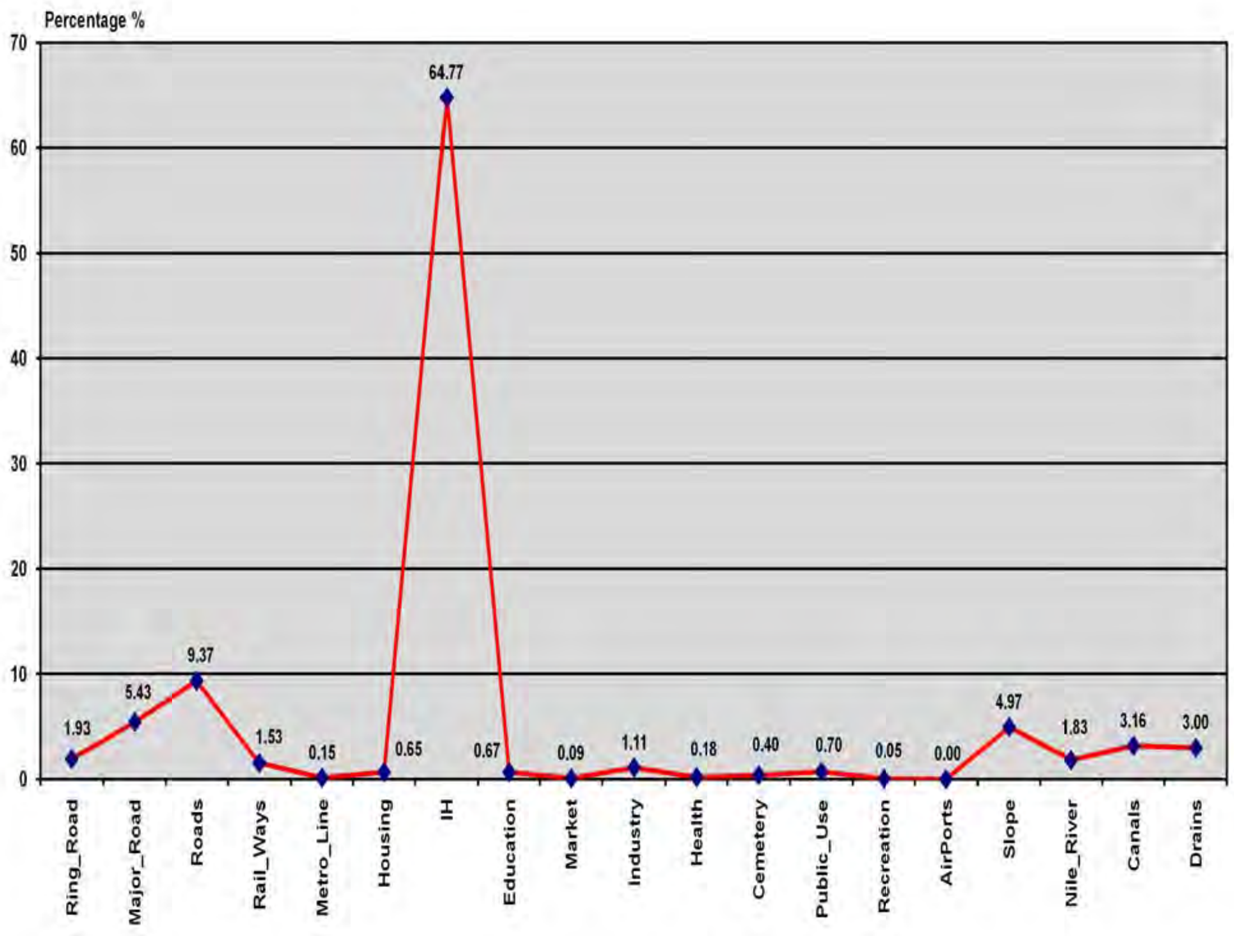


Figure (6 – 52) The calibration results of Matrix: **LU5_Net5_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.80**	**1.50**
Level 3	**0.60**	**1**
Level 4	**0.40**	**0.75**
Level 5	**0.20**	**0.50**

	Factor Name	Percentage %
Network	**Ring Road**	**3.05 %**
	Major Road	**8.52 %**
	Roads	**14.69 %**
	Rail Ways	**2.41 %**
	Metro Line	0.24 %
Land Use	Housing	0.53 %
	Informal Housing	**52.74 %**
	Education	0.55 %
	Market	0.07 %
	Industry	0.90 %
	Health	0.15 %
	Cemetery	0.33 %
	Public Use	0.57 %
	Recreation	0.04 %
	Air Ports	0.00
	Slope	**4.05 %**
Water	**Nile River**	**1.49 %**
	Canals	**4.96 %**
	Drains	**4.71 %**

Results

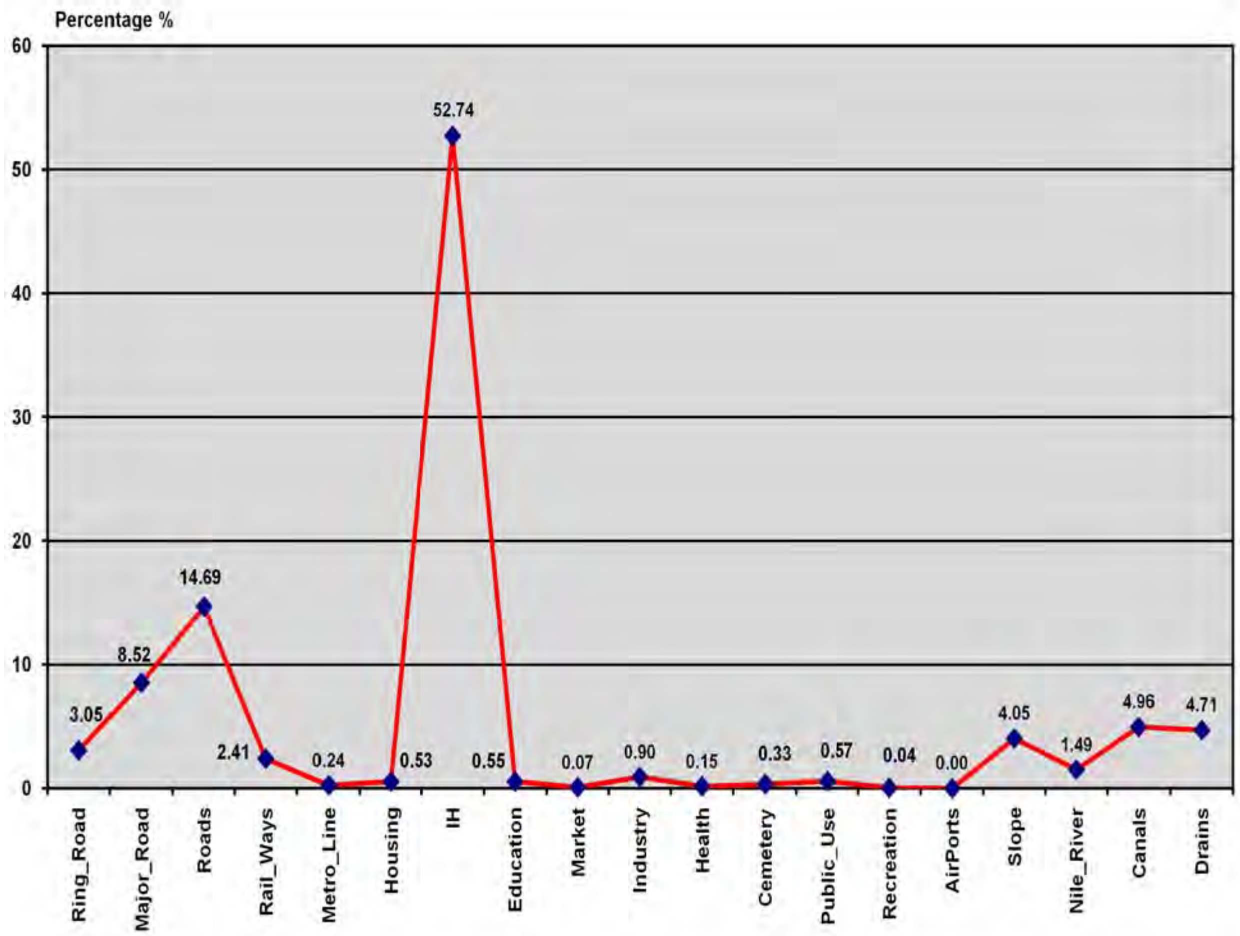


Figure (6 – 53) The calibration results of Matrix: **LU5_Net5_2**

Level	Land use weights	Roads & Water weights
level 1	**1**	**1**
Level 2	**0.90**	**0.90**
Level 3	**0.70**	**0.70**
Level 4	**0.50**	**0.50**
Level 5	**0.30**	**0.30**
Level 6	**0.20**	**0.20**

	Factor Name	Percentage %
Network	**Ring Road**	**2.15 %**
	Major Road	**5.21 %**
	Roads	**9.05 %**
	Rail Ways	**1.27 %**
	Metro Line	0.15 %
Land Use	Housing	0.78 %
	Informal Housing	**65.27 %**
	Education	0.70 %
	Market	0.09 %
	Industry	**1.25 %**
	Health	0.20 %
	Cemetery	0.44 %
	Public Use	0.82 %
	Recreation	**1.10 %**
	Air Ports	0.00
	Slope	**3.50 %**
Water	Nile River	**2.07 %**
	Canals	**3.09 %**
	Drains	**2.84 %**

Results

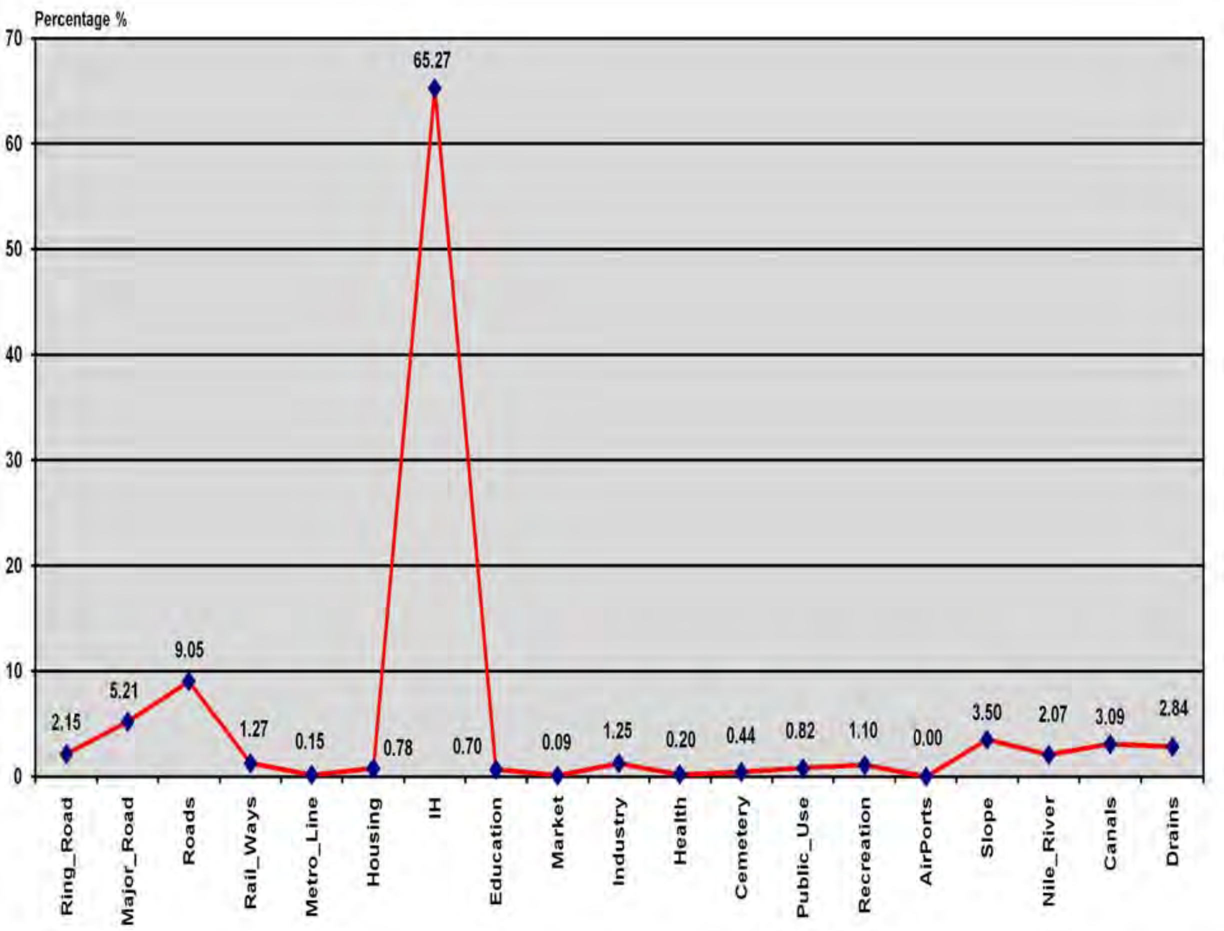


Figure (6 – 54) The calibration results of Matrix: **LU6_Net6_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.90**	**1.75**
Level 3	**0.70**	**1.50**
Level 4	**0.50**	**1.25**
Level 5	**0.30**	**1**
Level 6	**0.20**	**0.75**

	Factor Name	Percentage %
Network	**Ring Road**	**4.14 %**
	Major Road	**9.75 %**
	Roads	**16.75 %**
	Rail Ways	**2.40 %**
	Metro Line	0.30 %
Land Use	Housing	0.57 %
	Informal Housing	**47.63 %**
	Education	0.51 %
	Market	0.07 %
	Industry	0.91 %
	Health	0.15 %
	Cemetery	0.32 %
	Public Use	0.60 %
	Recreation	0.80 %
	Air Ports	0.00
	Slope	**2.55 %**
Water	Nile River	**1.51 %**
	Canals	**5.82 %**
	Drains	**5.22 %**

Results

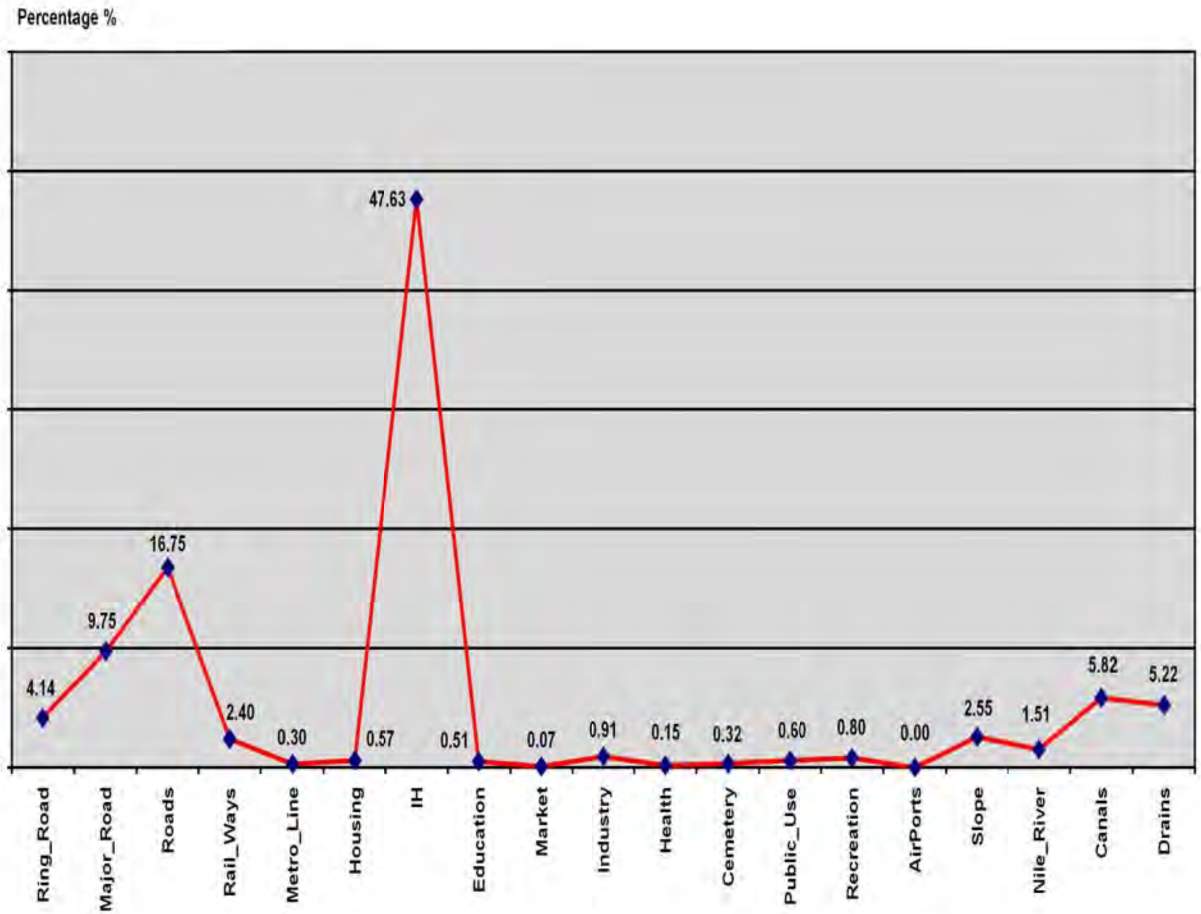


Figure (6 – 55) The calibration results of Matrix: **LU6_Net6_2**

Level	Land use weights	Roads & Water weights
level 1	**1**	**1**
Level 2	**0.90**	**0.90**
Level 3	**0.75**	**0.75**
Level 4	**0.60**	**0.60**
Level 5	**0.45**	**0.45**
Level 6	**0.30**	**0.30**
Level 7	**0.15**	**0.15**

	Factor Name	Percentage %
Network	**Ring Road**	**1.97 %**
	Major Road	**5.31 %**
	Roads	**8.77 %**
	Rail Ways	**1.47 %**
	Metro Line	0.16 %
Land Use	Housing	0.92 %
	Informal Housing	**65.82 %**
	Education	0.72 %
	Market	0.10 %
	Industry	**1.39 %**
	Health	0.22 %
	Cemetery	0.47 %
	Public Use	0.93 %
	Recreation	**1.06 %**
	Air Ports	0.00
	Slope	**2.60 %**
Water	Nile River	**2.32 %**
	Canals	**3.04 %**
	Drains	**2.73 %**

Results

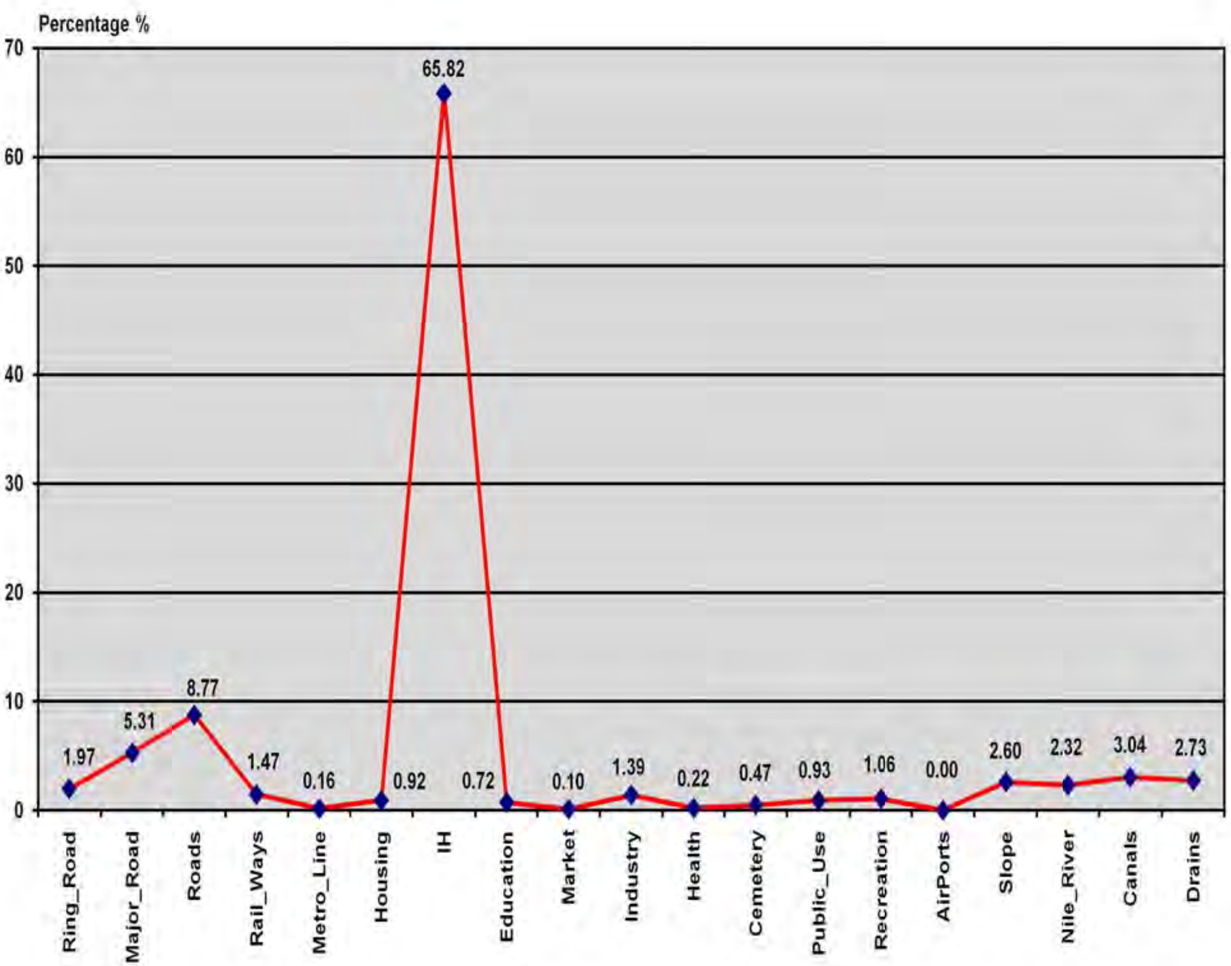


Figure (6 – 56) The calibration results of Matrix: **LU7_Net7_1**

Level	Land use weights	Roads & Water weights
level 1	**1**	**2**
Level 2	**0.90**	**1.75**
Level 3	**0.75**	**1.50**
Level 4	**0.60**	**1.25**
Level 5	**0.45**	**1**
Level 6	**0.30**	**0.75**
Level 7	**0.15**	**0.50**

	Factor Name	Percentage %
Network	**Ring Road**	**3.87 %**
	Major Road	**8.69 %**
	Roads	**15.21 %**
	Rail Ways	**2.21 %**
	Metro Line	0.29 %
Land Use	Housing	0.72 %
	Informal Housing	**51.61 %**
	Education	0.57 %
	Market	0.08 %
	Industry	**1.08 %**
	Health	0.17 %
	Cemetery	0.37 %
	Public Use	0.72 %
	Recreation	0.83 %
	Air Ports	0.00
	Slope	**2.04 %**
Water	Nile River	**1.78 %**
	Canals	**5.15 %**
	Drains	**4.61 %**

Results

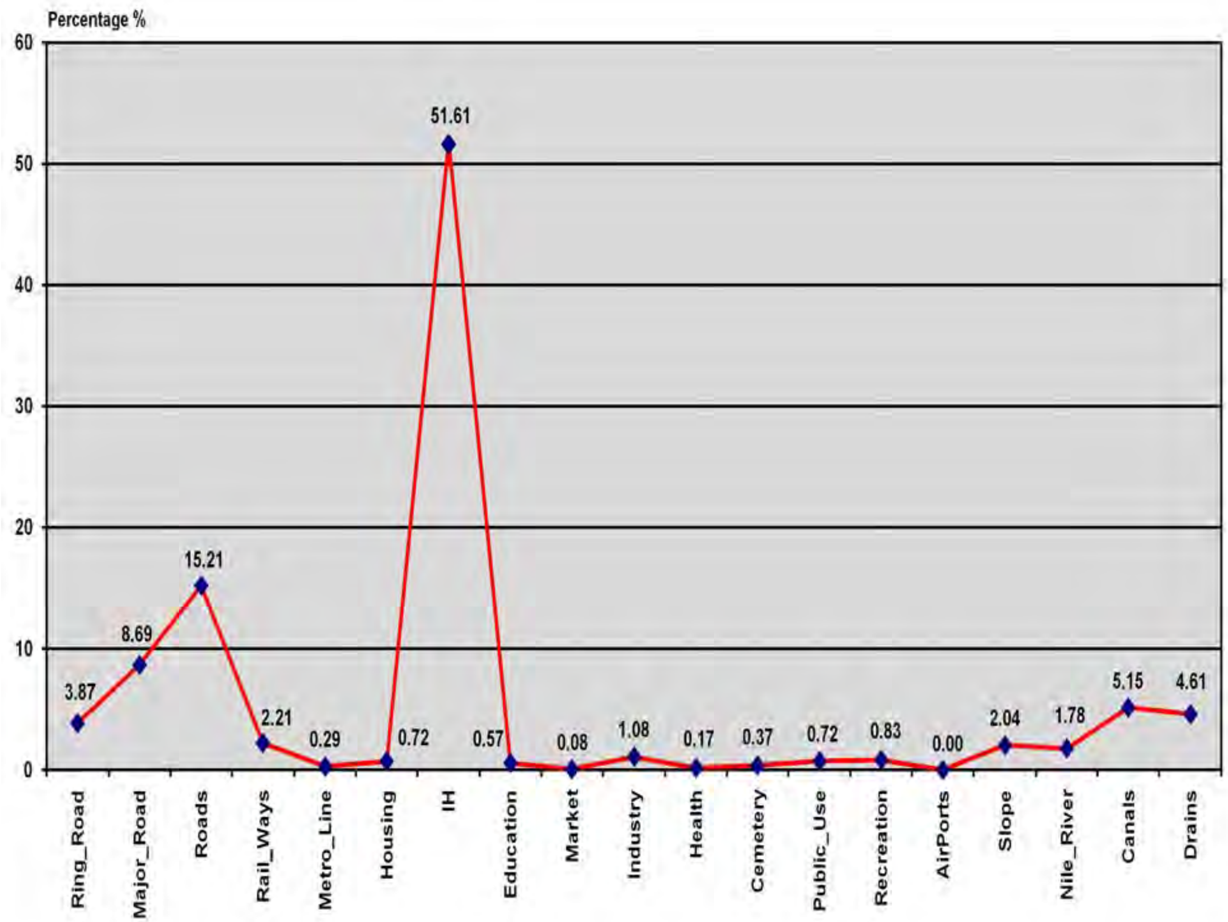


Figure (6 – 57) The calibration results of Matrix: **LU7_Net7_2**

(6-6-3) Testing of Growth Factors Calibration Results

This section will test and evaluate the calibration phase results to select the most **suitable growth factor influence ratio** *(degree of contribution)* to expand **IH**, and the corresponding **size of neighborhood matrix** that simulate the behavior of **IH** expansion in **GCR**.

To do this, we will predict the **IH** areas in year **2006** based on the existing land use map in **2001**, and compare the predicted **IH** areas with a recent **Satellite Image** taken in **2006** to choose the alternative that have highest rate of coincidence with the **built-up** area in year **2006**.

To predict the IH areas in 2006 we will proceed the following steps:

(6-6-3-1) Estimation of the Probability Map in year 2006

In this step, we will use the **IHGM** probability module *(as discussed in section 6-4-3)* to estimate the areas that have high probability to change from **vacant** *(agriculture or desert)* to **IH** areas in **2006**. In the case of **GCR**, we estimate the probability map in **2006** many times, in each attempt we use one of the proposed alternatives in the calibration phase and its corresponding results *(see figures 6-40 to 6-57).*

The probability module contains the following two steps:

a) Definition of the transition rules

The transition rule defines the cases and conditions under which an **IH** cell can be emerged, *(see section 6-4-3-1),* in this step the user defines:

- **The influence ratio of land use growth factors** to expand **IH** areas, which produced from the calibration phase, and the corresponding size of neighborhood matrix and its levels weights, as shown in Figure (6-58/A).
- **The influence ratio of roads and transportation networks growth factors** to expand **IH** areas which produced from the calibration phase, and the corresponding size of neighborhood matrix and its levels weights, as shown in Figure (6-58/B).
- **The influence ratio of watercourses growth factors** to expand **IH** areas which produced from the calibration phase, and the corresponding size of neighborhood matrix and its levels weights, as shown in Figure (6-58/C).

- **The slope transition rules**, including the slope categories and the transition rule for each category.

b) Estimation of the probability to change map

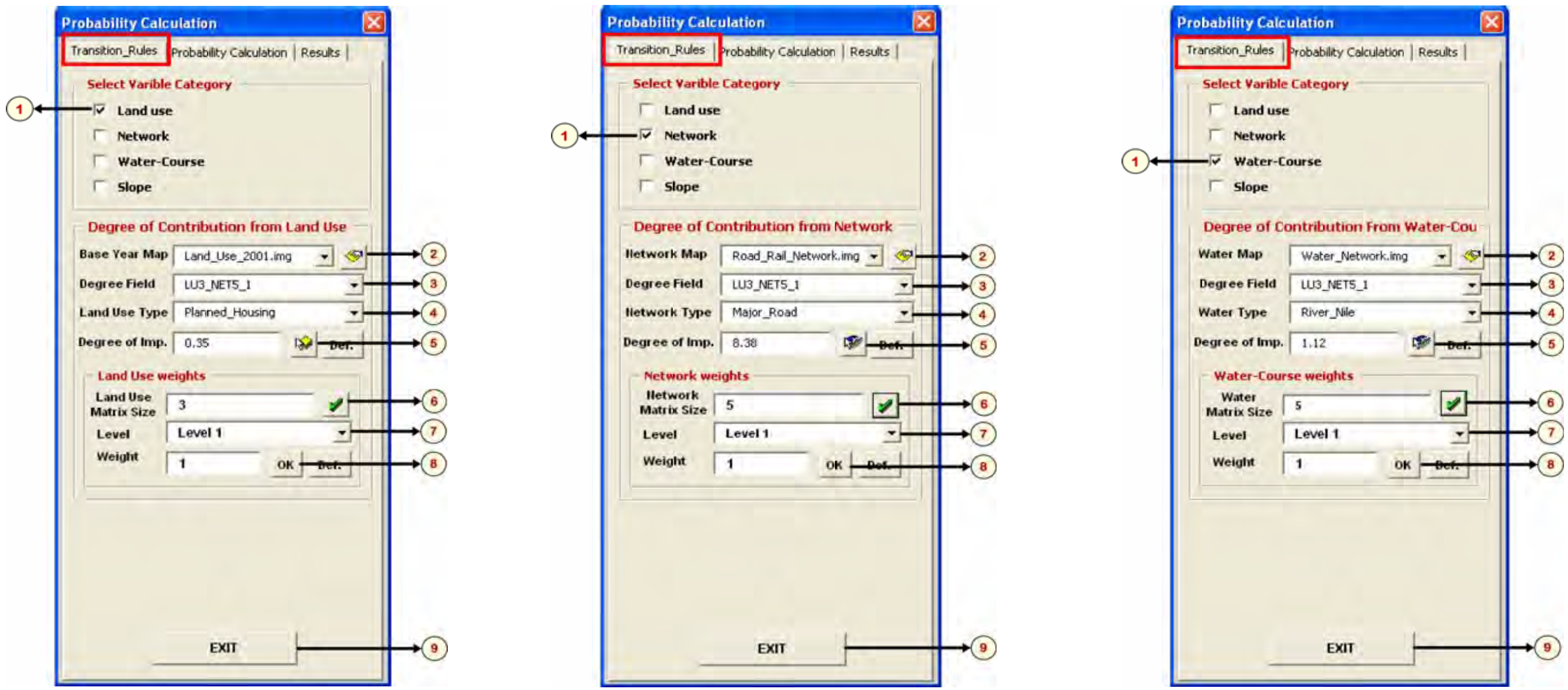
The probability to change macro will use to calculate the **vacant pixel** relative probability value to change into **IH cell**, by considering the contribution of all neighboring growth factors and those weights in each level of the neighborhood matrix, *(see section 6-4-3-2).* This sub-module starts by define :

- The **land use** map in the **base prediction** year *(2001)*,
- The **roads** and **transportation networks** map in the **base prediction** year *(2001)*,
- The **watercourses** map in the **base prediction** year *(2001)*,
- The study area **slope map**,
- The **land cover** map in the **base prediction** year *(2001)*,
- The output **probability map** *(point layer)* in the **target prediction** year *(2006)*, as shown in Figure (6-59).

The probability map in 2006 was estimated many times, each attempt use one of the calibration alternatives results. The probability to change sub-module calculates the relative probability scores for all cells around the existing **IH** pixels, within the defined **L(s)** and **N(s)**.

The probability to change sub-module estimates the number of pixels that satisfy the transition rules and suitable *(qualified)* to change from **vacant** to **IH** pixel in the next period.

In the case of GCR, The number of estimated IH pixels varies from alternative to other, relative to the defined size of neighborhood matrix and the transition rules.



Land use growth factors		Roads and transportation growth factors		Watercourses growth factors	
1	Choose the growth factors category,	**4**	Choose the growth factor name,	**7**	Choose the matrix level,
2	Choose the map of base prediction year, *(2006)*	**5**	Assign the influence ratio for the selected growth factor,	**8**	Assign the growth category weight at the selected level,
3	Choose the field that contains the influence ratios of growth factors,	**6**	Assign the neighborhood matrix size for the selected growth factors category,	**9**	The EXIT button.

Figure (6-58) The **transition rules** dialog box

1 The **land use** map in the **base prediction** year *(2001),*

2 The **roads** and **transportation networks** map in the **base prediction** year *(2001),*

3 The **watercourses** map in the **base prediction** year *(2001),*

4 The study area **slope map**,

5 The **land cover** map in the **base prediction** year *(2001),*

6 The **districts** map, *(Qism or El_ahayaa)*

7 The output **probability map** *(point layer)* in the **target prediction** year *(2006),*

8 The **target prediction** year *(2006),*

9 The **probability to change** calculation buttonm

10 The **EXIT** button.

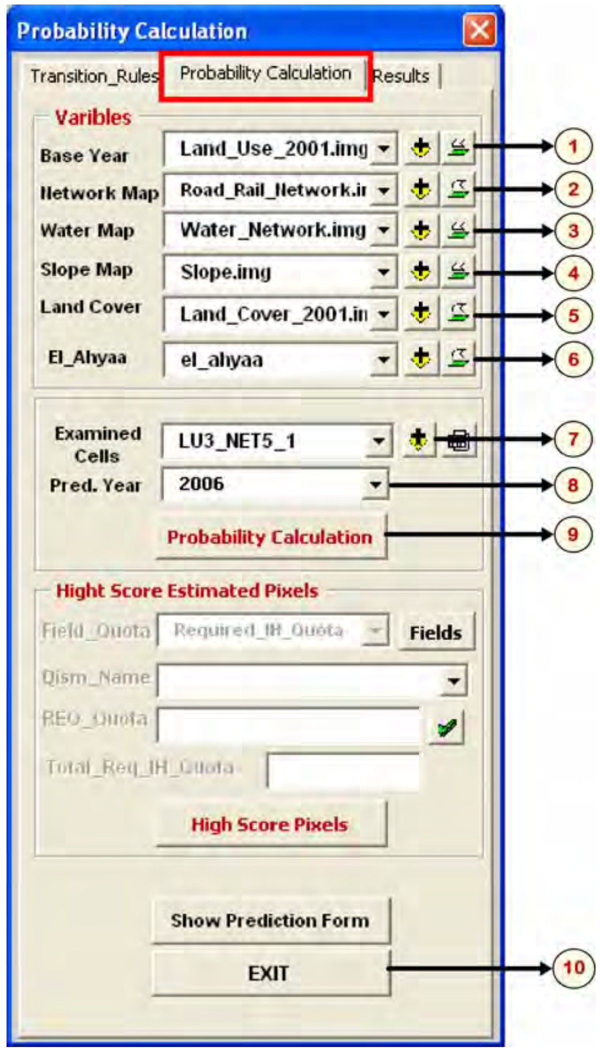


Figure (6-59) The **Probability to change** dialog box

(6-6-3-2) Prediction and Allocation of the IH in Year 2006
(the Mobility Sub-Module)

After developing many alternatives for the probability to change in **2006**, then the **mobility sub-module** starts to compare the **relative probability scores** for all the expected **IH** pixels with the **relative calibration value** for both land use and network factors. By Sorting the expected **IH** pixels at the district level, and convert the highest probability pixels into **IH** in each district, to match with the required statistical areas at the district level *(Qism or hay)*, *(see section 6-4-3-3).*

The **mobility sub-module** reduces the predicted **IH** pixels that produced in the previous step to the required **IH** quota, by comparing the required statistical **No of pixels** in **2006** with the **No of pixels** that have high probability to change into **IH** at the district level *(Qism or hay), (see table 6-13).*
The **mobility sub-module** was run many times, each attempt was use one of the expected probability map in year **2006**. Figure (6-60) show the **mobility sub-module dialog box** and the allocation results form.

1 Choose the field that contains the number of required statistical **IH** quota from **2001** to **2006**,

2 The district name, *(Qism or El_ahayaa)*

3 The required number of **IH** pixels for the selected district,

4 The total required **IH** quota for the entire region from **2001** to **2006**,

5 The high score probability button,

6 The **EXIT** button.

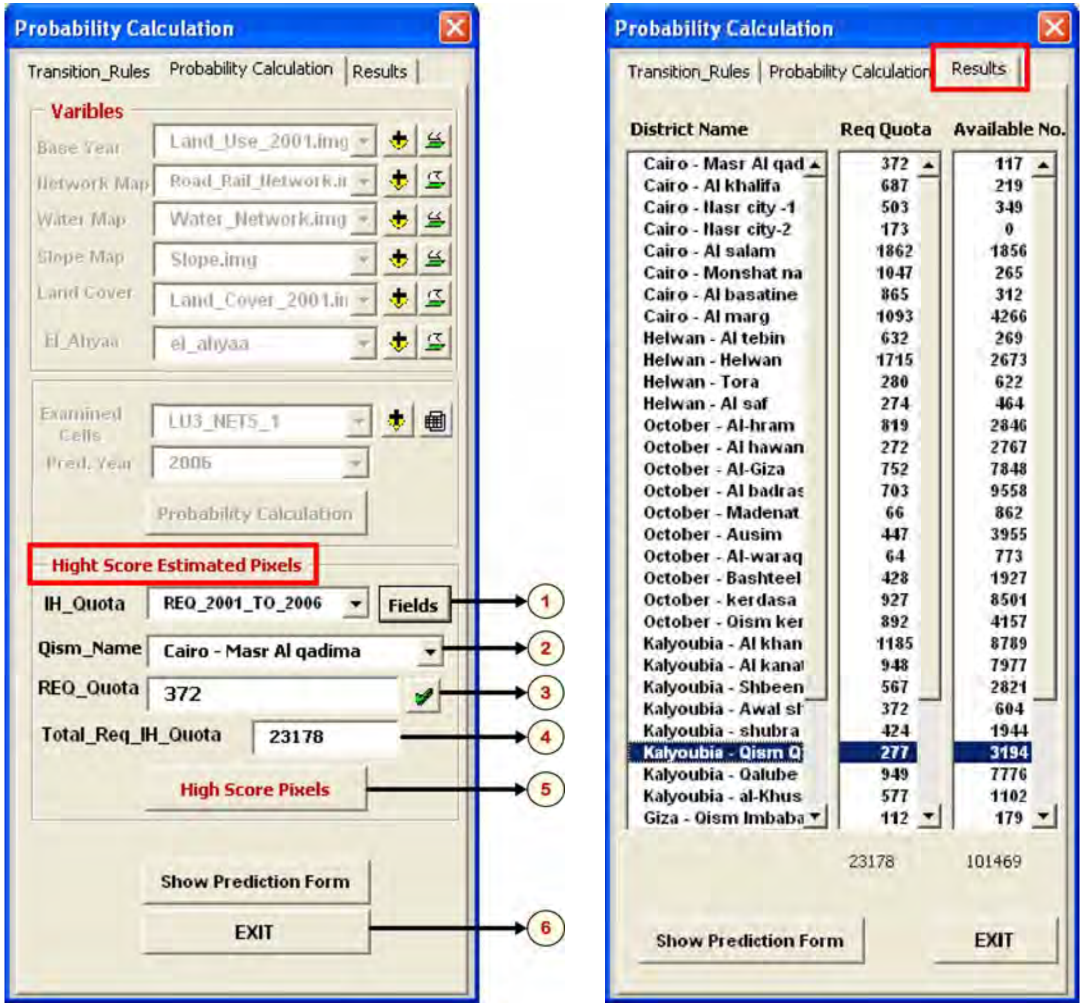


Figure (6-60) The **mobility sub-module** dialog box and the allocation results form.

(6-6-3-3) Choosing of the Best Allocation Alternative

The **IHGM** underwent a series of modifications to optimize the simulation results. To achieve a statistical validation between **the reality map** and **the simulated map** in **2006**, the **VALIDATE** procedure was used to test **the quantity**, **the location accuracy** of the simulated outputs and other **statistics measurements**. Overall, the quantity scores of the simulated maps perfectly agreed with the reality map.

The **predicted urban expansion in 2006** *(or the high score probability maps)* represents the test map, that will compare with a **V**ery **H**igh **R**esolution **(VHR) Quick-Bird** satellite image taking in **2006** *(1m resolution),* and choose the alternative assumptions that have highest percentage of coincidence with the real situation of the region in **2006**. Then we can use this alternative assumption and its corresponding calibration results in the prediction phase.

The urban extent in **2006** was digitized from the **Quick-Bird** satellite image, and the **ArcGIS spatial analysis tools** was used to compare between the high score probability maps with the real urban extents in **2006**, to choose the best allocation alternative.

Table (6-15) shows the coincidence rate for each alternative with the real urban extents in **2006**.

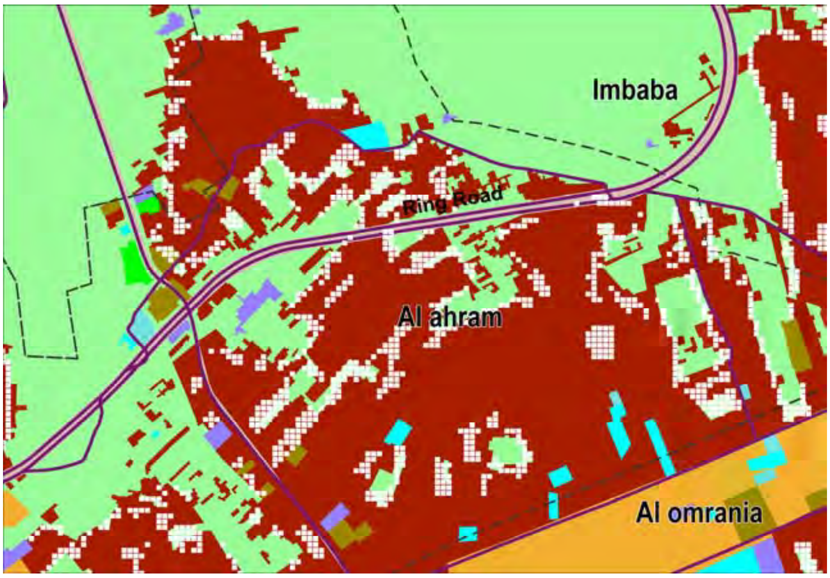
Matrix Name	Total Estimated IH pixels	No. of statistical required quota in 2006	No. of matched pixels with 2006 map	Percentage %
Lu3_Net3_1	102261	23178	19164	**82.7 %**
Lu3_Net3_2	102261	23178	17540	**75.7 %**
Lu3_Net4_1	102261	23178	19248	**83.0 %**
Lu3_Net4_2	102261	23178	16661	**71.9 %**
Lu3_Net5_1	102261	23178	20982	**90.5 %**
Lu3_Net5_2	102261	23178	15026	**64.8 %**
Lu3_Net6_1	102261	23178	18829	**81.2 %**
Lu3_Net6_2	102261	23178	14023	**60.5 %**
Lu3_Net7_1	102261	23178	16758	**72.3 %**
Lu3_Net7_2	102261	23178	13552	**58.5 %**
Lu4_Net5_1	131170	23178	20493	**88.4 %**
Lu4_Net5_2	131170	23178	18648	**80.5 %**
Lu5_Net5_1	159047	23178	18716	**80.7 %**
Lu5_Net5_2	159047	23178	17299	**74.6 %**
Lu6_Net6_1	186056	23178	16972	**73.2 %**
Lu6_Net6_2	186056	23178	17106	**73.8 %**
Lu7_Net7_1	212195	23178	16922	**73.0 %**
Lu7_Net7_2	212195	23178	16603	**71.6 %**

Table (6-15) The coincidence percentage for each alternative
with the real urban extents in **2006**

From table (6-15) we show that, the alternative (**Lu3_Net5_1**) has **90.5%** of coincidence with the urban extents in **2006**, while the alternative (**Lu4_Net5_1**) has **88.4%** of coincidence. i.e., we will use the assumption of alternative (**Lu3_Net5_1**), and its corresponding **calibration results** to simulate and predict the urban expansion for **GCR** from **2011** to **2046** with **5 years** periods, *figure (6-44) shows the alternative assumption including, the matrix size, levels weights and the influence ratio f growth factors.*

Giza

Al-Ahram



Giza

Bolaq Al-Dakrour

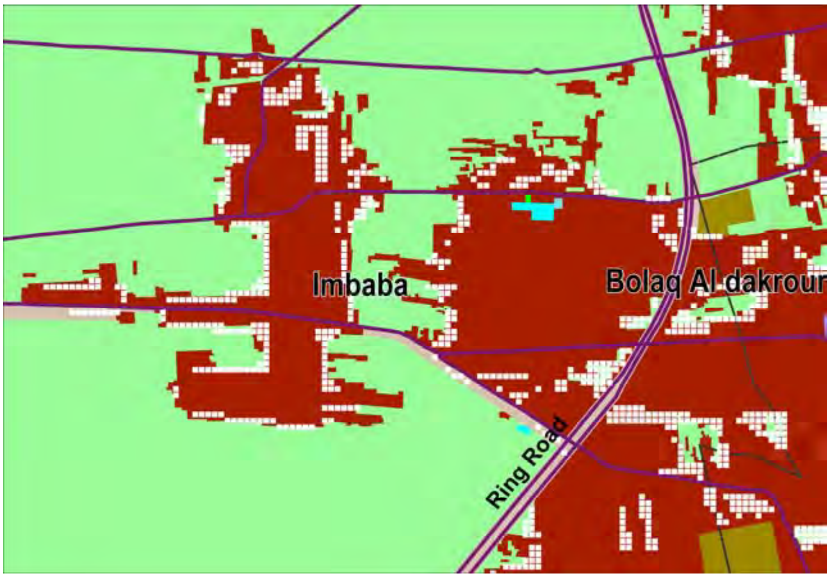
Giza

Al-Omraniyah

Figure (6-61) Comparison between the expected **IH** areas by using alternative **Lu3_Net5_1** with the real map in **2006**

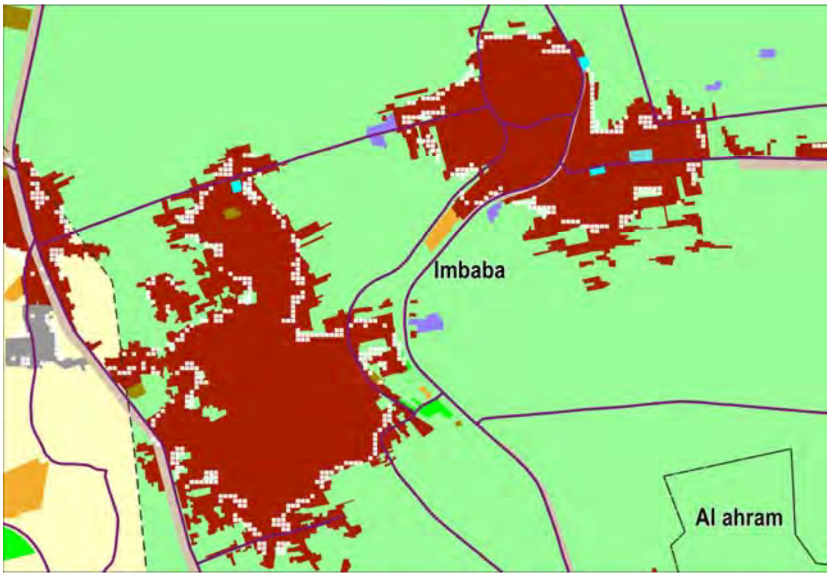
Giza

Qism Imbaba



Giza

kerdasa



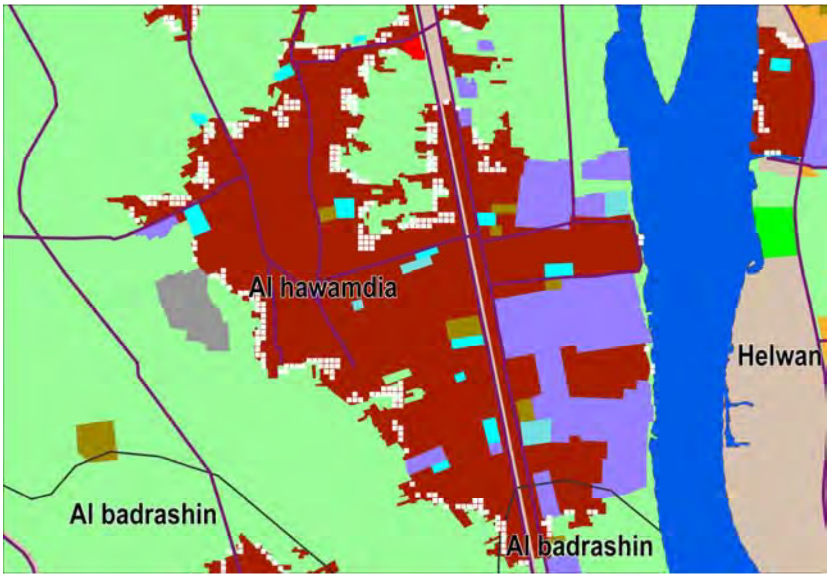
Giza

Al-Waraq

Figure (6-61) Comparison between the expected **IH** areas by using alternative **Lu3_Net5_1** with the real map in **2006** (cont.)

October

Al-Hawamdya

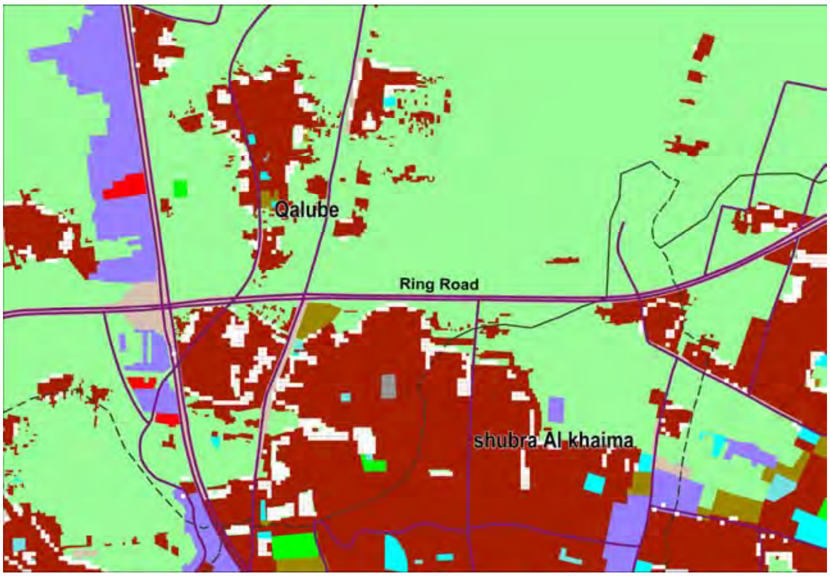


Kalyoubia

Shubra

Al-Khaima

and Qalube



Kalyoubia

Al-Marg

and Al-Salam

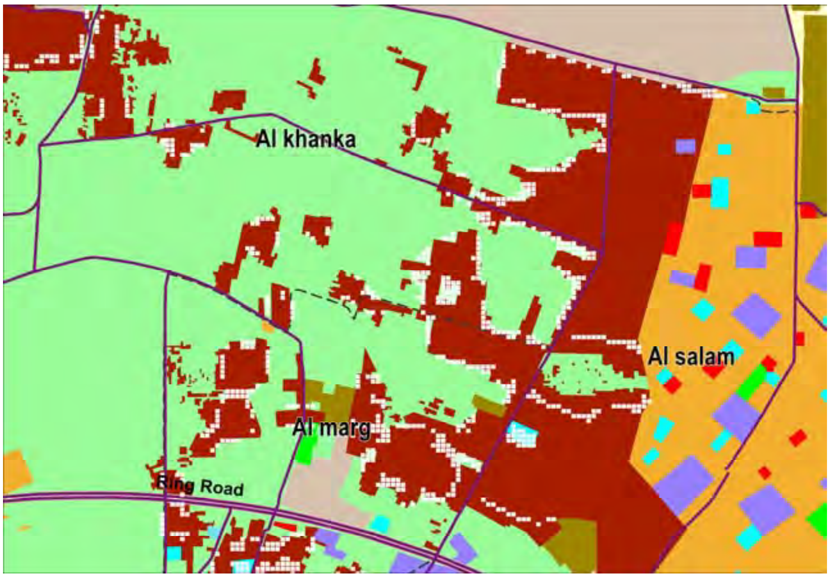
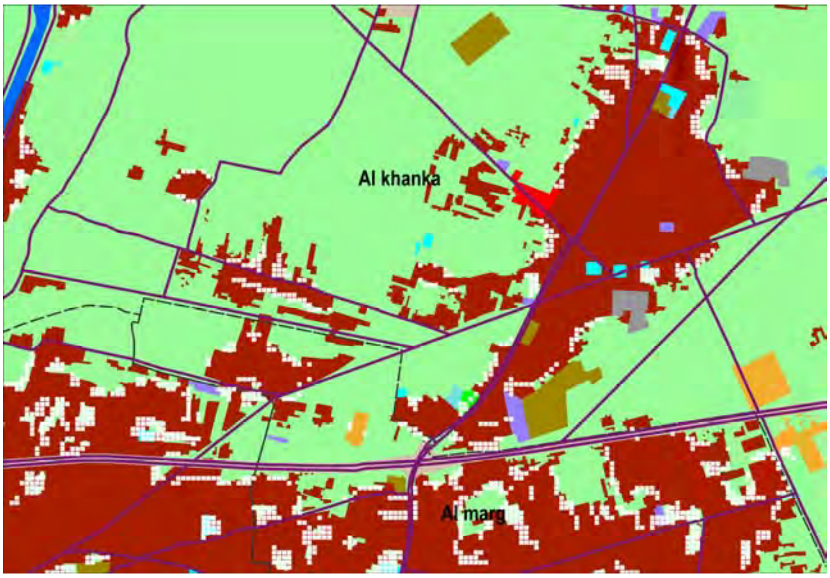


Figure (6-61) Comparison between the expected **IH** areas by using alternative **Lu3_Net5_1** with the real map in **2006** (cont.)

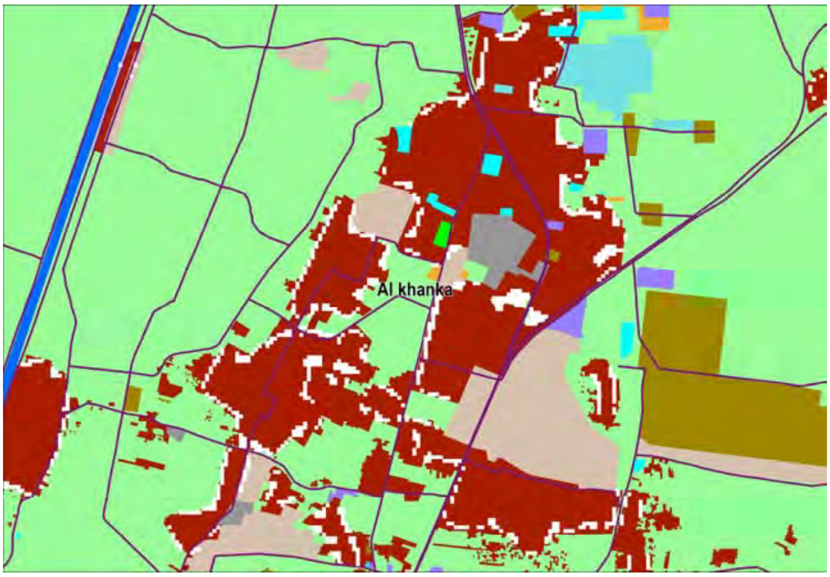
Kalyoubia

Al-Khanka



Kalyoubia

Al-Khanka



Cairo

Al-Marg

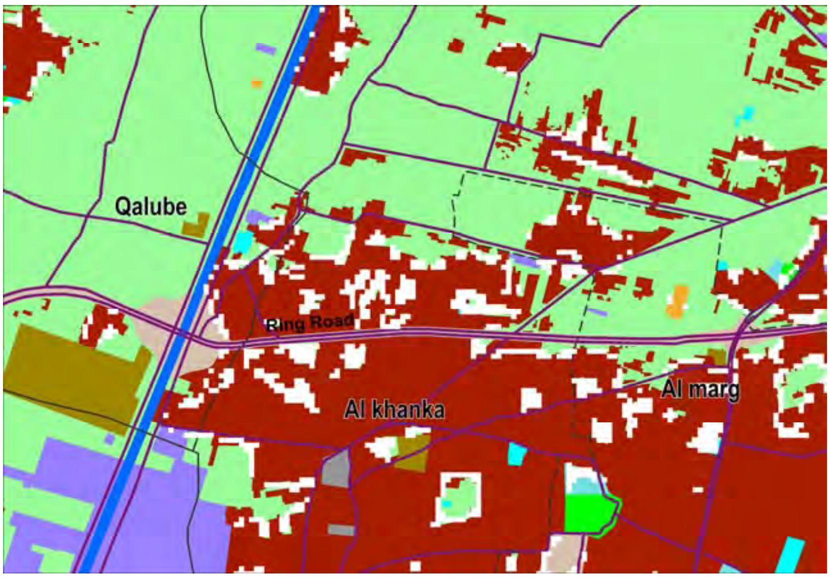


Figure (6-61) Comparison between the expected **IH** areas by using alternative **Lu3_Net5_1** with the real map in **2006** (cont.)

(6-6-4) Prediction of the Future Informal Housing Growth in GCR

The previous sections has been described the various stages undertaken to determine the influence ratio of growth factors, and the best neighborhood matrix size for both **land use** and **network** growth factors. **Importantly, the model was developed to incorporate a range of growth factors, to explore their contribution degree on the expansion of IH and to capture changes over time.**

This section describes the final step of the proposed **IHGM**, particularly this section tests the model predictive ability to simulate the future expansion.

In this section, we will predict the **IH** areas in years **2011 to 2046 with 5 years periods** based on the existing land use map in **2006**, the existing transportation networks map in **2006**, the existing watercourses map in **2006**, the land cover map in **2006**, and the slope and geography map.

To do this, we will follow the following two steps:

a) Estimate the probability map from **2011** to **2046** with **5** years period *(8 iterations)*, including: transition rules definition and estimate the probability to change map, *(as described in section 6-6-3-1).*
b) Perdition and allocation of the expected **IH** in the high probability areas, in years **2011**, **2016**, **2021**, **2026**, **2031**, **2036**, **2041** and **2046** respectively *(as described in section 6-6-3-2).*

Figures (6-63 to 6-70) show the expected informal housing growth in **GCR**

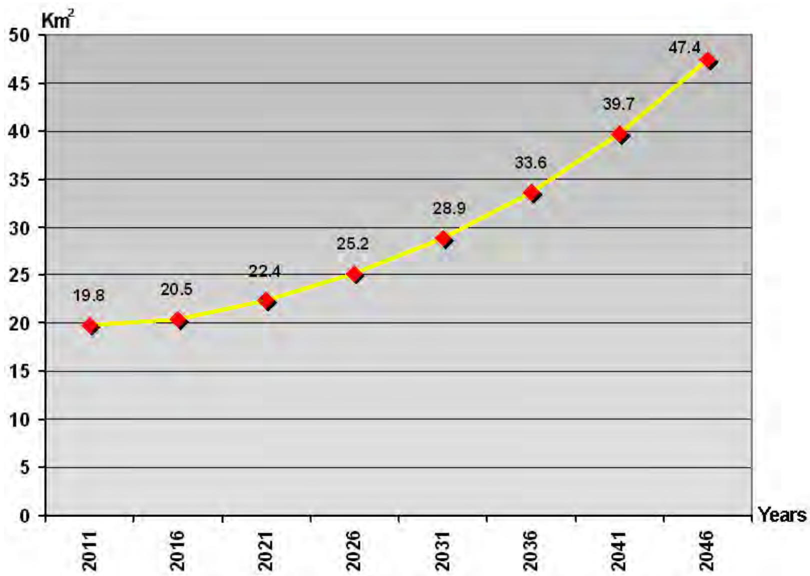


Figure (6-62) The expected informal housing growth in **GCR** from **2011** to **2046**

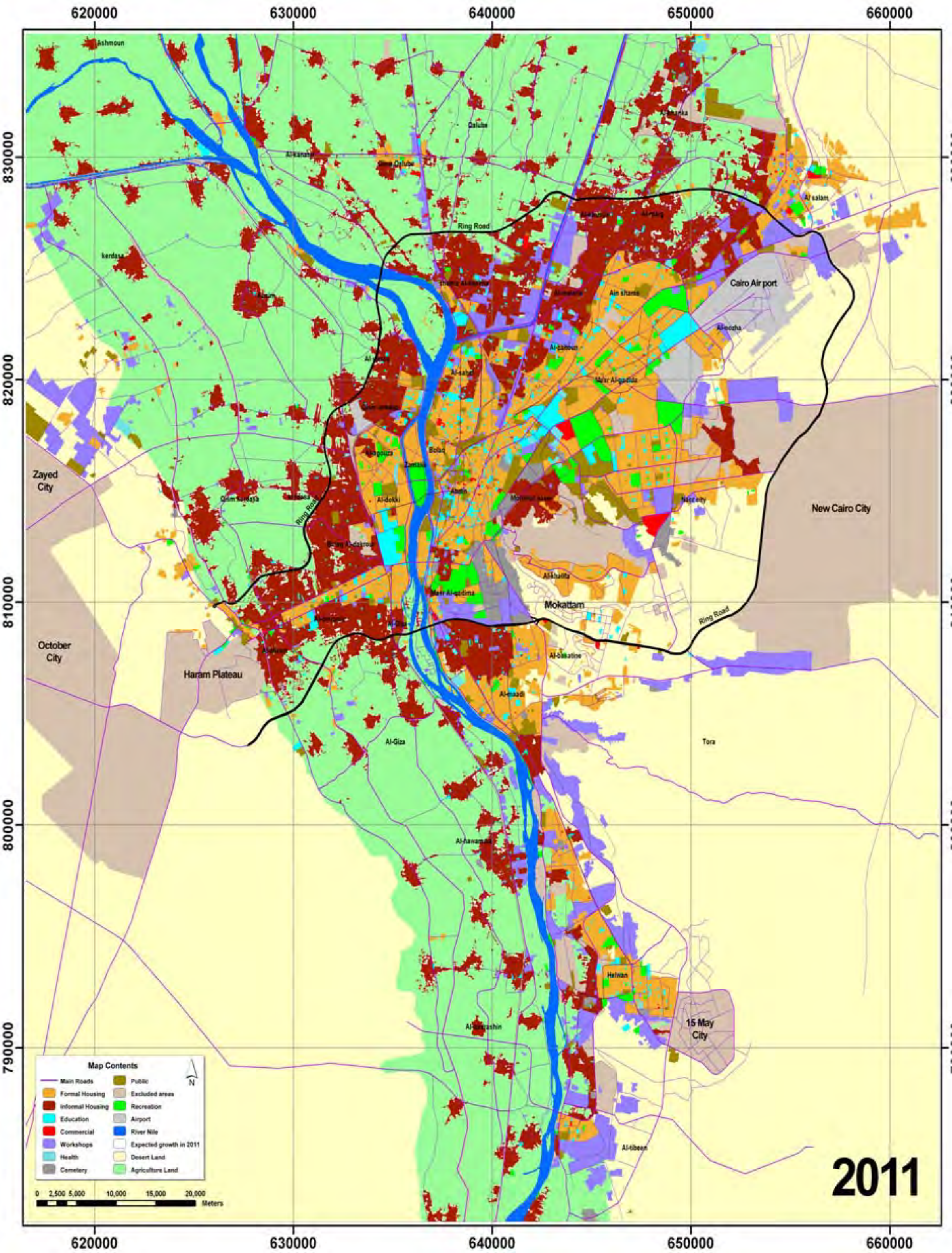


Figure (6-63) Allocation of the expected informal housing growth in **GCR** by year **2011**

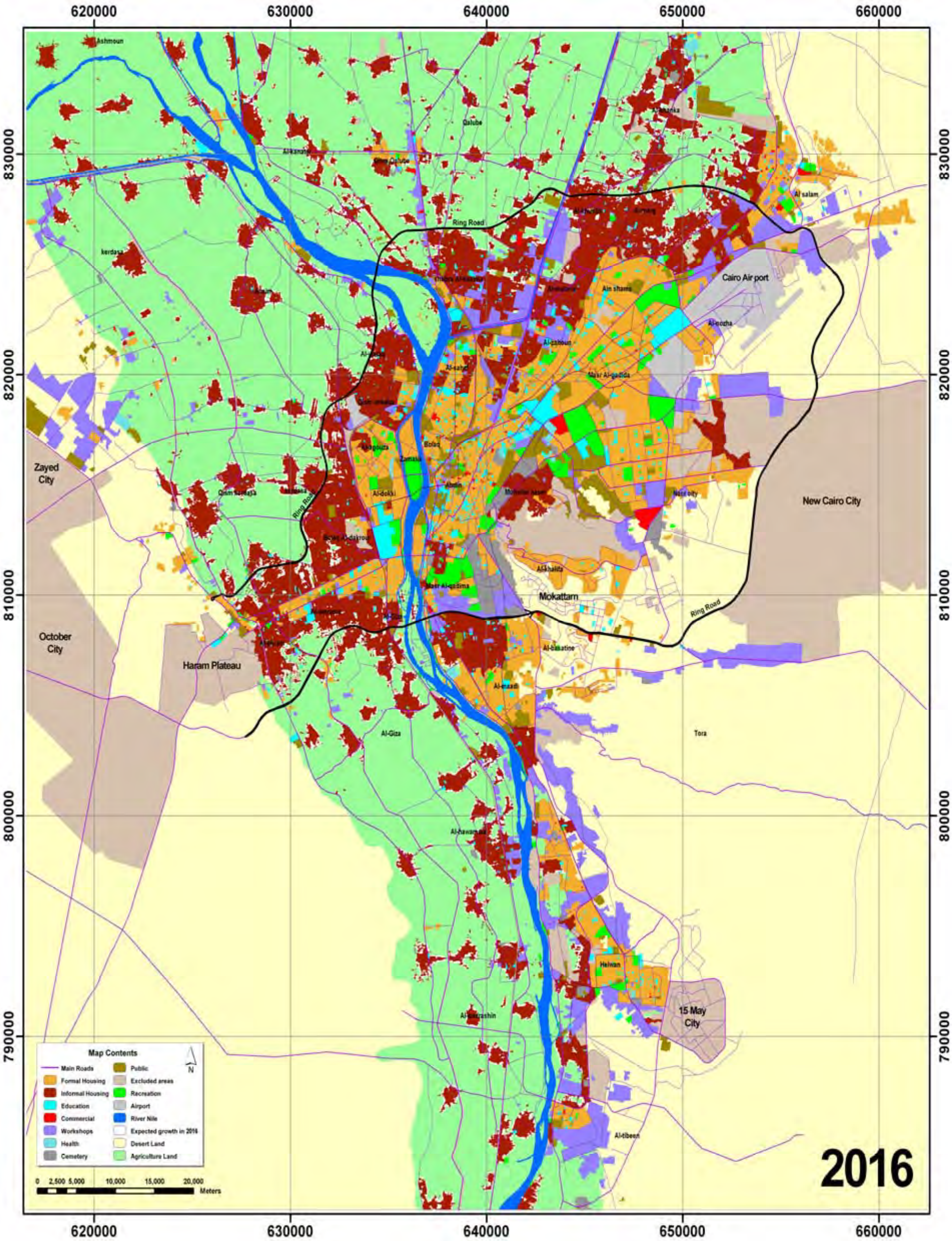


Figure (6-64) Allocation of the expected informal housing growth in **GCR** by year **2016**

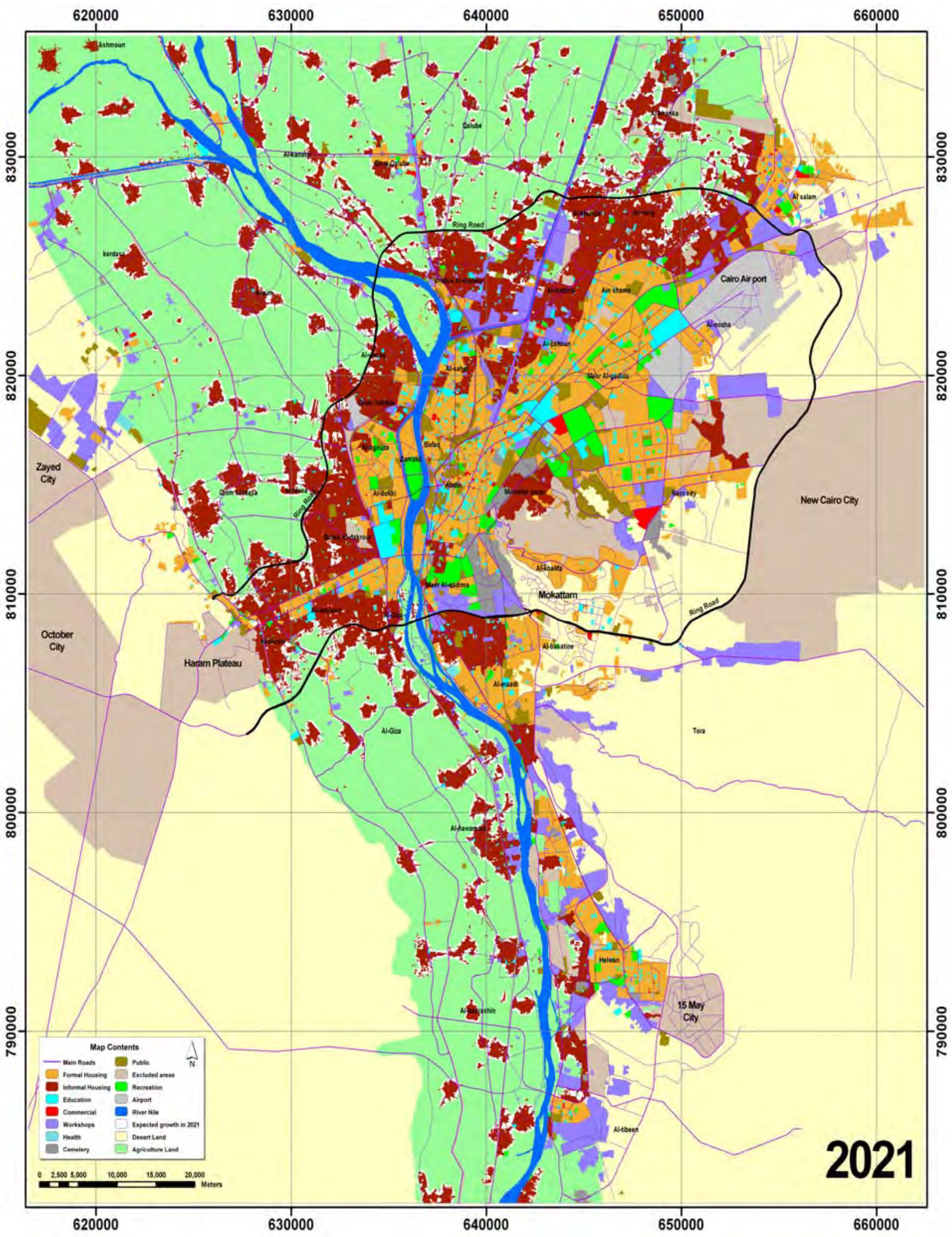


Figure (6-65) Allocation of the expected informal housing growth in **GCR** by year **2021**

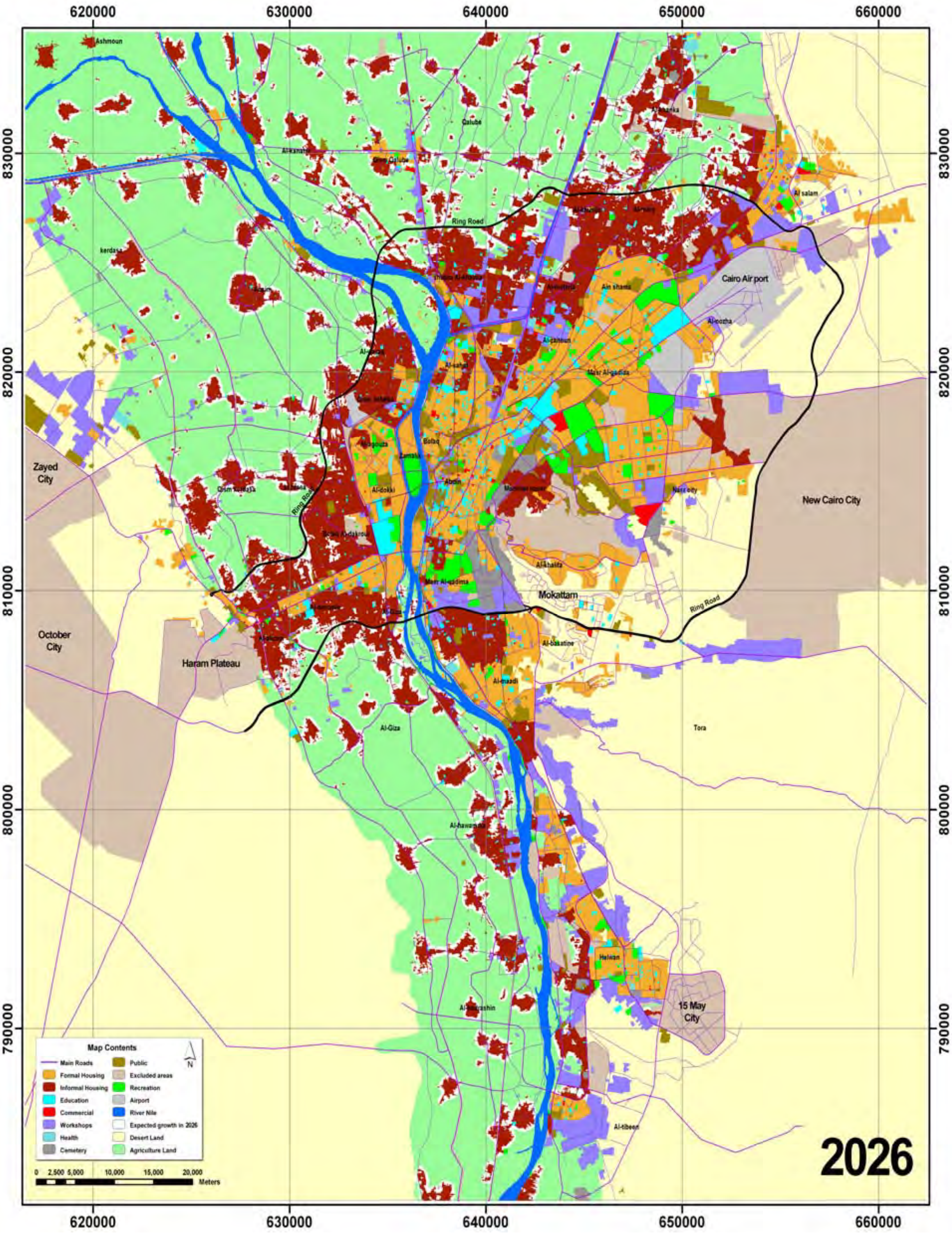


Figure (6-66) Allocation of the expected informal housing growth in **GCR** by year **2026**

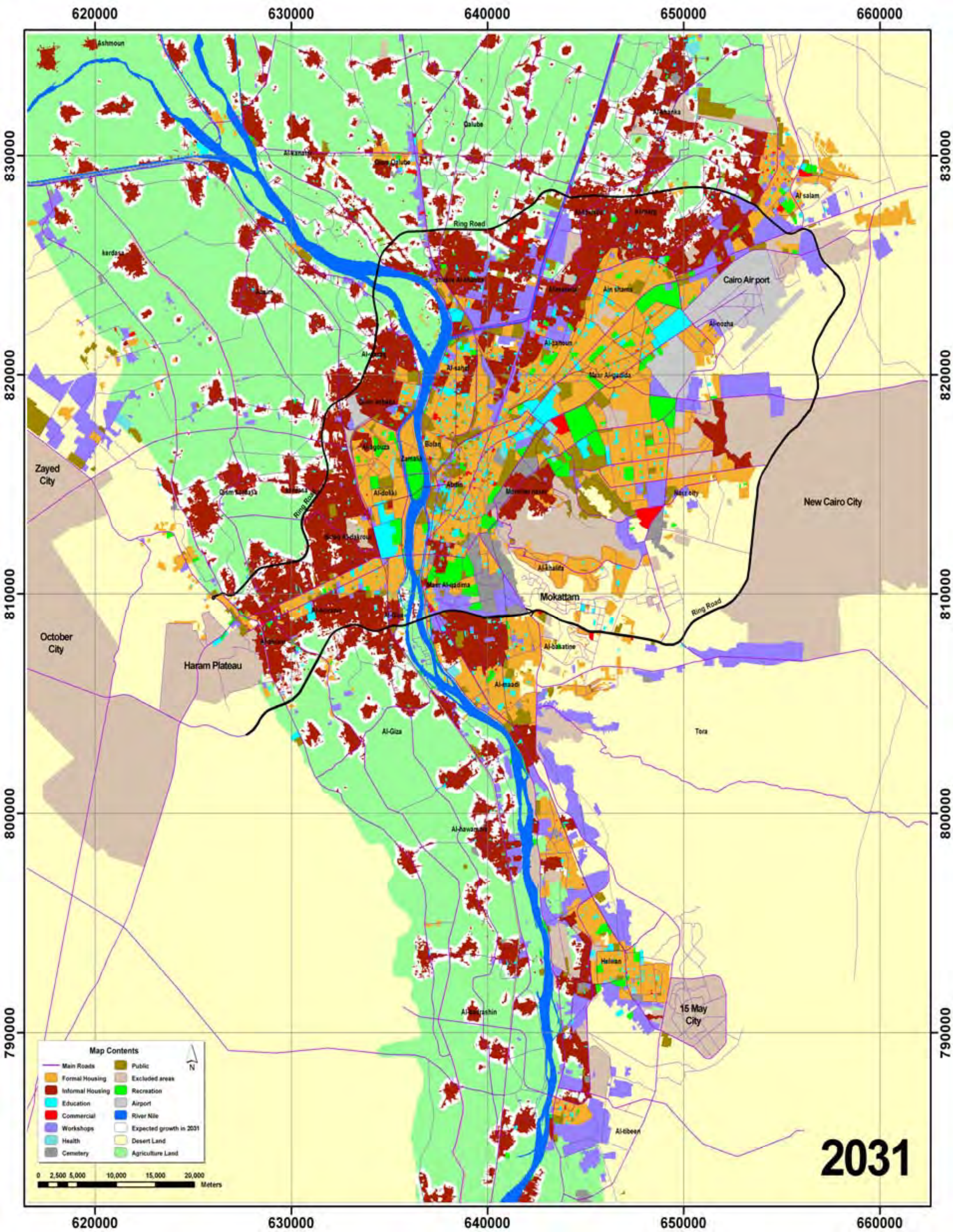


Figure (6-67) Allocation of the expected informal housing growth in **GCR** by year **2031**

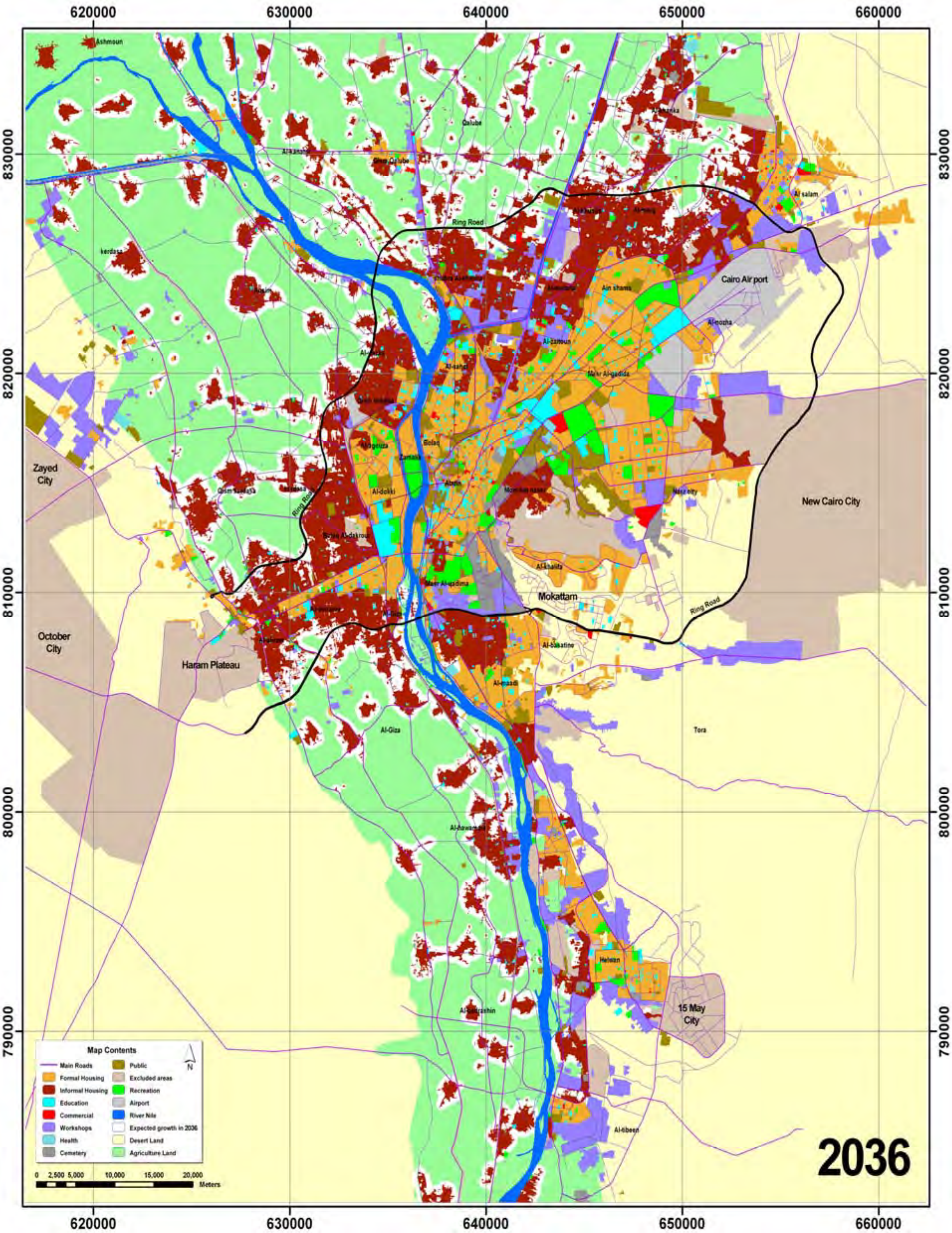


Figure (6-68) Allocation of the expected informal housing growth in **GCR** by year **2036**

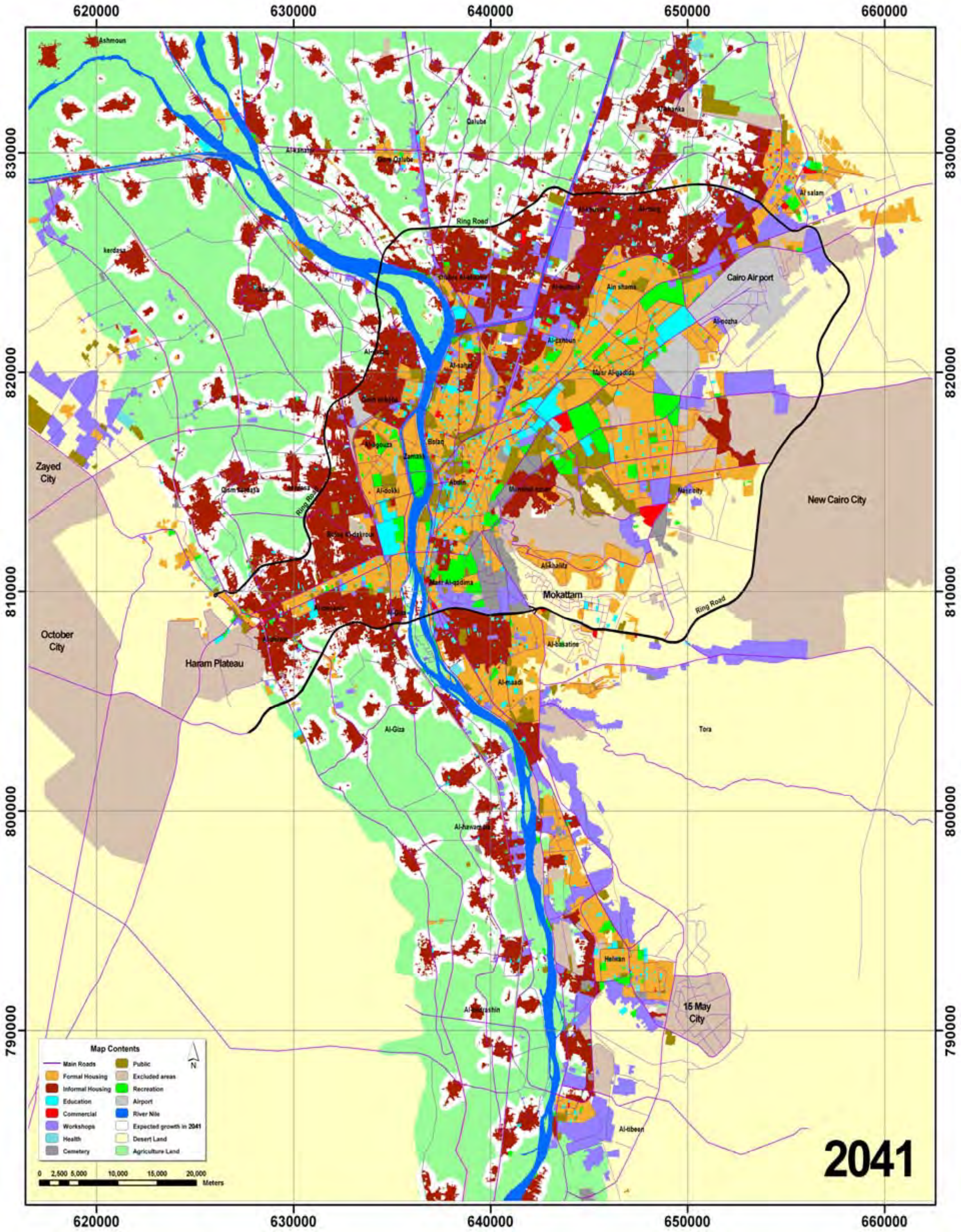


Figure (6-69) Allocation of the expected informal housing growth in **GCR** by year **2041**

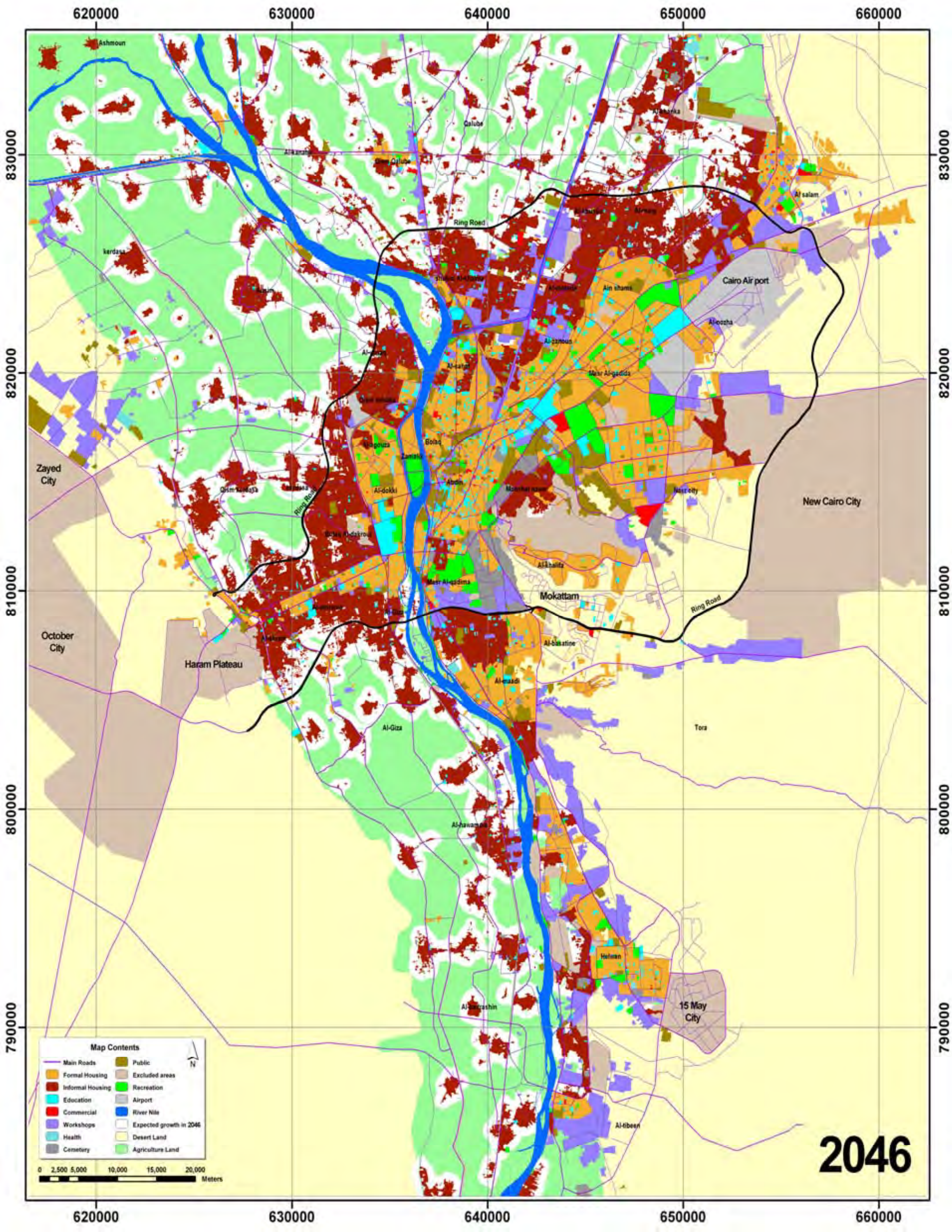


Figure (6-70) Allocation of the expected informal housing growth in **GCR** by year **2046**

(6-7) Discussion and Conclusions

This Chapter has presented the proposed **I**nformal **H**ousing **G**rowth **M**odel **(IHGM)** and examined the model in a **real-world** scenario using the available information about **IH** in **GCR**, the capital city of **Egypt**.

The **IHGM** is an attempt to test **theories**, **hypotheses** and **factors** of **IH growth**. In doing so, the **IHGM** has shown the potential to suggest answers to *What If?* questions. For instance, what would happen if new **main road** or **industry area** *(boost factor)* will construct in an area dominated by informal housing?

The proposed model implemented various rules based upon **constraint factors**, **probabilities**, **different stages**, and **various growth factors**.

Various developmental phases of the model show its capacity to accommodate a **significant range of variables** and **time-scales**, and to **generate relevant outcomes**. Importantly, the model has been able to incorporate both **physical factors** *(such as land uses, roads, water-bodies, geography, … etc.,),* as well as **socio-economic factors** *(such as service areas, markets, and places of workshops).*

The proposed **growth factors** have been calibrated using a progressive approach, through the testing of various assumptions of the size of neighborhood matrix and the weights of growth factors at its levels. In particular, the expansion of **IH** was simulated under dominant factors, such as **existing informal areas**, **transportation networks**, **watercourses**, **topography**, **workshops**, and **market places**.

The application of the IHGM in the study area has successfully simulated IH growth over time. So that, the model can considered as useful tool for exploring and understanding the **IH** dynamics, also the dynamic visualization of the outputs have the potential to improve the understanding of the **IH** growth process.

This indicates that the model is an **appropriate way for allocating the future IH expansion in the most probable areas** and the possibilities to implement a new framework that integrates **GIS** and **CA** technologies into **IH** management approaches.

The proposed IHGM provides a good starting point for more sophisticated dynamics IH growth models.

The **IHGM** has shown that local conditions have an important influence to **IH** expansion. These results can contribute to formulate general rules of **IH** expansion.

It is therefore important to capture the local knowledge about the expansion of IH in specific area because it will help to explain and allocate the expected informal growth

The flexibility of the proposed model can provide a framework to take into **account residual allocations appropriate to local conditions**. Some of these residual allocations are the result of **local policies**, **economic conditions**, and **model uncertainties** that were not incorporated into the proposed model.

Based on the developed model in this Chapter, future studies and researches can now update the model to more efficient advanced level, through expanding its **functions** and **incorporate more growth factors** *(such as, multi-agent and non-predictable factors)* into the model.

Moreover, urban planners in LDC now have a tool to test their assumptions about the probable growth of IH. Similarly, governments and decision-makers can use the proposed framework to test and weigh up their development policies in order to improve strategic planning.

The next Chapter discusses the proposed **IHGM** results and uses these results to evaluate its benefits.

Chapter 7

Evaluation of the Informal Housing Growth Model

(7-1) Introduction

(7-2) Reliability

(7-3) Sensitivity

(7-4) Efficiently

(7-5) Utility

(7-6) Limitations of the Proposed Model

(7-7) Conclusions

(7-1) Introduction

This thesis has developed an **I**nformal **H**ousing **G**rowth **M**odel **(IHGM)** to assist the local community and planning practitioners in **L**ess **D**eveloped **C**ountries **(LDC)**, to better understand the behavior of informal housing **(IH)** emergence and growth, and hence, to positively intervene in the relevant **planning policies** and **planning actions**.

The previous Chapter presented the framework of the proposed **IHGM** and its application to a real world situation. The growth factors that considered in the model execution were calibrated, and estimate their weights, rates and influence ratios.

The proposed IHGM was developed to test its capacity to predict the emergence and growth of IH according to the theories, hypotheses and practical examples of such developments.

This Chapter evaluates the performance of the proposed model. The aim of the evaluation is to ensure that **the suggested model have a satisfactory range of accuracy consistent with the desired objectives from this research**.

<u>The appraisal of the proposed model considers some elements such as :</u>

a) The range of input variables,
b) The sensitivity of the used variables,
c) The format of the input data and output,
d) The accuracy of the output,
e) The usability of the model including its *"user-friendly"* nature.

The discussion and evaluation of the **IHGM** performance includes: **the model <u>reliability</u>**, **<u>sensitivity</u>**, **<u>efficiently</u>** and **<u>utility</u>**.

Some of these criteria were discussed in Chapter **Four** where a complete comparison were made between the <u>current operational urban dynamics models</u> to investigate a methodology to select an appropriate predictive model in **LDC**, the considered criteria were taken into account for evaluating the proposed model at this development stage.

(7-2) Reliability

Reliability refers to the quality and accuracy of the results provided by the model. (Couclelis, 1997), reliability checks the agreement and consistency of the results, specifically when applied the **IHGM** model on a real-world case study.
According to the literature, any computerized growth model *(such as **IHGM**)* should have the conceptual framework to achieve a reasonable accuracy limits (Bossel, 1994).

In the case of the proposed **IHGM** that developed in this thesis, **the reliability** mostly depends on the quantity and quality of the used data and the accuracy of predictions in the future. **In regard to these factors, the proposed IHGM has performed well**; it generated the expected growth based on the data input, the influence ratios of growth factors and their weights, transition rules and the probabilities.

The reliability of the model was evaluated through the following points :

1- The **proposed model** generated **IH** patterns according to the **proximity** to growth factors, such as existing **IH areas**, **topography**, **transportation networks** and **watercourses**. It used the existing land use as constraint on the emergence and spreading of the expected **IH** cells.

The model was able to progress previous research *(such as the **U**rban **G**rowth **M**odel that presented in Chapter Four)* by incorporating other growth factors such as **soil types**, **important markets** and **places of workshops**.

The inclusion of these factors into a predictive model in the context of LDC is an important step to explore and define factors that are responsible to spread and emerge of IH and therefore represents an important contribution and innovation in this area.

2- The proposed **IHGM** in this thesis has the ability to cope with the data requirements. i.e., the model offers flexible approach in data preparation and data requirement. The used data in the model is generally available in many **LDC** cities and include :

- **Physical features**, such as topography, existing **IH** patterns, watercourses, and transportation networks, as well as other land uses types.
- **Socio-economic aspects**, such as important markets and places of workshops.

The review of current urban dynamics models in **Chapter Four** made clear that the data must prepared with certain specification to ensure the execution of the model. These requirements include the **capacity** and **relevant** of the required data. **Chapter Four** highlighted the fact that these two factors have significant implications for the ease of data collection, preparation, level of dis-aggregation, data type, and the ability for the data to have a time-series component, as well as the number of required data files. Compared to other existing urban dynamics models *(e.g., What if ?, UGM, and TRANUS)*.

3- The proposed **IHGM** includes many features that can be easily **customized** *(or redefined)* to user-defined needs such as :

- The **influence ratios** of land use and transportation networks growth factors,
- The **size** of neighborhood matrix $\mathbf{L_{(s)}}$ and $\mathbf{N_{(s)}}$,
- The **weights of growth factors** at matrix levels (W_1, W_2, W_3, ...etc.,),
- The number of iterations *(time-series periods).*

This represents an innovation in this context. Therefore, the proposed model is flexible enough to be adjusted and have the potential to be implemented in other regions with a small number of modifications.

While the preparation of large amount of data can be time consuming for individuals or small urban planning team with little experience in **GIS** technologies, the ability of the proposed model to accommodate unlimited numbers and data types represent an important advantage in comparison to other urban dynamics models *(such as UPLAN, SLEUTH, and UrbanSim)*

4- The growth factors calibration phase made clear that it is possible to combine both **GIS** and **CA** technologies to simulate and predict **IH** dynamics. One of the advantages of the implemented **loose coupling approach** between the **CA macro** and the graphical facilities of **GIS environment** is that it makes it easy to build models from scratch, as well as, maintain models, modify probabilities and explore what happens if the model changes its structure due to new information. **This ability constitutes one of the most important characteristics of operational urban dynamics models** [(1)] (Agarwal et al, 2000).

[(1)] This article available at: http://caplter.asu.edu/biocom/Agarwal%20et%20al.pdf.

5- The prime objective of urban dynamics modelling is the ability to **predict realistic growth patterns**, one of the objectives of this research is to apply the proposed simulation approach to informal housing *(as a system)* in order to estimate how they change over time, so that we can understand their spatial characteristics and dynamic behavior.

The proposed **IHGM** has the capacity to provide dependable predictions of **informal housing growth**, the model ability to show this emergence was evaluated with respect to its ability to dynamically allocate the expected **IH**. **The model's capabilities were also successfully reflected in this case study**.

The application of the proposed model to **GCR** indicates that it is possible to predict the future expansion of **IH** once the growth factors have been **successfully calibrated**. Then, the user defines the model parameters such as, the annual and total pixel_gain, the growth factors weights, and the size of neighborhood matrix. The multiple output maps can be compiled together to produce an animation for the expected informal housing growth.

6- **The Final issue**, that must be considered, **is the model's ability to collect significant quantities of strategic planning data** (EPA, 2000), such as the future spatial distribution of **IH** patterns, which are hardly ever obtainable in most **LDC** cities, particularly if **IH** areas are not incorporated into future urban planning schemes.

In that context, the simulation of **IH** by using the proposed model could allow planners and policy-makers to perform a reliable preliminary **What if? analysis** using different growth factors in order to assessing the emergence and growth of **IH**, and evaluating which policies should be adopted, as well as the actions should be taken.

However, there were some **limitations** of the **GCR** spatial data, which could improve the prediction capacity of the model. Although, the variation of used factors and parameters in the **IHGM** have suggested different alternatives of transition rules and weights, that produced different growth probabilities, but the **GCR** spatial coverage of **roads network** did not continue up to the base prediction year *(2006)*, which means the prediction results can improved by incorporating the future expansion of roads and transportation network. **So that**, **for long-term prediction we should includes the future projects for roads**, **infrastructure**, **the major changes in land use and urban policies**.

Despite this limitation, the predictive capacity of the **IHGM** is a useful resource for planners in **LDC** seeking to expect the future growth of unplanned areas. In particular, visualization of the possible future expansion of **IH** may better inform strategic planning, especially in the area of **services**, **infrastructure**, **urban policy**, and **land management**.

On the other hand, **dynamic visualization** of the **IHGM** outputs is a useful method for assessment and monitoring of **IH** growth. The information available to the planners and decision-makers can be further improved if the dynamic visualization and animation of **IH** growth is incorporated into the planning process.

However, the proposed model does not take into consideration other important factors, such as :

- The changes in **urban policies**,
- The behavior and motivations of urban dwellers,
- The government bureaucracy toward **IH** areas.

The model performance could improve, if it possible to develop an appropriate method to incorporate these parameters into an IH modelling context.

(7-3) Sensitivity

The sensitivity evaluates the behavior of the model whenever changes are made to its parameters, structure, configuration and data inputs (Couclelis, 1997). The application of the proposed **IHGM** on the case of **GCR** has clearly demonstrated that modifications on the model parameters are affecting the model outputs.

The **IHGM** tested various hypotheses about **IH**, especially when different **sizes of neighborhood matrix** and **different weights** for both **land use** and **transportation networks factors were assumed**. The sensitivity of the model was evaluated through the following points :

1- The application of the proposed model on **GCR** made clear that the most sensitive factors correlating with the emergence and expansion of IH are **existing informal housing**, **major roads, secondary roads, ring road**, **workshop places**, **topography**, and **vacant lands**. On the other hand, **new cities lands** *(or areas that have known planning schemes)* and **protected areas**, such as military camps, airports and Pyramids plateau were represent a hindrance to expand **IH**, this prove that such areas can be excluded from future **IH** growth.

2- Different levels of sensitivity were embedded into the model **configuration** and **assumptions**. For instance, a new **IH** cell would only occur on **vacant land**. In addition, new **IH** cell would only generate at a certain *(user-defined)* proximity to existing **IH** *($L_{(s)}$ the size of land use matrix)*. Where, the proposed model calculates the probability to change for vacant cell according to its proximity from the existing **IH**, in contrast to other growth factors, such as **roads**, where growth occurs along the roads.

3- The application of **IHGM** on **GCR** clears that the model could be a **useful tool** for generating different scenarios of **IH** expansion that could support the decision-making process in urban planning. The sensitivity of the model lies in its ability to modify the growth rules and the influence ratios of the selected growth coefficients and their weights. **These facilities allow to predict the possible directions and extent of IH growth under a variety of future conditions**.

Thus, local government and urban stakeholders can make **informed decisions** about the growth of **IH** and, more importantly, can take **precautions** to curb the negative impact of informal housing.

(7-4) Efficiently

Efficiently evaluates how the output agrees with the conceptual framework of the model (Couclelis, 1997).

Two main methods are commonly used to validate the efficiently of urban dynamics models:

1. **The quantitative approach** *(measures of match)*, that uses statistics tests such as *chi-squared*, *kappa-statistics* and *fuzzy logic* to assess the results **goodness-of-fit**.
2. **The qualitative approach** (*pattern recognition)*, that uses techniques such as **graphical validation** or **visual comparison** to assess the simulation output (Torrens & O'Sullivan, 2001).

The **qualitative approach** is one of the preferred methods to evaluate urban simulation results, because local government and urban planners are more likely to use the **qualitative judgment** and **perception**, rather than the quantitative representation (Couclelis, 2002). Moreover, **the graphic comparison is one of the best ways to evaluate the model best-fit results**.

The developed **mobility module** in the proposed **IHGM** measures the **quantitative** validation of the prediction results; it also measures the level of precision of each simulation period *(see section 6-6-3-2)*. As shown in Chapter 6, section (6-6) the precision of the prediction results increased with the increasing of the proximity factor from land use factors ***(Lu(s))***. For instance, the implementation of the **IHGM** on **GCR** clearly discussed **18 alternatives** for the size of neighborhood matrix, and the mobility module demonstrated that, **the increasing of the proximity factor the increasing of the quantitative validation of the prediction results**.

The **IHGM** uses a progressive calibration approach, which consists of assuming the size of neighborhood matrix for both **land use** and **network** factors *(Lu(s) and N(s))*, then we run the calibration module to estimate the influence ratios of growth factors, that represent the growth factors contribution level to emerge and expand **IH**. Then it uses these ratios to simulate the prediction map for test year *(2006)*.

Then we use **The qualitative validation approach,** that use the **graphic comparison** between the simulated map in **2006** with a high resolution Satellite Image *(taken in 2006)* to choose the best alternative results, which has high coincidence rate between the simulated **IH** patterns and the Satellite Image.

In that way, different versions of the model were developed to reach a point where the simulated map *(2006)* was as close as possible to the real map. This method was refined using a **"trial and error"** approach *(see table (6-15), section (6-6-3-3))*. While this **"trial and error"** approach is sometimes tedious and time consuming, but this work would be reduced when the model was calibrated.

To achieve a better validation, it is necessary to calibrate and test the proposed IHGM on several other real situations, for example different cities in LDC.

In particular, the proposed model has demonstrated the main **driving forces** behind the expansion of **IH**, as well as estimating their respective influence ratios and weights at different stages of urban development.
The capacity to combine physical changes with **socio-cultural** and **socio-economic** aspects is also important in terms of increasing our understanding of **IH** behavior in order to improve urban planning responses. **This knowledge is especially vital for urban planners and local governments, so they can better control this phenomenon**.

Practically, the urban policies can be modified to monitor the expansion of **IH** in a particular direction, by acting upon the attractiveness of the prevalent criteria such as **roads**, **workshops** and **economic centers**.

(7-5) Utility

The utility of the proposed model will be evaluated by considering its usability; the usability refers to the efficiency and generality of the model (Couclelis, 1997).

Efficiency refers to the model's **allocation accuracy** over a given time period.

Generality refers to the applicability of the proposed **IHGM** successfully in different regions or cities with minor modifications.

The developed **IHGM** in this thesis displays a number of important utility improvements in comparison to other urban dynamics models, which increase its capacity to be relevant to planning in **LDC**, such as:

1- Compared to other urban dynamics models *(see Chapter Four)*, the **IHGM** is a **low cost model**. The model source code can be obtained free of charge by contact the author. This feature made the model can be **accessible**, **adapted** and **modified** by other developers. The expensiveness of urban dynamics models in general, remains the major **obstacle of spreading and developing** the existing urban dynamics models (Klosterman, 1994; Wegener, 2000).

Additionally, the assessment of existing urban dynamics models in **Chapter Four** clearly indicated that **fees attached** to some modelling packages *(such as TRANUS, SmartPlaces, and What If?)*, **represents serious limitation to implement these models in other contexts**. In addition, some urban dynamics modelling packages still operate as a **"black box"**, with restricted access to their sources code, which limits users to adapt and modify the model assumptions to any other context.

2- Another significant problem in existing urban dynamics models is their complexity in data requirement and preparation.

The proposed **IHGM** model provides a flexible environment where the user can integrate the desired and available types of data in one environment. In addition, the model does not requires to set **minimum** or **maximum** number of growth rules or coefficients to run it, and yet maintain the essential **IH** growth factors such as proximity to existing informal housing, land use types, transportation networks, watercourses, excluded areas and topography.

This feature provides another flexibility to the proposed model, in comparison to other urban dynamic models such as **SLEUTH** (Clarke & Gaydos, 1998), which accepts up to **five categories**, with **only two classes** *(urban and non urban)* (Xia & Yeh, 2001).

3- The **IHGM** allows the user to monitor the behavior of the program by adding a **toggle points** to the **Visual Basic** macro command line. Also, the program can be suspended at any time to make changes or view the available output. Unlike other urban dynamics models, **SLEUTH** for instance; the results are only available at the end of a lengthy operation.
Additionally, the calibration results are immediately available and displayed on the **GIS** environment, thus the modifying and changes can be easier.

4- **The IHGM support a wide range of data conversion format,** for instance the model converts the predicted vector map at any period *(high score probability layer)* to many types of **raster data** format, and merge any period predication map with the previous period. The outputs can exported to raster data format *(e.g., .BMP, .TIFF, .GIF, .IMG),* whereas other models, such as *SLEUT, UGM and What if?* do not provide this level of flexibility in regard to the output format.

5- The **IHGM** is versatile and can be implemented on standard **GIS software** *(ArcGIS 9.x)* with a **V**isual **B**asic application *(VBA)*. To successfully implement the program, it is desirable that the user has access to a computer with sufficient Central Processing Unit *(CPU)* capacity. The speed of the used computer will definitely improve the performance and the running time of the **IHGM** macro.

6- The versatility of the proposed model to use raster data *(during data preparation, for data analysis and for visualization)* imported from and exported to other applications constitutes an improvement in the characteristics of urban dynamics modelling.

7- The implementation of the proposed **IHGM** does not requires specific expertise of **Vi**sual **B**asic programming language, **C**ellular **A**utomata concepts and informal housing dynamics, but it only requires the basic knowledge of **GIS** technology *(such as: data preparation, rectification, geo-referencing, and data conversion from vector to raster)*. The proposed model provides a very easy **window-driven GIS application** that makes it more accessible and available to a wide range of potential users.

8- The **IHGM** has the ability to generate multiple outputs for dynamic visualization. These outputs can facilitate the creation of visual animations or *"movies"* of **IH** dynamics.

The visual animation component of the model allows a better understanding of the behavior of **IH** expansion over a time frame. *Therefore, it can use as a useful tool to sketch the direction of IH spread, such as its expansion along the transportation and watercourses features.*

9- The proposed **IHGM** can allow the rapid simulation of different development alternatives, which could improve interaction between urban stakeholders when assessing **IH** developments.

In particular, the proposed model can serve as a reliable tool for participatory planning, where IH stakeholders could use their expertise to suggest and discusses many alternatives for the future vision.

In the case study of **GCR**, the **IHGM** allowed the rapid simulation of different scenarios of growth. Access to such information could greatly improve communication and interaction between government officials, planners, private sector and **IH** communities. This is an important cooperation for **strategic planning**, **that can forecast the future spatial location of IH and then act before they become widespread**.

(7-6) Limitations of the Proposed Model

The previous section outlined the capacities and benefits of the **IHGM** across many evaluation criteria. **This section discusses some of the model limitations**.

1) The first limitation of the model relates to using a **cell-based** *(bottom-up)* approach in order to predict **IH** expansion. Cell based methods make it **difficult to accommodate *"top-down"* approaches**, and incorporate regional factors or policies, that also influence on the expansion of **IH**. Some of these "top-down" restrictions include :
   - **General conditions** *(economic, political and financial issues),*
   - **Local and regional urban policies** *(for example, the decision to build a regional or national highway could change the direction of IH growth).*

   In future, a comprehensive **IH** simulation model could incorporate other techniques, such as **multi-agents**, with **C**ellular **A**utomata and **GIS**.
   The multi-agent approach would allow to incorporate many **regional urban policies** within the predictive modelling, where **CA** would address general behavior and **GIS** would be used to prepare, organize the data input and display the outputs.

2) The second limitation is, the proposed **IHGM** does not has a statistical module to calculate and make **built-up area projection scenarios** *(regression, exponential, average annual built-up area,… etc,)* based on the historical urban development, and support the user to take a decision to choose the most realistic alternative.

3) The third limitation of the proposed model is the lack of testing on other cities. This was constrained by **time** and **available resources**. A full model validation depends on the application of the model to other cities experiencing rapid expansion of **IH**. In the future, the intention of the author is to improve the current version of the model and make the program generally available to other researchers, who interested in the subject of informal housing growth.

(7-7) Conclusions

In conclusion, this Chapter highlighted the important contribution of the proposed **IHGM** and gave a methodology to simulate and predict **IH** in **LDC**. In addition, this Chapter was discussed the model's limitations and suggests a ways to avoid these limitations.

In summary, this Chapter made it clear that **GIS technology** can be loosely coupled with the **CA modelling** to simulate the behavior of **IH** dynamics. The **V**isual **B**asic programming language used to implement the **simulation macro** that allows considerable flexibility and provides full control ability to modify and customize the influence ratios of growth factors and the model parameters.

The **IHGM** contains the logic of **IH** growth that deduced from the human behavior towards housing in most **LDC**, so it can support the urban researchers to give suggestions and recommendations towards the processes of unplanned expansion in **LDC**.

The proposed **IHGM** represents a new contribution to the domain of **informal settlement dynamics** and **urban development** in the context of **LDC**. The evaluation of the proposed model based upon its **reliability**, **sensitivity**, **efficiently** and **usability** has indicated that the **IHGM** can potentially improve the planning and decision-making processes that would lead to the improvement of the quality of life in developing cities.

This Chapter made clear that the proposed model possesses some limitations that can be overcome, especially in the model parameters settings that can be improved with multiple developments and testing on many real-world case studies. The proposed model is at this early stage requires many further improvement, especially in the area of fine-tuning the model, improving its user-friendliness capacity, decreasing the execution run time for both calibration and prediction algorithms.

Based on the evaluation and limitations of the **IHGM** discussed in this Chapter, the next Chapter will discuss the thesis conclusions and suggests possible directions for future work.

Chapter 8

Conclusions and Recommendations

(8-1) Introduction

The main objective of this research is to develop a **predictive model** for exploring the emergence and expansion of **I**nformal **H**ousing, and enrich the discourse on the rapid expansion of **IH** in **L**ess **D**eveloped **C**ountries **(LDC)**. To achieve this aim, five main parts were covered:

- The general characteristics and mechanisms of **IH** dynamics, and the previous developed policies to avoid it,
- Exploring a new concepts and approaches to develop realistic urban dynamics modelling,
- The review and comparison between existing operational urban dynamics models,
- The attempt of applying Clarke's Urban Growth Model **(SLEUTH)** to explore the **GCR** urban dynamics and evaluate the capacity of the model to produce realistic simulation results,
- Finally, presents the proposed **IHGM**, and apply it on the case of **GCR**.

The previous Chapter discussed and evaluated the performance of the proposed **I**nformal **H**ousing **G**rowth **M**odel **(IHGM)**. This Chapter first provides a summary of the thesis, then presents the main contribution of the proposed model, and finally suggests directions for further researches.

(8-2) Summary of Thesis

This thesis has proved that it is possible to predict the emergence and growth of informal housing **(IH)** patterns within the boundaries of **growth factors** that have available data, such as **physical, urban, land use, transportation**, **social** and **economical** factors; and with the assistance of computing techniques.

Simulation and modelling approaches for informal development has great importance for at least two reasons: **First,** because rapid expansion of **IH** represents a growing problem in most cities in **LDC** at both local and regional levels; **Second,** because the poor performance of past and current attempts to curb rapid expansion of **IH** has caused new problems, while failing to adequately resolve existing ones.

This leads to the need for developing new techniques that can be inspired by complex urban systems and current computing technologies.

This research has proven that **new approaches could be built based upon simulation and modelling techniques**, as **tools** that could ultimately help decision-makers and local governments in **LDC** cities to improve their understanding and management of **IH** growth.

This thesis has reviewed on some of the **existing urban dynamics models** and concluded that it was possible to build on their conceptual and theoretical frameworks by loosely coupling **G**eographic **I**nformation **S**ystems **(GIS)** and **C**ellular **A**utomata **(CA)** technologies. The thesis was organized through the following chapters:

Chapter 1 Presents the research overview, containing the research problem, scope, objectives, research methodology and questions, expected results through the research, the thesis hypotheses, and finally the thesis structure.

Chapter 2 illustrates the historical growth of **IH** in **GCR**, and shows it is one of the most prominent spatial facets of urbanization not only in **GCR** but also in most cities of **LDC**. In addition discuss the **previous policies** and **strategies** to curb the **IH** expansion, which were largely inefficient.

Chapter 3 presents the modelling and simulation capabilities of **G**eographic **I**nformation **S**ystems **(GIS)** and **C**ellular **A**utomata **(CA)** and their integration in urban dynamics modelling. Also, this Chapter demonstrates new concepts and approaches to achieve **realistic dynamic models**, which can simulate the dynamic expansion of **IH** in the context of unplanned areas.

Chapter 4 suggests a methodology to select the most appropriate urban dynamic model that could assist the understanding and prediction of **IH** dynamics in **LDC**. In addition, this chapter defines the criteria that must be considered in relation to urban expansion and **IH** modelling.

This Chapter makes a comparison between **Eight** urban dynamic packages to evaluate their contribution to simulate the growth of **IH** in **LDC** according to some selected criteria based on the defined objectives for this research.

Chapter 5 Test the possibility of applying the **SLEUTH** program *(Clarke's **U**rban **G**rowth **M**odel)* to explore and simulate the growth of informal housing in **GCR**, and test the capacity of the model to produce realistic simulation, by comparing and checking the level of accuracy between the model's outputs with real world expansion.

Chapter 6 illustrates the proposed loosely-coupled **GIS** and **CA** **I**nformal **H**ousing **G**rowth **M**odel (**IHGM),** and discusses the model framework, structure, its different modules and functions, as well as, the model implementation procedure. This chapter tests many scenarios by changing the **model parameters** and modify the influence ratios of growth factors. Finally, applying the proposed model on a real-world case study, to explore and predict the future expansion and extent of **CGR**, **Egypt**.

Chapter 7 evaluates the performance of the proposed model in order to define the model satisfactory and accuracy, through the model **reliability**, **sensitivity**, **efficiently** and **utility**.

Chapter 8 presents the thesis conclusions and recommendations for future researches.

(8-3) Research Conclusions

The proposed **I**nformal **H**ousing **G**rowth **M**odel represents a new contribution to the theoretical knowledge and practical capacity of urban dynamics modelling, especially in the following areas:

- Developing a useful and relevant model framework for the simulation and prediction of **IH** in fast growing cities of **LDC** as a **tool** for future strategic urban planning.

- Integrating **GIS** and **CA** technologies to develop the model framework where, **GIS** used in **data preparation**, **management**, **storage**, **retrieval** and **visualization interface**, where **CA** technology used to develop **dynamic exploration**, **interaction with functions**, **weighting coefficients**, **calibration**, **transition rules**, **prediction**, and **dynamic visualization**.

- Increasing the flexibility of the **data input** and **output**, automatic file conversion *(vector to raster conversion)* and accessibility to data in a loose-coupling approach between **GIS** and **CA** technologies.

- The simulation and dynamic visualization capacity of the **IHGM** provides a new possibility for planners and policy-makers to undertake a preliminary *What if?* analysis in order to assessing probable **IH** behavior under different conditions and evaluating which alternative policies should be taken. Also the model can **support the urban planning processes** by assisting urban researchers to better understand the unplanned expansion.

- Providing a predictive tool for **planner**, **policy makers**, and **local government official** to understand the **IH** dynamics in **LDC** cities, particularly in terms of the practical responses to their growth and expansion.

These capabilities of the proposed **IHGM** indicate that it has the potential to identify and predict the likely locations of **IH**, based upon the criteria that control the growth of informal housing in unplanned areas. This predictive capacity has been achieved because the **IHGM** incorporates the logic of **IH** growth, through simulating the different conditions that cause the expansion of popular housing in **LDC**.

The proposed **IHGM** also provides an indication of how modelling and simulation approaches can assist urban planning in areas such as **urban growth management and monitoring**, as well as, the evaluation of urban policies. Importantly, the proposed model has the potential to improve strategic and participatory urban planning in **LDC** cities, involving various urban stakeholders *(e.g., planners, local government officials, private sector stakeholders, non-government organizations and research institutions).*

Considering the original objectives of this thesis and the proposed predictive model specifications and its results, the aim of this research has therefore been achieved, especially in using new spatial technologies to model and simulate the expected expansion and growth of IH in the context of LDC.

(8-4) Recommendations for Future Researches

The recommendations for further researches arise from the application of the proposed model on a real-world data, its **evaluation** and **limitations**. There are **three** major areas to improve the model capacity and reliability that represents new opportunities for further researches, such as **hybrid modelling**, **complexity assessment**, and the **effectiveness** of the **IHGM**.

- The first potential area is the incorporation of **Multi-agent based models** into the **IH** simulation process.

  The **hybrid approach** has some potentialities to develop new conceptual framework that one will gain better understanding about **IH dynamics** by incorporating multi-agent behavior into the socio-economic and physical conditions of **IH**.

- The implemented **cell-based** modelling approach within the proposed **IHGM** draws its probabilities and growth directions from a *bottom-up* approach. However, it has become clear from this research that informal settlers, policy-makers, private sector stakeholders and non government organizations are all involved in the emergence and growth of unplanned developments (Batty, M.,1999).

  For instance, planning restrictions, infrastructure, and transportation elements such as roads, are implemented from a *top-down* perspective, and can not take its contribution to emerge **IH** from local perspective. **Therefore, it would enrich future researches to be able to incorporate or take into account the decisions and local factors that affect IH expansion through a hybrid approach** *(such as GIS, CA and multi-agent based models),* whereby the **two approaches** *(bottom-up and top-down)* are included within a single prediction and modelling package.

- The second potential area is the measurement of the level of **uncertainties** and **complexities**. This research has shown that there are limits to predictions and simulations.

  Testing the proposed **predictive model** against known **real-world** situation produces some **unknown factors** that were not taken into account; these factors could be incorporated *(used)* to identify their level of contribution to the expansion of **IH**.

Future researches could investigate how the *"non-predictable"* factors, such as **future political decisions** and **social instabilities**, (Batty, M., 2001),[1] could be considered in future models; and how they can influence the overall output of the model.

- Finally, the proposed **IHGM** could be improved and refined into a more sophisticated, popular and user-friendly version to be more readable and operational (White, R., & Engelen, G. 1994). **It would then become a very useful resource for urban planners in LDC cities with limited knowledge of programming and CA techniques**, who could apply the model without having special knowledge about the program.

- Although this research did not aim to develop a **usable software**, the development of a **menu-driven** version of the proposed model has emerged as a **useful tool to explore in the future**, this upgrade would produce several benefits such as a greater accessibility to audience, improve the model functionality when testing the model on other cities, knowledge sharing, and increased commercial potential, as well as providing a more usable and comprehensive tool for urban planners and decision-makers.

Finally, these recommendations are general ideas for future researches, but they serve to show that there is significant scope for further researches on the topic of informal housing, urban stakeholders and the integration of urban dynamics modelling into the planning process.

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بسم الله الرحمن الرحيم

نمذجة و محاكاة النمو المستقبلي لمناطق الإسكان اللارسمي

منهج قائم علي دمج تقنيات نظم المعلومات الجغرافيه و الخلايا ذاتية الحركه

أ) ملخص البحث

هناك حاجه ماسه إلي فهم طبيعة و أسباب النمو السريع لمناطق الإسكان اللارسمي داخل المدن و بصفه خاصه مدن بلدان العالم النامي، إن المحاولات السابقه لدراسة التطور و النمو العمراني أستخدمت المناهج الوصفيه والنظريه وأهتمت بالعوامل الإجتماعيه والإقتصاديه والسياسيه التي أثرت علي نمو و إنتشار العمران بصفه عامه، بالرغم من ذلك فإن هذه المحاولات **لم تسفر عن أدوات تخطيطيه فعاله** للتنبؤ بأماكن نشأة و إنتشار مناطق الإسكان اللارسمي، و من ثم وضع السياسات والقوانين للحد من هذا الإنتشار و إعادة توجيهه.

بالرغم من تعدد و تعقيد العوامل المؤثره فى النمو و الإنتشار العمراني، فإنه يوجد العديد من التجارب التي قامت بدراسة تطور النظم العمرانيه و العوامل المؤثره فيها ، مدعومه بالتطور الهائل فى برمجة الحاسب الآلي ، والتي ساهمت فى الوصول إلي مناهج و أدوات جديده لمحاكاة التوسع و النمو المستقبلي فى المناطق المخططه. هذه المحاولات نتج عنها مجموعه من التطبيقات والأدوات العمرانيه **لمحاكاة النمو المستقبلي فى المناطق المخططه**، والتي تم إستخدامها بنجاح فى العديد من بلدان العالم المتقدم، مثل مدينة **مرسيليا** بفرنسا ، ومدينة **سان فرانسيسكو**، و منطقة **جنوب كارولينا** بالولايات المتحده الأمريكيه، و منطقة **خليج هيرفي** بأستراليا.

هذا البحث يناقش أسباب عدم ملائمة إستخدام هذه التطبيقات للتنبؤ و محاكاة النمو المستقبلي لمناطق الإسكان اللارسمي فى مدن بلدان العالم النامي و بصفه خاصه إقليم القاهره الكبري، و يرجع ذلك إلي إختلاف أسباب و عوامل النمو وإختلاف القوي المحركه للنمو و الإنتشار. و الآن، فإنه بمساعدة الأدوات و التطبيقات التي تم تطويرها مؤخراً فى دراسات النظم العمرانيه ببلدان العالم المتقدم، مدعوماً بأمكانيات و قوة برامج المحاكاه الإلكترونيه الحديثه يمكن من خلالها **تطوير و تصميم منهجيه ورؤيه جديده تصلح للتطبيق لحالة ديناميكا النمو العشوائى اللارسمي فى المناطق الغير مخططه** ببلدان العالم النامي.

بناءاً علي ذلك، **فإن الهدف الرئيسي لهذا البحث هو <u>تطوير نموذج عمراني قادر علي محاكاة النمو المستقبلي</u> خلال فترات زمنيه محدده (Simulation Model) و بصفه خاصه نمو و إنتشار مناطق الإسكان اللارسمي فى إقليم القاهره الكبري.**

إن النموذج المقترح فى هذا البحث (**I**nformal **H**ousing **G**rowth **M**odel, **IHGM**) سوف يركز بصفه أساسيه علي تحديد **عوامل و أسباب** نمو مناطق الإسكان اللارسمي ، لوضع سياسات فعاله لإدارة و توجيه هذا النمو فى الأتجاهات التي تخدم المخطط الهيكلي. إن النموذج المقترح يتبني منهجية دمج تقنيات **نظم المعلومات الجغرافيه (GIS)** مع تقنيات **الخلايا ذاتية الحركه (CA)** لتحليل ديناميكا العمران، حيث سوف يتم إستخدام تقنيات الخلايا ذاتية الحركه **(CA)** لتصميم برنامج للتنبؤ بأماكن نشأة و إنتشارمناطق الإسكان اللارسمي من خلال نمذجة **العوامل و المتغيرات المؤثره فى النمو**، و تقدير درجة تأثير كل عامل علي حده بدراسة مراحل التطور التاريخي للنمو، و يتم تشغيل هذا البرنامج علي مجموعه من الخرائط و البيانات المكانيه التي توضح توزيع و تطور إنتشار المناطق العمرانيه خلال مراحل زمنيه مختلفه منتجه بأستخدام نظم المعلومات الجغرافيه **(GIS)** .

و ذلك بهدف تصميم نموذج عمراني واقعي (Realistic Predicative Urban Model) يمكن إستخدامه لمحاكاة الإنتشار و النمو المستقبلي غير المخطط و إنتاج خريطه رقميه توضح مناطق التوسع المستقبلي خلال فترات زمنيه محدده.

و سوف يتم تطبيق النموذج المقترح علي حالة النمو المتزايد في **إقليم القاهره الكبري** بجمهورية مصر العربيه ، بالإضافه إلي تقييم أداء و دقة النتائج المستنتجه من البرنامج المقترح **(IHGM)** من خلال المقارنه مع صور الأقمار الصناعيه الحديثه لإحدي سنوات التنبؤ المستقبلي ، بالأضافه إلي مناقشة و تحديد أوجه القصور فى النموذج المقترح مع وضع تصور لإمكانية تلافي نقاط الضعف فى الدراسات المستقبليه.

إن النموذج المقترح سوف يؤسس لمنهجيه و وجهة نظر جديده لملء الفجوه الحاليه بين الدراسات و الأبحاث العلميه و ظاهرة الإنتشار الرهيب لمناطق الإسكان اللارسمي ، بهدف زيادة قدرة المخططين و صناع القرار و السياسه الحضريه لإستكشاف التوسع السريع لتلك المناطق.

إن النموذج المقترح سوف يعطى رؤيه موضوعيه لنمو و إنتشار العمران اللارسمى فى المناطق الغير مخططه ، بالأضافه إلى سهولة و مرونة تطبيقه فى أقاليم و مناطق أخرى.

ب) المشكله البحثيه

تضاعف عدد سكان العالم أكثر من الضعف خلال الخمسون سنه الماضيه، حيث كان عدد سكان العالم حوالي **٢,٥٣٥ مليار نسمه في عام** ١٩٥٠ ، و قدر عدد سكان العالم بنحو ٤,٠٧٦ **مليار نسمه في عام ١٩٧٥** و بلغ **٦,٦٧١ مليار نسمه في عام ٢٠٠٧**، حيث يعيش ٦ من كل ٧ أشخاص فى البلدان الأقل تقدماً.
ووفقاً لتقارير و إحصائيات منظمة الأمم المتحده للسكان (٢٠٠٢) فإن عدد سكان العالم سوف يزداد و ينمو بمعدلات عاليه خلال **الثلاثون سنه القادمه**، و يتوقع أن يصل سكان العالم حوالي **٨,٢٧ مليار نسمه بحلول عام ٢٠٣٠**، أي بزياده قدرها **٢,٢ مليار نسمه** بالمقارنه بأحصائيات عام ٢٠٠٠، و يتوقع ان تكون **أغلب هذه الزياده في بلدان العالم الثالث (بنسبة ٨٦ ٪ - حوالي ١,٩ مليار نسمه) و بصفه خاصه فى إفريقيا و آسيا و أمريكا اللاتينيه، و التي تعاني إقتصادياتها من العديد من المشاكل و غير مؤهله لمواجهة هذا النمو السكاني و ما ينتج عنه من نمو عمراني.**

و من جهه أخري فقد وصل عدد سكان المدن و المناطق الحضريه حوالي **نصف سكان العالم**، و يتركز **ثلاثة أرباع** سكان الحضر فى مدن بلدان العالم المتقدم، و وفقاً لتقديرات منظمة الأمم المتحده للسكان عام ٢٠٠٧ فإن حوالي ٩٨٪ من الزياده المتوقعه فى سكان بلدان العالم النامي **سوف يتركزون فى المدن و المناطق الحضريه**.
إن النمو السكاني المتوقع و تركزه في المدن الكبري و المناطق الحضريه سوف يؤدي إلي تغيير نسق التوزيع المكاني للمستوطنات البشريه، حيث تم الإشاره إلي أن هذا النمو المضطرد هو ظاهره عامه لمعظم بلدان العالم النامي.
فعلى سبيل المثال قارة إفريقيا، حيث الغالبيه العظمى من الدول تصنف بأنها بلدان فقيره، لديها أعلى معدل نمو للسكان في العالم يصل إلي ٢,٢٪ بالمقارنه بالمتوسط السنوي العالمي و الذي يقدر بنحو ١,٢٪ ، و لذلك فإنه يتوقع بأن تساهم البلدان الإفريقيه فقط بنحو ٢١,٧٪ من سكان العالم في المستقبل و بحلول عام ٢٠٣٠.

و من المتوقع أنه بحلول عام ٢٠٣٠ فإن **بلدان العالم النامي سوف يغلب عليها الطابع الحضري أكثر من الطابع الريفي**، حيث أنه فى بداية القرن العشرين كان يوجد **(١٦)** مدينه فقط يزيد عدد سكانها عن المليون نسمه و تركزت هذه المدن فى الدول الصناعيه الكبري، و الآن يوجد حوالي **(٤٠٠)** مدينه يزيد عدد سكانها عن المليون نسمه منتشره حول العالم، منها حوالي **(٣٠٠)** مدينه فى البلدان الأقل تقدماً. **حيث يعيش علي الأقل ربع سكان هذه المدن تحت حد الفقر**، سمات هذا الفقر واضحه جداً فى كل المدن الكبري بتلك البلدان حيث تنتشر **الأحياء شديدة الأزدحام، و بيئة الإسكان الغير صحيه، والتلوث، و عدم وجود مصادر مياه نظيفه، و نقص خدمات الصرف الصحي و الكهرباء و الخدمات الإجتماعيه الأخري**. ومع ذلك فإن مدن بلدان العالم النامي تتوسع و ينتشر بها نمط الإسكان العشوائي *(الأهلي)* فى المناطق الغير مخططه، و يستقطب هذا النمط من الإسكان عدد كبير من المهاجرين الريفيين بالإضافه إلي الزياده السكانيه الطبيعيه.

و من الملاحظ وجود تباين بين معدلات النمو الحضري لبلدان القاره الواحده، **و الذي ينتج عنه نمو و تغير سريع فى شكل و حجم المناطق الحضريه**، و يتركز هذا التغير داخل و علي أطراف المدن حيث تظهر مناطق الإسكان اللارسمي و تستوعب حوالي ٩٨ ٪ من إجمالي النمو في بعض بلدان العالم النامي (ياوندي – الكاميرون). و بصفه عامه فإن أكثر من ٨٠ ٪ من المستوطنات الجديده تندرج فى فئة المستوطنات اللارسميه أو بعباره أخرى

المستوطنات الشعبيه، حيث أنها تمثل مناطق جديده تم إنشاؤها دون إتباع القواعد و الضوابط التخطيطيه علي أطراف المدن سواءً كانت علي حساب الأراضي الزراعيه أو الصحراويه (مركز الأمم المتحده للمستوطنات البشريه ، ٢٠٠٣).

و بصفه عامه فإن الزياده السكانيه و ما ينتج عنها من نمو المناطق الحضريه بشكل غير مخطط سوف يساعد علي زيادة مناطق الإسكان اللارسمي التي تمثل بيئه عمرانيه تفتقر إلي توفر الخدمات و المرافق الأساسيه و هذا النمط العمراني سيجعل التنميه المستدامه للبيئه المبنيه في المدن أكثر تعقيدا.

وتشير الأبحاث و الدراسات إلى تعدد الأسباب و العوامل التي تساعد علي إنتشار و نمو هذا النمط من الإسكان، منها علي سبيل المثال: **زيادة معدلات النمو السكاني، عدم وجود استراتيجيه و منهجيه متكامله للنمو علي مستوي الإقليم، إنتشار و تنوع مشروعات الإسكان الشعبي و التي تمثل واحده من أعقد التحديات التي تواجه البلدان الفقيره.** كل هذه الأسباب سوف تؤدي إلي زيادة رقعة و حدود النمو الغير المنضبط خارج و علي اطراف المدن. و ذلك لأنه ما بين ٤٠-٦٠ ٪ **من المستوطنات الحضريه في تلك البلدان تصنف بأنها غير رسميه ،** وتصل إلى ٨٠ ٪ منها مستوطنات جديده **تم إنشاؤها خارج الزمامات الرسميه للمدن و القري خلال الخمسون سنه الماضيه**، ومن جهة أخري فإن هذه الحدود و الزمامات **مكانياً و جغرافياً** ضعيفه و غير قادره علي منع التوسع الحضري خارجها.(مركز الأمم المتحده للمستوطنات البشريه ، ٢٠٠٣) .

و علي الجانب الأخر فإنه لابد من الأعتراف بوجود نقص كبير فى الأبحاث و الدراسات التي تناقش العوامل و المتغيرات المؤثره علي التوسع العمراني اللارسمي خارج حدود المدن فى بلدان العالم النامي ، بالأضافه إلي وضع الدراسات و تطوير الأدوات اللازمه للتنبؤ بالنمو المستقبلي ، و ذلك بهدف دعم مهمه التخطيط لوضع السياسات المستقبليه لمواجهة هذا النمو. خاصاً أنه يوجد العديد من الدراسات و الأبحاث التي قامت بدراسة و محاكاة النمو المستقبلي فى بلدان العالم المتقدم، و نتج عنها العديد من البرامج و التطبيقات التي يمكن إستخدامها للتنبؤ المكاني بالنمو المستقبلي في بلدان العالم النامي.

و بصفه عامه فانه لدراسة النمو العمراني المستقبلي لابد من الإجابه علي سؤالين هامين:

أولا: أين تقع المناطق التي سوف تجذب التدفق السكاني المستقبلي ؟

ثانيا: ما هي الأدوات و التقنيات التي يمكن أن تساعد مخططي المدن لوضع السياسات العمرانيه لمنع أو مواجهه أو توجيه حركة النمو السكاني إلي مناطق أخري و الآثار المترتبه على التوسع الحضري؟

تبدأ الإجابه على هذين السؤالين من وجهة نظر إنتشار المناطق اللارسميه والتحديات التي تواجه مخططي المدن ، ومن المهم بإيجاز عرض العمليات والفعاليات التى تسهم فى توسيع و نمو هذه المناطق، و **بصفه خاصه فى إقليم القاهره الكبري فى جمهورية مصر العربيه:**

١) مشروعات الإسكان الشعبى *(الأهلي)* هي أكبر المصادر التي تزيد من نمو و إنتشار العمران الشعبي فى المناطق الحضريه حيث يساهم بنحو **٩٠** ٪ [١] - ٨٤ ٪ (GTZ, 2009) [٢] من إجمالي النمو فى الإقليم بالمقارنه بمشروعات الإسكان الحكومي أو المشروعات التي تقوم بها الشركات و المؤسسات المتخصصه.

[١] جريدة الأهرام المصريه ١٧ نوفمبر ٢٠٠٤ – ص ٣

[2] This article available at: http://www.gtz-aegypten@gtz.de

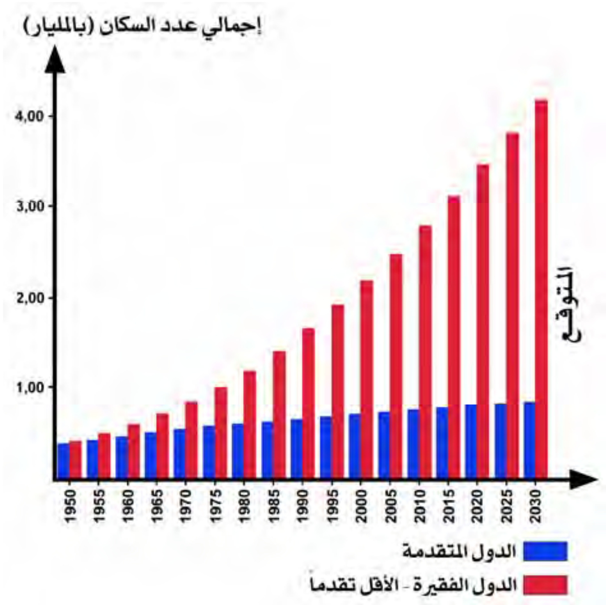
٢) عزوف الجمعيات و المؤسسات الأهليه عن ممارسة أنشطة إدارة العمران و إلقاء العبء علي الحكومات و أجهزة المدن و المحليات، مما أدي إلي تعقيد و صعوبة الظروف التي تنشأ فيها المناطق العشوائيه.

٣) عدم مقدرة أجهزة المدن و المحليات علي إمداد المرافق و الخدمات الضروريه لتلك المناطق المستحدثه حول و داخل الإقليم ساهم بشكل كبير في تعقيد و صعوبة تأهيل و تطوير هذه المناطق بالرغم من إنتشار هذا النمط من الإسكان فى أغلب أحياء القاهره الكبري.

نتيجة لهذه الأسباب و أسباب أخري **إقتصاديه و ثقافيه و إجتماعيه و أحياناً سياسيه**، أصبحت أغلب مدن بلدان الدول الناميه و منها مصر **تعاني من نمو المناطق اللارسميه و الغير مخططه خارج حدود المدن**، و أصبح العمران اللارسمي يمثل ما بين ٣٠ ٪ إلي ٦٠ ٪ من إجمالي المناطق المأهوله بالسكان بتلك الدول (موئل الامم المتحده ، ٢٠٠١).

إن الإستراتيجيات و السياسات العمرانيه المتبعه حالياً لمواجهة أسباب إنتشار النمو اللارسمي غير فعاله، و الدليل علي ذلك هو عدم مقدرة هذه السياسات علي الحد من النمو.

إن الدراسات السابقه لهذه الظاهره هي أغلبها دراسات وصفيه، و لم تتمكن من تقديم منهج تنبؤي للوضع المستقبلي لنمو تلك المناطق، و تقديم تصوراً للأراضي المؤهله حول و داخل المدن لإستقطاب هذا النوع من الإسكان، بهدف وضع و إقتراح السياسات المناسبه لمواجهة زحف العمران اللارسمي علي المدي البعيد.



تدرج النمو السكاني بالمدن ما بين عام **١٩٥٠- ٢٠٠٥** و المتوقع حتي عام **٢٠٣٠** (المصدر: منظمة الأمم المتحده للسكان، ٢٠٠٢)

و بصفه خاصه فإن جمهورية مصر العربيه، تضاعف عدد سكانها حوالي **٣ مرات** خلال الخمسين سنه الأخيره، حيث زاد عدد السكان من حوالي **٢٥ مليون نسمه عام ١٩٥٠** إلي أكثر من **٧٣ مليون نسمه حسب إحصاء ٢٠٠٦**، و ذلك بالرغم من إنحدار منحني معدل النمو السكاني خلال العقود السابقه، حيث بلغ معدل النمو ٢,٤٪ فى الفتره ما بين ١٩٧٦-١٩٨٦ و تناقص إلي ٢,١٪ فى الفتره ما بين ١٩٨٦- ١٩٩٦ و وصل إلي ١,٩٪ فى الفتره ما بين ١٩٩٦-٢٠٠٦، و يقدر معدل النمو السنوي حاليا ١,٦٪. و يعزي هذه الزياده إلي المحافظات الريفيه فى الدلتا و الصعيد و المحافظات الحدوديه (الجهاز المركزي للتعبئه العامه و الأحصاء، ٢٠٠٨).

و الآن، وصل عدد سكان مصر إلي ٧٧,٧ مليون نسمه فى بداية عام ٢٠١٠ وفقاً لتقديرات الجهاز المركزي للتعبئه العامه و الأحصاء [١]، وهذا يعني أن الكثافه السكانيه علي مستوي الجمهوريه تزيد علي ٧٧ شخص/كم٢.

[١] موقع الجهاز المركزي للتعبئه العامه و الإحصاء (http://www.capmas.gov.eg)

و إذا أخذنا بعين الأعتبار أن ٩٩٪ من السكان يعيشون فى منطقة الوادي و الدلتا و التي تقدر بنحو ٣,٥٪ (١) **من مساحه الجمهوريه فإن الكثافه الصافيه تزيد عن ٢,٢٠٠ شخص / كم٢. التي تمثل واحده من أكبر الكثافات السكانيه فى العالم. ويتوقع أن يصل عدد سكان مصر إلى ١٣٦,٥ مليون نسمه بحلول عام ٢٠٥٠** (الجهاز المركزي للتعبئه العامه و الأحصاء، ٢٠٠٨)، **بالإضافه إلى ذلك فقد تجاوزت الأحجام السكانيه لمئات القرى العشرة آلاف نسمه دون إعتبارها مدينه رسمياً** (الهيئه العامه للتخطيط العمراني، ٢٠٠٦).

بالأضافه إلي هذه البيانات و الحقائق فقد إنتشرت مناطق الإسكان اللارسمي خارج حدود المدن و القري علي الأراضى الزراعيه و الصحراويه علي حد السواء، و فى دراسه لمركز المعلومات و دعم اتخاذ القرار التابع لرئاسة مجلس الوزراء عام ٢٠٠٨، فقد تم حصر المناطق العشوائيه فى **١٠** محافظات و هي **القاهره، الأسكندريه، القليوبيه، الجيزه، الفيوم، بني سويف، المنيا، أسيوط، سوهاج، قنا.** و أظهرت هذه الدراسه إنتشار ظاهرة الإسكان اللارسمي حتي أصبحت تمثل إحدي سمات الحضر المصري، فإلي جانب ضياع الهويه المميزه للريف و الحضر الناتجه عن التضارب فى تصنيف التجمعات العمرانيه، فإن الإمتدادات العشوائيه بالمدن المصريه ساهمت بصوره مباشره في تشويه الهيكل العمراني و النسيج الحضري لهذه المدن، **حيث تصل نسبة الإمتدادات فى بعض المدن إلي حوالي** ٧٧ ٪ **من النمو العمراني للمدينه** *(بني مزار– المنيا)* **و وصلت إلي** ٨٧ ٪ **من الأمتدادات العمرانيه لمدينه كبيره مثل الجيزه، و فى نفس الوقت فقد بلغ حجم سكان العشوائيات إلي سكان المدن ما بين ٢٥ ٪ كما فى محافظة اسيوط،** ٦٢ ٪ **كما فى محافظة الجيزه** (خريطة التنميه و التعمير لجمهورية مصر العربيه عام ٢٠١٧ – الهيئه العامه للتخطيط العمراني، ١٩٩٨).

و يعتبر إقليم القاهره الكبرى مثا جيد لنمو مناطق الإسكان اللارسمي، حيث تضاعفت الكتله العمرانيه للأقليم حوالي **٣** مرات خلال الخمسين سنه الأخيره، و يسكن الإقليم حوالي **١٦ مليون نسمه و يعد إقليم القاهره الكبري رقم ١١ فى الترتيب العالمي من حيث المدن الأكثر سكاناً،** بمعدل زياده سنويه حوالي ١,٦١٪ (٢)، و تنتشر داخل و حول الإقليم مناطق الإسكان الشعبي واللارسمي، **حتي وصلت نسبة الوحدات السكنيه التي أنشئت بطريقه غير رسميه فى القاهره إلي حوالي** ٨٤ ٪ **من جملة ما تم انشاؤه خلال الخمسين سنه الماضيه و يوجد بالإقليم حوالي** ٨١ **منطقه غير رسميه** (د. مصطفى مدبولي ' ٢٠٠٥). **و هذه المعدلات تعطي إشاره واضحه للتوسع و الإنتشار المستمر لهذا النمط من الإسكان في القاهره الكبري، و الآن أصبحت مناطق الإسكان اللارسمي هي إحدي سمات النمط الحضري السائد داخل و حول الإقليم و المناطق المخططه هي الأستثناء** (خريطة التنميه و التعمير لجمهورية مصر العربيه عام ٢٠١٧ – الهيئه العامه للتخطيط العمراني، ١٩٩٨).
فعلي الرغم من أن هذا القطاع لبي إحتياجات الإسكان لأعداد كبيره من السكان إلا أنه أدي إلي ظهور العديد من المشاكل العمرانيه و البيئيه مثل القصور فى الخدمات و المرافق العامه و تداخل الإستعمالات الغير ملائمه كالمناطق الحرفيه الملوثه في عدد كبير من المحافظات.
بناءاً علي هذه المناقشه، فإن هذا البحث يقترح تطوير أدوات و تقنيات جديده لمساعدة المخطط العمراني علي تحديد و دراسة العوامل التي تؤثر علي نمو مناطق الإسكان اللارسمي حتي يمكن فهم و إدارة هذا النمط من الإسكان.

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(1) This article available at: http://www.country-data.com/frd/cs/egtoc.html *(last accessed 15/4/2008)*
(2) This article available at: http://www.demographia.com/db-worldua.pdf *(last accessed 15/4/2008)*

ت) أهمية البحث

بينما تنمو المدن وتتطور فإن مهمة إدارة المدن تصبح أكثر تعقيداً، و كنتيجة لذلك أنتشرت العديد من المشاكل العمرانيه و الإجتماعيه و البيئيه نتيجة لنمو و إتساع رقعة المدن خارج الحدود الإداريه و السياسيه .
و من المتوقع أنه بحلول عام **٢٠٣٠**، فإن حوالي **٥٠٪ من سكان الدول الناميه** و بصفه خاصه **إفريقيا و أسيا** سوف يتركزون فى المناطق الحضريه و المدن. **و لاشك أن هذه أخبار جيده تعبر عن تحضر العالم، و بالتالي فإن التحدي علي مدي الثلاثون سنه القادمه سوف يتركز علي كيفية الإستفاه من هذا التحضر و التعمير المتوقع و تقليل مخاطره و آثاره السلبيه .**

و للنجاح فى هذا التحدي، فإن هذا يتطلب توفير أدوات و وسائل للتخطيط المستقبلي و توفير بيانات و معلومات حديثه وموثقه فى جميع المجالات التي تخدم التخطيط العمراني، **مثل الأستشعار عن بعد، و الخرائط الحديثه، و البيانات السكانيه، و الإحصائيات العمرانيه التي تساعد المخطط علي تحديد سمات التغير الحضري، و قياس مدي تطور و إنتشار المدن بشكل فعال،** حتي الآن فان هذه القضايا لم تأخذ القدر الكافى من الأهتمام.

و من جهة أخري، أدي انتشار الحاسب الآلي و تنوع تطبيقاته إلي إندماج كافة العلوم و المعارف بتقنياتها المختلفه مع الحاسب الآلي ، حتي أنه لا تجد علم من علوم المعرفه سواءً الهندسه أو الطب أو الزراعه أو الجيوليوجيا أو المناخ .... الخ، إلا و تغيرت أدواته و أساليب إدارته و طبيعة العمل به، و ذلك بتأثر هذه العلوم و اندماجها و تكاملها مع تقنيات الحاسب الآلي. حتي أصبحت كل المهام التي كانت تتم ب<u>الطرق اليدويه فى الماضي، تدار و يتم إنجازها بأستخدام الحاسب الآلي مما ساعد علي سرعة إنجازها و توفير الجهد و الوقت و العماله</u>، مع تحقيق أعلي قدر من الدقه و الكفاءه فى العمل.

و الآن تدخل الحاسب الآلي بقوه فى التخطيط العمراني و ظهرت العديد من التطبيقات و الأدوات و البرامج التي تخدم مجالات التخطيط المختلفه، سواءً فى المراحل الأوليه للتخطيط أو رفع و تحديث البيانات من الطبيعه أو رسم خرائط الأساس و البنيه الأساسيه أو إعداد البدائل و السيناريوهات التخطيطيه أو التنبؤ بالنمو المستقبلي.

و تأتي أهمية هذا البحث من خلال ضرورة إستخدام التقنيات الحديثه ، وخاصة **نظم المعلومات الجغرافيه (GIS)** و **الخلايا ذاتية الحركه (CA)** فى وضع منهجيه و إطار عام ل<u>إتخاذ القرار التخطيطي المستقبلي، و بصفه خاصه التنبؤ بأماكن و إتجاهات نمو مناطق الإسكان اللارسمي داخل و حول المدن</u> ، و ذلك من أجل تحسين فعالية وكفاءه عمليات التخطيط ، بالإضافه إلى إلقاء الضوء على العديد من الأتجاهات العالميه الحديثه التي تطورت للتنبؤ بالنمو المستقبلي فى بلدان العالم المتقدم ، و تحديد كيفية الإستفاده من هذه التجارب و إعادة هيكلتها مع المتغيرات التي تؤثر على النمو العمراني لجعلها ملائمه للأستخدام فى بلدان العالم النامي، و بصفه خاصه داخل المجتمع المصري.

ث) الهدف من البحث

إن الهدف الرئيسي لهذا البحث هو تطوير نموذج عمراني قادر علي محاكاة النمو العمراني خلال فترات زمنيه محدده (Simulation Model – Prediction Model) و بصفه خاصه نمو و أنتشار الإسكان اللارسمي فى المناطق الغير مخططه (Informal Housing – Popular Housing) بالقاهره الكبري.

هذه الدراسه سوف تحاول أن تؤسس لمنهجيه و وجهة نظر جديده لملء الفجوه الحاليه بين الدراسات و الأبحاث العلميه و هذه الظاهره العمرانيه، بهدف زيادة القدره العمليه للمخططين و صناع القرار و السياسه الحضريه لإستكشاف التوسع السريع لمناطق الإسكان اللارسمي.

و لا يزال حتي الآن فهم عوامل و سلوك إنتشار تلك المناطق محدوداً، لذلك فإن هذا البحث يتبني منهج <u>لدراسة و نمذجة العوامل و المتغيرات المؤثره فى النمو</u>، و معايرة (Calibration) تلك العوامل من خلال دراسة تطور و إنتشار العمران فى الماضى ثم عمل محاكاة للتنبؤ المستقبلي بناءاً علي هذه العوامل.

بالرغم من تعدد و تعقيد العوامل المؤثره فى النمو و الإنتشار العمراني، فإنه يوجد العديد من المحاولات و التجارب التي قامت بدراسة النظم العمرانيه و العوامل المؤثره فيها ، مدعومه بالتطور الهائل فى برمجة الحاسب الآلي، و التي يمكن أن تساهم فى الوصول إلي رؤيه جديده فى توقع النمو الغير مخطط.

و مثال ذلك: دمج تقنيات **نظم المعلومات الجغرافيه (GIS)** مع **تقنيات الخلايا ذاتية الحركه (CA)** لتحليل ديناميكا العمران. هذه المحاولات نتج عنها مجموعه من التطبيقات و الأدوات تم استخدامها بنجاح فى العديد من بلدان العالم المتقدم، مثل مدينة **مرسيليا بفرنسا** ، و مدينة **سان فرانسيسكو**، و منطقة **جنوب كارولينا** بالولايات المتحده الأمريكيه، و منطقة **خليج هيرفي** بأستراليا.

و الهدف الرئيسي لهذا البحث هو تطوير نموذج عمراني تنبوئي (Predictive Model) يتناول المتغيرات و العوامل المؤثره فى النمو و تطبيق هذا النموذج علي ديناميكا العمران لمناطق الإسكان اللارسمي فى القاهره الكبري.

<u>**و للوصول إلي الهدف الرئيسى لهذا البحث سوف يتم إستخدام مسارين رئيسيين:**</u>

<u>**الأول:**</u> إستخدام <u>تقنيات نظم المعلومات الجغرافيه</u> **(GIS)** فى دراسة التطور التاريخي لنمو مناطق الإسكان اللارسمي داخل و حول الإقليم و عرض النتائج المتوقعه للنموالمستقبلي.

<u>**الثاني:**</u> إستخدام <u>تقنيات الخلايا ذاتية الحركه</u> **(CA)** فى تصميم برنامج التنبؤ بأماكن ظهور و إنتشارمناطق الإسكان اللارسمي من خلال نمذجة **العوامل المؤثره فى النمو،** و أستنباط درجة تأثير كل عامل علي حده من خلال مراحل التطور التاريخي. ثم إجراء عملية التنبؤ بإستخدام الأوزان المستنتجه من مرحلة المعايره.

والهدف من هذا التكامل هو تصميم نموذج عمراني واقعي (Realistic Predictive Urban Model) يمكن إستخدامه لمحاكاة النمو المستقبلي غير المخطط لتوقع أنماط و إتجاهات النمو المستقبلي لإتاحة الفرصه لإمكانية وضع السياسات لتوجيهه و مواجهة هذا النوع من النمو، بالإضافه إلي تحسين البيئه الأجتماعيه و الصحيه للمناطق الموجوده حالياً.

أهداف البحث

النظريات و التكنولوجيات الحديثة

مناطق الإسكان اللارسمي

- النظريات و الدراسات المتاحة
- مناطق و آليات إنتشار النمو اللارسمي
- عوامل إنتشار النمو اللارسمي الغير مخطط
- السياسات المتبعة لمواجهة هذه الظاهره

تقنيات الحاسب الآلي و ثورة المعلومات

- GIS
- CA
- OOP
- SM

الأساليب المتبعة للوصول لأهداف البحث

- دراسة التطور التاريخي لنمو مناطق الإسكان اللارسمي
- تقييم نماذج التنبؤ المستخدمه فى بلدان العالم المتقدم
- معايرة العوامل والمتغيرات المؤثره علي النمو
- تطبيق معايير وأوزان قابلية تغيير استخدامات الأراضي

النتائج المتوقعه

- تطوير نموذج عمراني ديناميكي يعمل علي الحاسب الآلي
- التنبؤ بالنمو المستقبلي لمناطق الإسكان اللارسمي
- التنبؤ بالحدود النهائيه لمنطقة الدراسة حتى عام ٢٠٤٦
- ما هي السياسات الواجب اتباعها لتخفيف الآثار السلبيه للنمو المستقبلي

المنهجيه المتبعه خلال الرساله

ج) الأسئله المطروحه من خلال البحث

للوصول إلي الأهداف الموضوعه لهذا البحث، فقد تم تنظيم هذه الدراسه بحيث تضع إطاراً عام للإجابه علي الإشكاليات العمرانيه و التخطيطيه الآتيه:

اولاً: هل تطبيقات ديناميكا العمران التي تم تطويرها لمحاكاة النمو المستقبلي في المناطق المخططه مناسبه لمحاكاه نمو و إنتشار مناطق الإسكان اللارسمي فى بلدان العالم الأقل تقدماً ؟

وهذه الإشكاليه يمكن تفسيرها من خلال الإجابه علي الأسئله الآتيه:

١) ما هي التطبيقات و الأدوات المتاحه حالياً لإستكشاف ديناميكا العمران بصفه عامه، و هل تم تطبيقها فى مدن بلدان العالم النامي بصفه خاصه ؟

٢) هل تطبيقات ديناميكا العمران الحاليه و التي تم تطويرها لمحاكاة النمو المستقبلي في المناطق المخططه مناسبه لمحاكاة النمو الغير مخطط فى مدن بلدان العالم النامي ؟

٣) ما هي القواعد و المعايير التي يمكن إستخدامها لمحاكاة ونمذجة عوامل نمو هذه المناطق فى بلدان العالم النامي ؟

ثانياً: هل تقنيات الخلايا ذاتية الحركه (CA) و نظم المعلومات الجغرافيه (GIS) الموجوده حالياً قادره علي تطوير نموذج (برنامج) عمراني ديناميكي للتنبؤ بأماكن و أتجاهات نمو مناطق الإسكان اللارسمي فى المناطق الغير مخططه مثل حالة إقليم القاهره الكبري ؟

وهذه الإشكاليه يمكن تفسيرها من خلال الإجابه علي الأسئله الآتيه:

١) كيفية إستخدام إمكانيات الحاسب الآلي و تقنيات البرمجه الشيئيه **(OOP)** فى بناء نماذج عمرانيه مكانيه (Spatial Modelling)، لتوثيق الوضع التاريخي و معايرة عوامل النمو للمناطق اللارسميه ؟

٢) ما هي العوامل الأساسيه المؤثره فى إنتشار و نمو هذا النمط العمراني ؟

٣) ما هي المساهمات التي يمكن أن تقدمها **تقنيات الخلايا ذاتية الحركه (CA) و نظم المعلومات الجغرافيه (GIS)** فى دراسة التطور التاريخي لتلك المستقرات وإستنتاج نسب مساهمه العوامل المختلفه فى النمو، ثم محاكاة الوضع المستقبلي لنمو و إنتشار هذه المناطق.

لإستكشاف هذه الاسئله، فإنه يقترح تطوير برنامج يعتمد على أسلوب النمذجه المكانيه (Spatial Modelling) للعوامل المؤثره فى نمو المستقرات اللارسميه (IS) بأستخدام أدوات و تقنيات الخلايا ذاتية الحركه (CA) و دمجها فى بيئة نظم المعلومات الجغرافيه (GIS) للوصول إلي فهم أفضل لنمو تلك المناطق.

إن النموذج المقترح هو خطوه هامه الأمام، لانه سوف يعرض كيفية دمج تقنيات الخلايا ذاتية الحركه و نظم المعلومات الجغرافيه، لإنتاج نماذج عمرانيه ديناميكيه تقوم بدمج العوامل الإجتماعيه و الديموغرافيه و السكانيه ذات العلاقه بنمو المناطق اللارسميه فى المناطق الغير مخططه و بصفه خاصه إقليم القاهره الكبري.

ح) فرضية البحث

إن توظيف التقنيات و التكنولوجيات الحديثه المصاحبه لثورة الاتصالات و تكنولوجيا المعلومات و بصفه خاصه نظم المعلومات الجغرافيه (GIS) و الخلايا ذاتية الحركه (CA) كأدوات مساعده فى دراسات التخطيط المستقبلي *(التخطيط للمستقبل)* يمكن من خلالها تطوير أدوات مفيده للتنبؤ بالنمو و التوسع الحضري المستقبلي لذلك فإن الفرضيه الرئيسيه لهذا البحث هو إمكانية تصميم و تطوير برنامج عمراني ديناميكي يتناول العوامل المؤثره علي النمو و لديه القدره علي التنبؤ المستقبلي لنمو و إنتشار مناطق الإسكان اللارسمي فى القاهره الكبري.

إن توظيف هذه النظم و الأدوات عند إعداد دراسات التخطيط المستقبلي سوف يؤدي إلي تغيير نسق العمل التخطيطي من العمل اليدوي التقليدي إلي التخطيط المتواصل، حيث أن هذه الأدوات والنظم يمكن ان توفر منهجيه اكثر فاعليه و مرونه في التعامل مع العوامل التي تؤثر على ظهور ونمو المناطق اللارسميه ، وإلى فهم طبيعه و اتجاهات نموها ، بهدف مساعدة متخذ القرار فى وضع السياسات اللازمه للتحكم و توجيه النمو في الإتجاهات التي تخدم المخطط ، و ذلك بهدف تحقيق تنميه عمرانيه و اقتصاديه و اجتماعيه شامله في جميع نواحي الحياه.

خ) النتائج المتوقعه من البحث

1) **تطوير نموذج عمراني ديناميكي يعمل على الحاسب الآلي (Urban Prediction Model)**

البرنامج المقترح يقوم بإستخدام تقنيات نظم المعلومات الجغرافيه **(GIS)** و الخلايا ذاتية الحركه **(CA)** لحساب و توقع أماكن نمو مناطق الإسكان اللارسمي و تطورها خلال فترات زمنيه محدده.

2) **محاكاة التطور المستقبلي للعمران بناءاً علي مجموعه من المعايير و المحددات للوصول إلى مجموعه من السيناريوهات المستقبليه للنمو العمراني.**

التنبؤ بالتطور المستقبلي للنمو، إستناداً علي مجموعه من العوامل (العمرانيه، الديموغرافيه، الإجتماعيه – الإقتصاديه – ... الخ) المستنتجه من الدراسه التاريخيه التي أثرت بشكل كبير علي إنتشار العمران فى المناطق الغير مخططه، بالإضافه إلى إمكانية تطوير النظام بناءاً علي الدراسه التطبيقيه.

3) **التنبؤ بالحدود النهائيه لمنطقة الدراسه حتي عام ٢٠٤٦.**

إن المعلومات و النتائج المستخلصه من هذا البحث، سواء البيانات الرقميه أو المكانيه (Spatial Data) ، لشكل و تطور العمران المستقبلي يمكن أن تستخدم كأداه قويه لدعم القرار التخطيطي و بصفه خاصه دراسات التخطيط المستقبلي و كيفية إدارة و توجيه النمو.

4) **ما هي السياسات الواجب إتباعها من الآن لتخفيف و تجنب الآثار السلبيه للنمو المتوقع فى المستقبل.**

من خلال الوضع الحالي لمنطقة الدراسه، و الرؤيه المستقبليه للنمو المتوقع، يمكن طرح العديد من السياسات العمرانيه و الوسائل التي من شانها تجنب الآثار السلبيه للنمو المتوقع، أو و ضع السياسات التي تساعد على توجيه النمو لبعض المناطق، و الحد منه في المناطق الأخري.

هيكل البحث

الباب الأول
منهج نظري

الفصل الأول: المقدمه و أهداف البحث

يقوم بعرض المشكله البحثيه، وأهمية البحث، والأهداف الموضوعه، و المنهج المتبع للوصول لهذه الأهداف، و الأسئله المطروحه للأجابه عليها من خلال البحث، والنتائج المتوقعه من البحث و فى النهايه يعرض هيكل البحث بصوره موجزه.

الفصل الثانى: المشكله التي يعالجها البحث

يتناول هذا الفصل عرض لمشكله انتشار مناطق الإسكان اللارسمي فى إقليم القاهره الكبري، و يعرض مناطق تمركز وإنتشار هذه المناطق، خصائص هذه المناطق من النواحي الاقتصاديه و القانونيه و الاجتماعيه و السكانيه، كما يعرض السياسات العمرانيه و القوانين التي تم إتخاذها لمنع و الحد من إنتشار هذا النمط العمراني.

الباب الثاني
منهج تحليلي و تحليلي مقارن

الفصل الثالث: إمكانيات استخدام **GIS** و **CA** فى النمذجه العمرانيه.

يعرض الإمكانيات المتاحه لكلاً من تقنيات **(GIS)** و**(CA)** ، و يتم إقتراح منهجيه لإمكانية تكاملهما و دمجهما **لإنتاج نماذج عمرانيه ديناميكيه**، تعطي نتائج اكثر واقعيه عن النمو المستقبلي لمناطق الإسكان اللارسمي فى بلدان العالم النامي.

الفصل الرابع: مراجعة نماذج ديناميكا العمران

هذا الفصل يقوم بمراجعة نماذج الديناميكا الحضريه التي تم تطويرها فى العديد من الجامعات و المؤسسات البحثيه العالميه، بهدف تقييم تلك النماذج و دراسة مدي ملائمتها للتطبيق فى حالة النمو اللارسمي فى بلدان العالم النامي، و بصفه خاصه إقليم القاهره الكبري.

الفصل الخامس: التنبؤ بالنمو المستقبلي لإقليم القاهره الكبري باستخدام برنامج **(SLEUTH)**

يعرض تطبيق برنامج **(SLEUTH)** للتنبؤ بالنمو المستقبلي لأقليم القاهره الكبري، و يتناول عرض قصور إستخدام هذا البرنامج فى التنبؤ بدقه فى حاله استخدامه فى المناطق الغير مخططه.

الباب الثالث
منهج تطبيقي

الفصل السادس: البرنامج المقترح

يعرض وصف لهيكل البرنامج المقترح تطويره من خلال الرساله، حيث يتم تطبيق البرنامج علي حاله **إقليم القاهره الكبري**، لاستكشاف النمو المستقبلي بالإقليم حتي عام ٢٠٤٦.

الفصل السابع: تقييم البرنامج المقترح

فى هذا الفصل يتم تقييم البرنامج المقترح مع عرض نقاط القوه و الضعف من خلال مجموعه من معايير التقييم.

الفصل الثامن: النتائج و التوصيات

يعرض ملخص الرساله مع إبراز النتائج الرئيسيه للبحث، و إقتراح بعض التوصيات لتناولها فى الأبحاث و الدراسات المستقبليه فى هذا المجال.

د) هيكل البحث

تم تقسيم البحث إلي ثلاثة أبواب تنقسم إلي ثمانية فصول، و تشمل ما يلي :

الباب الأول: (منهج نظري - أستقرائي)

يتناول هذا الباب نظره عامه علي البحث و يعرض الإطار النظرى لنمو الإسكان اللارسمي **(IH)** فى المناطق الغير مخططه و بصفه خاصه حالة إقليم القاهره الكبري. و يتكون من الفصلين الأول و الثاني كما يلي:

الفصل الأول: المقدمه و أهداف البحث. Introduction and Research Objectives

يعرض هذا الفصل المشكله البحثيه، و أهمية البحث، و الأهداف الموضوعه، و المنهج المتبع للوصول لهذه الأهداف، و الأسئله المطروحه للأجابه عليها من خلال البحث، و النتائج المتوقعه من البحث و فى النهايه يعرض هيكل البحث بصوره موجزه.

الفصل الثاني: المشكله التي يعالجها البحث. The Problem of Informal Housing

يتناول هذا الفصل عرض لمشكلة إنتشار مناطق الإسكان اللارسمي فى إقليم القاهره الكبري، حيث يعرض مناطق تمركز وإنتشار هذه المناطق، بالإضافه إلي خصائص هذه المناطق من النواحي الإقتصاديه و القانونيه و الإجتماعيه و السكانيه، كما يعرض السياسات العمرانيه و القوانين التي تم إتخاذها لمنع و الحد من إنتشار هذا النمط العمراني.

الباب الثاني: (منهج تحليلي و تحليلي مقارن)

يقوم هذا الباب بمناقشة و تحليل المفاهيم و النظريات التي تناولت تطور و نمو المدن بصفه عامه، بالإضافه إلي عرض برامج و أدوات نماذج ديناميكا العمران الحاليه. و يتكون من الفصول الثالث و الرابع و الخامس كما يلي:

الفصل الثالث: إمكانيات استخدام نظم المعلومات الجغرافيه **(GIS)** و الخلايا ذاتية الحركه (CA) فى بناء النماذج العمرانيه. GIS and CA Urban Models

يعرض هذا الفصل أدوات و تقنيات نظم المعلومات الجغرافيه **(GIS)** و الخلايا ذاتية الحركه **(CA)** و يقوم بعرض المنهجيه المقترحه لإمكانية تكاملهما لإنتاج نماذج عمرانيه ديناميكيه، لكي تعطي نتائج أكثر واقعيه عن النمو المستقبلي، لمناطق الإسكان اللارسمي فى بلدان العالم النامي.

الفصل الرابع: مراجعة نماذج ديناميكا العمران. Review of Previous Urban Dynamics Models

هذا الفصل يقوم بمراجعة نماذج ديناميكا العمران الحاليه التي تم تطويرها فى العديد من الجامعات و المؤسسات البحثيه و الإكاديميه العالميه، و ذلك بهدف تقييم تلك النماذج و دراسة مدي ملائمة تطبيقها فى حاله مناطق الإسكان اللارسمي فى بلدان العالم النامي. حيث يعرض هذا الفصل **(٨)** نماذج تم اختيارها لتمثل كافة الإتجاهات المتبعه لتوقع النمو المستقبلي، مع عرض مميزات و عيوب كل منها فى حالة تطبيقها فى القاهره الكبري.

الفصل الخامس: التنبؤ بالنمو المستقبلي باستخدام (SLEUTH). Application of SLEUTH Model

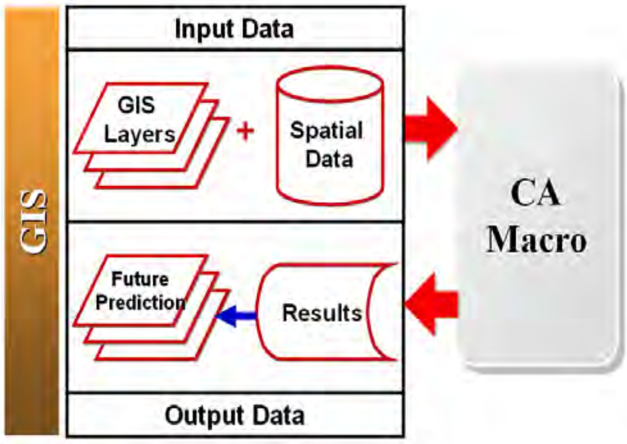
يعرض هذا الفصل تطبيق نموذج من أشهر النماذج العالميه التي تستخدم فى التنبؤ و محاكاة النمو العمراني المستقبلي فى مدن بلدان العالم المتقدم و هو برنامج [1] **(SLEUTH, C**larke **G**rowth **M**odel) و الذي تم تطويره فى قسم الجغرافيا بجامعة كاليفورنيا بالولايات المتحده الأمريكيه. و يعرض هذا الفصل قصور إستخدام هذا البرنامج فى التنبؤ بدقه فى حالة إستخدامه لدراسة النمو المستقبلي لإقليم القاهره الكبري، و يناقش إمكانية إدخال بعض التعديلات علي البرنامج بهدف زيادة قدرة البرنامج علي تناول بعض العوامل و المتغيرات التي تؤثر بشكل مباشر فى نمو المناطق العشوائيه فى القاهره الكبري.

الباب الثالث: (منهج تطبيقي)

يعرض هذا الباب البرنامج المقترح تطويره من خلال الرساله، و ذلك من خلال الربط بين النتائج و الأستنتاجات التي تم التوصل اليها فى الدراسه النظريه *(الباب الأول)* مع التقنيات و التكنولوجيات الحديثه التي تم مناقشتها حول ديناميكا النمو العمراني *(الباب الثاني)* . و يتكون من الفصول السادس و السابع و الثامن كما يلي:

الفصل السادس: البرنامج المقترح. The Proposed **IHGM** Model

هذا الفصل يقوم بعرض ووصف هيكل البرنامج المقترح تطويره من خلال الرساله لدراسة وإستكشاف النمو المستقبلي لمناطق الإسكان اللارسمي، حيث تم تطبيق البرنامج المقترح علي **إقليم القاهره الكبري**، لإستكشاف إتجاهات النمو المتوقعه بالأقليم، والتنبؤ بالتوزيع المكاني للأمتدادات المستقبليه حتي عام ٢٠٤٦ كل ٥ سنوات.



الأسلوب المقترح لدمج نظم المعلومات الجغرافيه مع تقنيات الخلايا ذاتية الحركه

الفصل السابع: تقييم البرنامج المقترح. The Model Evaluation

هذا الفصل يقوم بتقييم نتائج النموذج المقترح مع عرض نقاط القوه و الضعف من خلال مجموعه من معايير التقييم.

الفصل الثامن: النتائج و التوصيات. Conclusions and Recommendations

يعرض هذا الفصل ملخص الرساله مع إبراز النتائج الرئيسيه للبحث، و إقتراح بعض التوصيات لتناولها فى الأبحاث و الدراسات المستقبليه فى هذا المجال.

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[1] **SLEUTH** *(**S**lope, **L**and use, **E**xclusion, **U**rban, **T**ransportation, **H**ill-shading)*, SLEUTH model and relevant materials can be obtained from http//:www.ncgia.ucsb.edu/projects/gig/

نمذجة و محاكاة النمو المستقبلي لمناطق الإسكان اللارسمي

منهج قائم علي دمج تقنيات نظم ا علومات ا غرافيه و ا لايا ذاتية ا ركه

إعـــــداد

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رساله مقدمه الى كلية الهندسه ، جامعة القاهره
كجزء من متطلبات الحصول على درجة الدكتوراه
فى الهندسه المعماريه

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فى الهندسه المعماريه

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