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ESTIMATION OF SEA LEVEL RISE HAZARDOUS IMPACTS IN EGYPT WITHIN A GIS ENVIRONMENT

ABSTRACT

The global warming, and other, environmental phenomena have led to a global rise trend of sea level. Recent estimates of projected sea level rise at year 2100 expect that it can reach more than a meter. Several hazards are anticipated due to the rise of sea level, including shoreline retreat and loss of populated areas particularly in coastal regions. This research study assess those impacts on the Egyptian coastal areas of the Nile Delta, that extend approximately over 170 x 90 Km. Since there is no available precise national Digital Elevation Models (DEM) for this area, four global DEMs have been obtained and utilized. First, these DEMs have been examined, based on real terrestrial data points, to determine the optimal DEM that precisely represents the Egyptian topography. Next, the precise DEM (SRTM 3") has been represented in a Geographic Information System (GIS) environment containing 2206381 data points. Furthermore, several scenarios of the projected sea level rise (ranging from 0.25 to 1.5 m) have been investigated. It has been found that the estimated loss of populated lands varies from 292 to 2731 square kilometers. The spatial distributions of the loss of lands have been graphically mapped for each scenario. The effectiveness of utilizing the GIS technology in such an environmental assessment research has been confirmed. The achieved results should be employed, by the decision makers, in the development policies of coastal regions in Egypt.

Key Words: GIS, Sea Level Rise, Digital Elevation Model, Environmental Impacts, Egypt.

1. INTRODUCTION

Several types of environmental threats have been recognized, on the global scale, as results of the global warming phenomena. The increasing emission of carbon dioxide gas, CO_2, into the atmosphere and the burning of large areas of tropical forests, along with other factors, have led to altering the global energy budget and, thus, resulted in a global increase of the mean temperature of the Earth. Sea level rise is a vital aspect of the environmental hazards due to its potential impacts on human population living in coastal regions and on islands. Sea level rise results in coastal floods, salt water intrusion, excessive erosion, soil salinization, deterioration of coastal ecosystems.

The rate of the mean global sea level rise (GSLR) in the twentieth century have been estimated, based on two different data types as: (1) based on tide gauge data, GSLR equals 1.8 mm/year; (2) based on satellite altimetry data, GSLR equals 3.1 mm/year (Solomon et al., 2007). However, it should be mentioned that these average rates of the sea level rise are not geographically uniform, and there are regions of the Earth have relatively larger values. Projecting the sea level rise at the end of the twenty-first century reveals that the expected rise of the sea level varies between 0.18 m and 0.59 m (ibid). Other studies (e.g. Dasgupta et al. 2007) expect that global warming can promote GSLR of 1-3 m, and unexpected rapid breakup of the Greenland and West Antarctic ice sheets might produce a 5-m GSLR in this century. In Egypt, the rate of sea level rise in the twentieth century has been recently estimated as 1.7 mm/year at Alexandria (e.g. Dawod et al, 2005, and Mohamed, 2005).

Recently, the Geographic Information System (GIS) technology has been extensively utilized to evaluate the hazardous impacts of the environmental changes, particularly the effects of sea level rise. Numerous merits of utilizing GIS in such assessment studies have been attained, such as the capability of spatial representation of the anticipated effects, the integration of several data types in a unique environment, and the ability of modelling the expected flood scenarios (e.g. Dasgupta et al., 2007, Sposito 2007, Lee 2005, Szlafsztein 2005, Koohzare et al., 2004, and Marfai 2003).

2. OBJECTIVES

In Egypt, the issue of sea level rise and its anticipated harmful impacts has been addressed by several researchers. Assessment studies integrating the GIS and remote sensing technologies have been carried out for several regions such as: Marsa Matrouh (El Raey et al, 2006), Alexandria and Rossetta (El Raey, 2005), Abu Qir bay (El Raey et al., 2005), and Nile Delta (Agrawala et al., 2004, and El Raey, 2004). Most of these studies are restricted to small regions since they depend on the utilization of remote sensing images to construct a Digital Elevation Model (DEM), which constitute a major item in the data processing stages.

The current research suggests a new approach, which is the adaptation of global high-resolution DEMs in such environmental assessment studies. The objectives of this study are:

1- Evaluation of available high-resolution DEMs to determine the "optimum" model in representing the topography of the study area;
2- The integration of global DEMs into a GIS environment;
3- The determination of total areas subjected to floods under several sea level rise scenarios; and
4- Mapping the spatial distribution of these regions' threats.

3. THE STUDY AREA

The study area constitutes a major part of the Nile Delta, the main area in Egypt with expected environmental hazards following the sea level rise. The study area, shown in Figure 1, extends in the north direction from latitude 30.5^o N to 31.6^o N (about 90 Km), and extends in the east direction from longitude 30.5^o E to 32.6^o E (about 170 Km). This area combines regions belong to 8 different governorates. A main reason that the study area does not involve the entire Nile Delta region is the huge data sets dealing with high-resolution global DEMs (particularly the 90-meter resolution model) and the technical specification limitations of a normal PC computer. However, it is highly recommended to use the suggested processing strategy for the entire Egyptian coastal areas using a high-specification workstation computer that can handles a huge amount of data.

4. EVALUATION OF GLOBAL HIGH-RESOLUTION DEMS

Since there is no accessible precise national DEM for the study area, four global DEMs have been obtained and utilized. These DEMs are: the Shuttle Radar Topography Mission (SRTM) model of 3" and 30" resolution, the DTM2002 model of 30" resolution, and the ETOPO2v2 model of 2' resolution. Except the DTM2002, all other DEMs are available free of charge and can be downloaded from the Internet.

The SRTM, flown on Space Shuttle Endeavour in February 2000, was a joint project of the National Aeronautics and Space Administration, the National Geospatial Intelligence Agency (NGA) (formerly National Imagery and Mapping Agency, NIMA) of the U.S. Department of Defense (DoD), and DLR. The SRTM objective was to acquire a digital elevation model of all land between about 60° north latitude and 56° south latitude, about 80 percent of Earth's land surface. Three DEM have been derived from SRTM data: (1) a 1-arc second (approximately 30 meters) version, which is only for USA, (2) a global 3-arc second (approximately 90 meters) version, and (3) a global 30-arc second (approximately 900 meters) version. (For more information about SRTM, see e.g. Farr et al, 2004, and USGS 2007). The SRTM3 DEM has been evaluated and utilized in several research studies. For example, Denker (2005) compared the SRTM 3 against a 1-second DEM in Germany, and estimated the standard deviation of the differences that equals 7.9 m. Moreover, Ghoneim and El-Baz (2007) have applied the SRTM 3 to construct a complete drainage map of the entire Tushka area, south of Egypt. The DTM2002 global DEM has been developed based on several sources of data, such as: the GTOPO30 and GLOBE global 30″ DEMs; the ACE 30″ DEM; Near ocean-wide bathymetric information predicted from altimetry data and constrained by ship-borne depth soundings; the Generic Mapping Tools (GMT) high-resolution global shoreline and land type database; new 5-km grids of ice surface elevations from altimetry data and the JGP95E geoid model over Antarctica and Greenland; revised ice thickness data over Antarctica and Greenland; and depth data (30″) for the Great Lakes (Saleh and Pavlis 2002). DTM2002 was compiled in a 30″ version that provides surface elevations and ocean depths only, and in 2′ and 5′ versions that include depth data for certain large lakes and ice thickness information (ibid). A part of DTM2002 (the 30" version) corresponding to the Egyptian territories has been obtained (Saleh 2004) and utilized in this research. The ETOPO2v2 global gridded 2-minute dataset has been released in 2006 by the U.S. National Geophysical Data Center (NGDC), the US NOAA Satellite and Information Service. ETOPO2v2 is a global relief for both land and ocean (available from http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html)

First, these four DEMs have been examined, based on a terrestrial dataset of 127 points with known orthometric heights, to determine the optimal DEM that precisely represents the Egyptian topography. Even though the study area is almost flat and the number of the available check points is small, this judgment step is considered as a proportional performance comparison of these DEMs in a relative sense. The attained results are presented in Table 1, with SRTM3" produced the smallest standard deviation value of 3.0 m. Thus, it is suggested that the SRTM 3" DEM may be considered the optimum global DEM representing the topography variations in the study area. Figures 2, 3, and 4 present a shaded-relief, a contour, and a 3D views, respectively, of the SRTM 3" DEM correspond to the study area.

5. DETERMINATION OF SEA LEVEL RISE IMPACTS USING GIS

Two computer packages have been utilized in the data processing stage. First, the Global Mapper 9.01 (TM) software has been used to combine, then transform, the downloaded SRTM 3" files from the raster format to XYZ text files. Second, the ESRI Arc GIS 9.2 (TM) has been used to build a Triangular Irregular Network (TIN), a contour map, and a 3D surface of this combined dataset. Additionally, the computations have been carried out using the 3D Analyst extension of the ARC GIS package.

First, it has been noticed that there are large regions of the study area that are already under the zero mean sea level. These low lands, shown in Figure 5, sum an area of 2466 square kilometers. Furthermore, the areas surrounded between contour lines equals 0.25, 0.5, 0.75, 1.0, 1.25, 1.5 m have been computed. Table 2 and Figure 6 present the achieved results. It can be seen that a sea level rise of

0.25, 0.5, 0.75, 1.0, 1.25, 1.5 m will led to loss of lands equal 292, 587, 885, 2023, 2378, and 2731 square kilometers respectively. These figures are quite significant since these areas losses constitute, in the same order, 2%, 5%, 7%, 17%, 19%, and 22% of the total area. It is a matter of fact that loosing such areas will lead to several other harmful impacts on the population and economy of the country. The population of those eight governorates (under study) constitute about 32.8% of the total population of Egypt, as of the January-2006's published official census (e.g. http://www.capmas.gov.eg/). Thus, the anticipated environmental threats can not only being justified based on the areas of the loss of lands, but also have to tack into consideration all other types of threats from the physical and the socio-economic points of view (El Raey, 2004 and Agrawala et al., 2004).

A major advantage of utilizing GIS is its capability of representing the spatial distribution of the results. Figures 7, 8, 9, and 10 depicts the geographical patterns of the expected loss of lands under the scenarios of sea level rise equals 0.25, 0.5, 1.0, and 1.5 m respectively. It can be noticed that the Kafr El-Sheikh is the most suffered governorate

6. CONCLUSIONS

The present-day rapid climate changes cause potential environmental threats, particularly the faster rise of sea level on a global basis. The projected sea level rise in the twenty-first century can reach a meter or more. The coastal areas in Egypt and the Nile Delta are expected to several hazardous impacts due to the sea level rise. This study utilize the high-precision SRTM 3" global DEM, within a GIS environment, to asses the loss of lands in the Nile Delta under several sea level rise scenarios ranging from 0.25 m to 1.5 m. The estimated results show that the anticipated loss of low lands range between 292 and 2731 square kilometers, that constitute about 2-22 % of the total area under consideration. These figures are extremely crucial, and call for an immediate national plane for coastal protection taking into considerations the faster sea level rise trend. Additionally, the spatial distributions of the expected loss of lands have been geographically represented through GIS. It has been shown that that Kafr El-Sheikh is the most suffered governorate in the study area. The suggested processing strategy, integrating global high-precision DEM and GIS, is quite significant in such an environmental assessment research, at least until a precise national DEM for Egypt be available.

REFERENCES

Agrawala, S., Moehner, A., El Raey, M., Conway, D., van Aalst, M., Hagenstad, M., and Smith, J., 2004, Development and climate change in Egypt: Focus on coastal resources and the Nile, A report published by the Organization for Economic Co-operation and Development (OECD), Paris. France.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D., and Yan, J., 2007, The impact of sea level rise on developing countries: A comparative analysis, World Bank Policy Research Working Paper No. 4136, February.

Dawod, G., Meligy, M., and Mohamed, H., 2005, Assessment and modelling of sea level rise and metrological changes in Egypt, Proceedings of the Ain-Shams First International Conference on Environmental Engineering (ASCEE-1), Cairo, Egypt, April 11-12, pp. 573-582.

Denker, H., 2005, Evaluation of SRTM3 and GTOPO30 terrain data in Germany, In IAG International Symposium on Gravity, Geoid and Space Missions (GGSM2004), Ed. C Jekeli, L Bastos, and J Fernandes, V. 129, pp. 218-223.

El Raey, M., and Mohammed; W. 2006, Impact of Sea Level Rise on Marsa Matruh City – Egypt: A Spatial Approach, Presented in the Conference of Earth Observation and Geoinformation Sciences in Support of Africa's Development, Oct. 30 – Nov. 2, Cairo, Egypt.

El Raey, M., Nasr, S., Frihy, O., Fouda, Y., El-Hattab, M., Elbadawy, O., Shalaby, A., and Mohammed, W., 2005, Remote sensing and GIS for sustainable development of the coastal area of Abu Qir bay, Egypt, Sea to Sea Regional Forum, pp. 275-280, Cairo, Egypt.

El Raey, M., 2005, Mapping Areas Affected by Sea-level Rise due to Climate Change in the Nile Delta until 2100, Presented at the First World International Studies Conference, Istanbul, Turkey, August 24- 27.

El Raey, M., 2004, Adaptation to Climate Change for Sustainable Development in the Coastal Zone of Egypt, Presented at the global forum on sustainable development: Development and climate change, The Organization for Economic Co-operation and Development (OECD), Paris. France.

Farr, T, Rosen, P., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Hill, C., Burbank, D., Barbara, S., and Alsdorf, D., 2004, The Shuttle Radar Topography Mission, Rev. Geophys., 45, RG2004, Jet Propulsion Laboratory, California Institute of Technology, USA. Available from: http://www2.jpl.nasa.gov/srtm/SRTM_paper.pdf

Ghoneim, E. and El-Baz, F., 2007, The application of radar topographic data to mapping of a mega-paleodrainage in the Eastern Sahara, Journal of Arid Environments, V. 69, pp. 658–675.

Koohzare, A., Vanícek, P., and Santos, M., 2004, Spatial analysis and treatment of tide gauge records using GIS, Presented at the GEOIDE Sixth Annual Scientific Conference, May 30 -June 1, Gatineau, QC, Canada.

Lee, E., 2005, GIS modeling of wetlands elevation change in response to projected sea level rise, Trinity Bay, Texas., MSC Thesis, University of North Texas, Texas, USA.
Marfai, M., 2003, GIS modelling of river and tidal flood hazards in a waterfront city: A case study of Semarang city, Indonesia, MSC Thesis, The international institute for geo-information science and earth observation (ITC), Enschede, The Netherlands.
Mohamed, H.F., 2005, Realization and redefinition of the Egyptian vertical datum based on recent heterogeneous observations, PhD Dissertation, Shoubra faculty of engineering, Benha university, Egypt.
Saleh, J. ,2004, Personal communications.
Saleh, J., and Pavlis, N. ,2002, The development and evaluation of the global digital terrain model DTM2002, Presented at the 3rd Meeting of the International Gravity and Geoid Commission, GG2002, August 26 - 30, Thessaloniki, Greece.
Solomon, S., D. Qin, M. Manning, R.B. Alley, T. Berntsen, N.L. Bindoff, Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P. Whetton, R.A. Wood and D. Wratt, 2007, Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (Available on-line from: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-ts.pdf)
Sposito, V., 2007, A strategic approach to climate change impacts and adaptation, Applied GIS, V. 2, No. 3, pp. 23.1–23.26, Published online: March 2007, Source: http://publications.epress.monash.edu/doi/full/10.2104/ag060023?cookieSet=1S , Accessed December 2007.
Stormst, J., and Kroonenbergt, S., 2007, The impact of rapid sea level changes on recent Azerbaijan beach ridges, Journal of Coastal Research, V. 23, No. 2, pp. 521- 527.
Szlafsztein, C., 2005, Climate change, Sea-level rise and Coastal Natural Hazards: A GIS-Based Vulnerability Assessment, State of Pará, Brazil, Proceedings of the International workshop on human security and climate change, Asker, Brazil, June 21–23.
Ustun, A., Bildirici, I., Selvi, H. Zahit , and Abbak, R., 2006, An evaluation of SRTM3 DTM data: validity, problems and solutions, The International Conference on Cartography and GIS, January 25-28, Borovec, Bulgaria.
USGS (The US Geological Survey), 2007, The Seamless Shuttle Radar Topography Mission (SRTM): Finished 3 Arc Second, http://seamless.usgs.gov/website/seamless/products/srtm3arc.asp, Accessed Dec. 2007.

Table 1: Statistics of height differences of global DEMs compared to known check points (in meters)

Item	DEM			
	SRTM3"	DTM2002	SRTM30"	ETOPO2v2
Minimum	-5	-12	-14	-16
Maximum	5	6	5	7
Mean	0.2	-0.5	-1.4	-2.2
Standard Deviation	3.0	4.2	5.3	5.8

Table 2: The expected loss of lands under several sea level rise scenarios

Sea Level Rise	Loss of Areas (sq.km)	% of Total Areas
0.25 m	292	2 %
0.50 m	587	5 %
0.75 m	885	7 %
1.00 m	2023	17 %
1.25 m	2378	19 %
1.50 m	2731	22 %

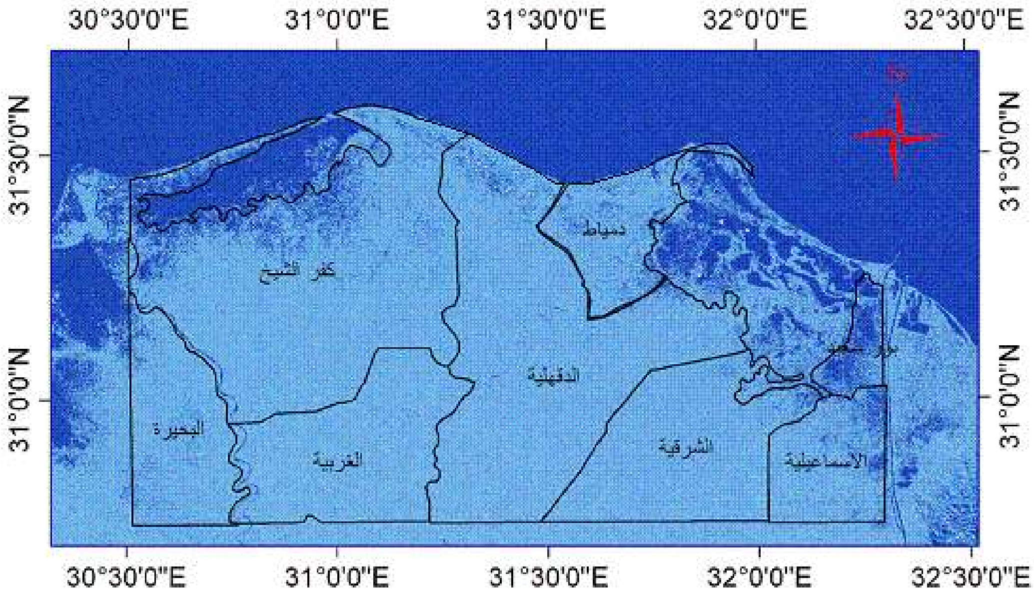

Figure 1: The study area

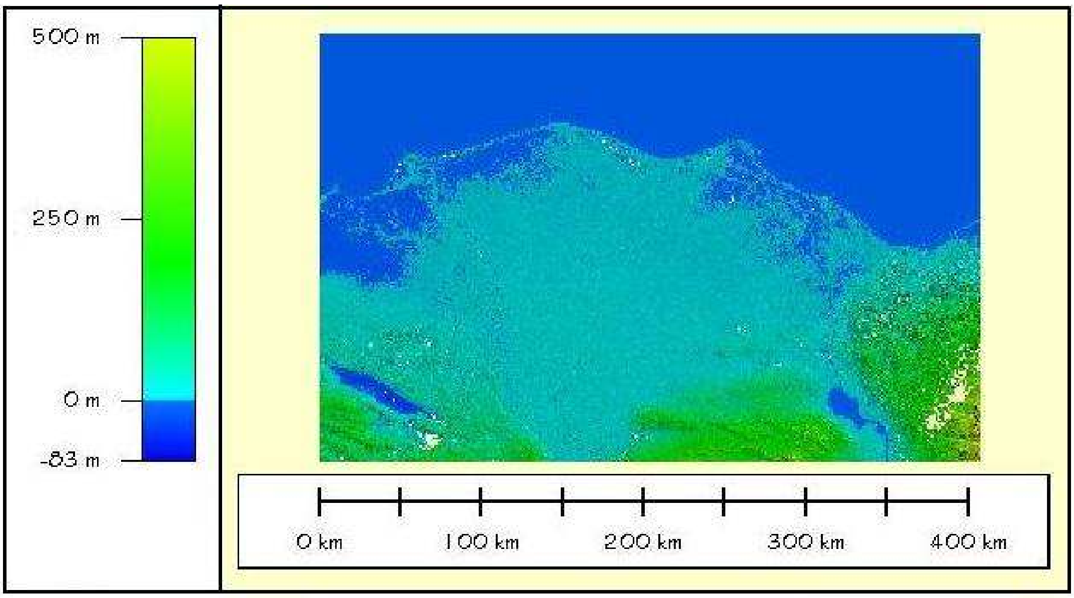

Figure 2: A shaded-relief representation of the study area using the SRTM 3" DEM

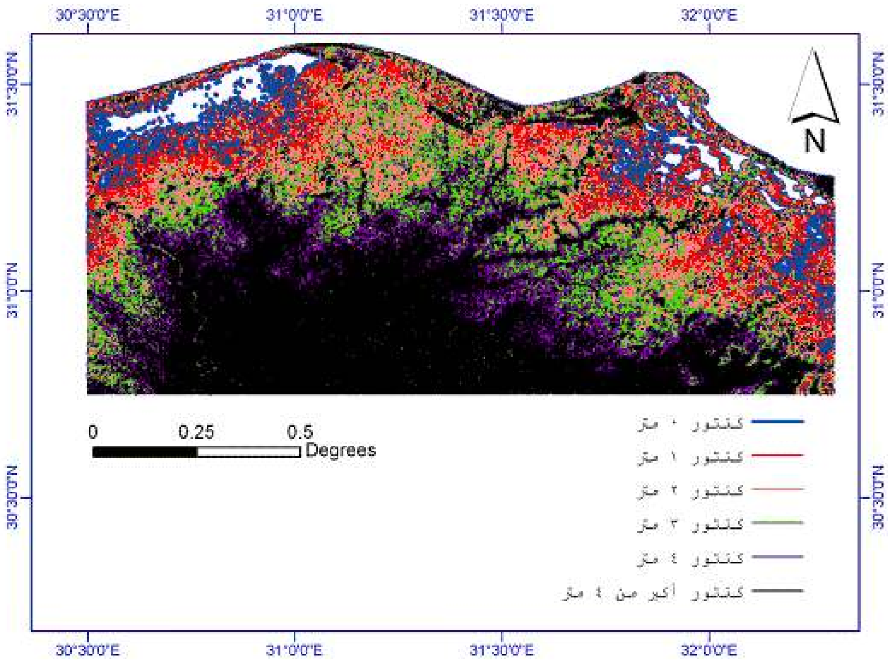

Figure 3: A contour representation of the study area using the SRTM 3" DEM

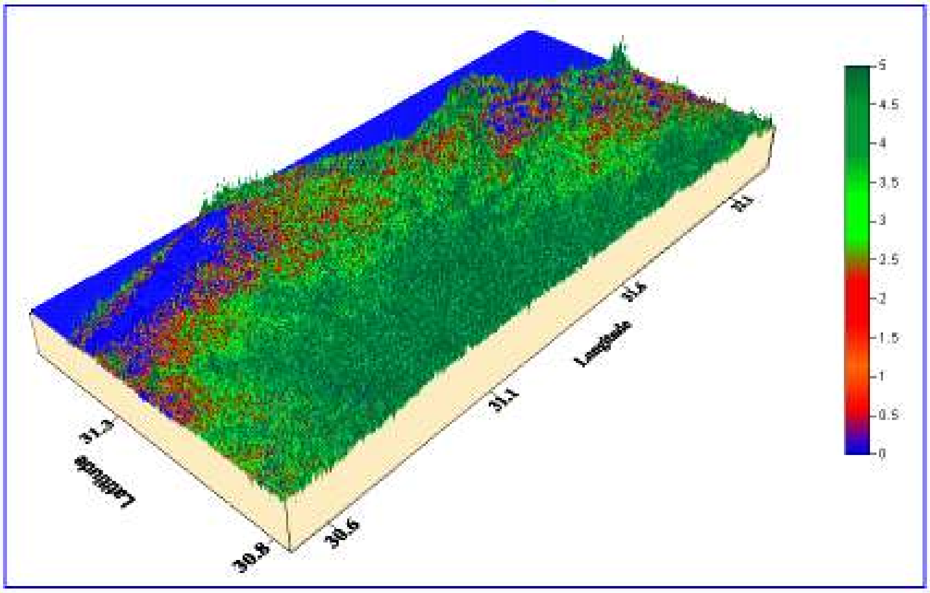

Figure 4: A 3D representation of the study area using the SRTM 3" DEM

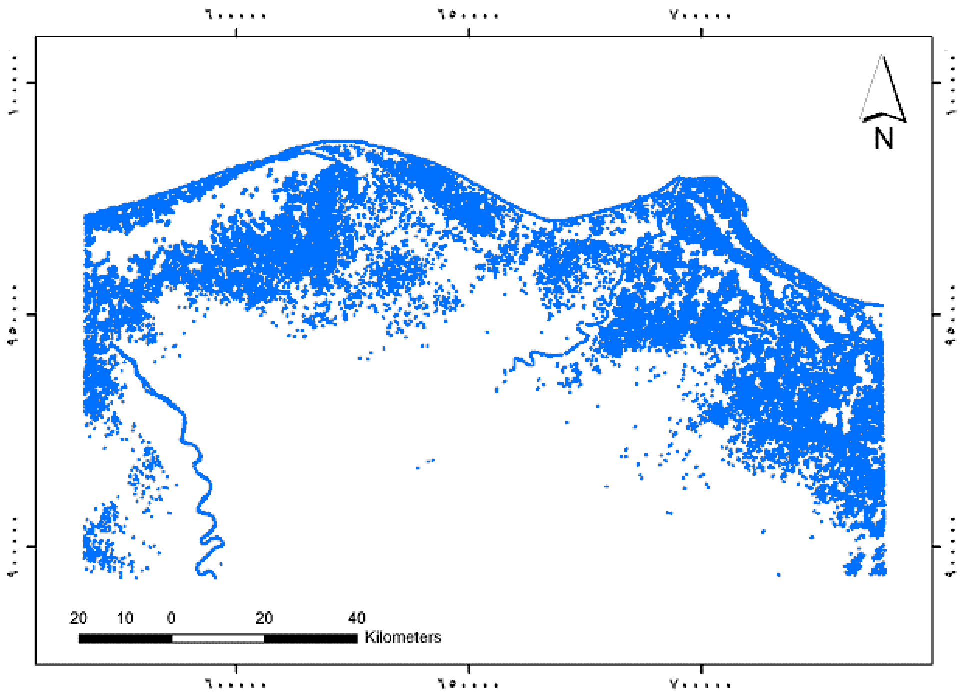

Figure 5: Regions corresponds to zero heights within the study area

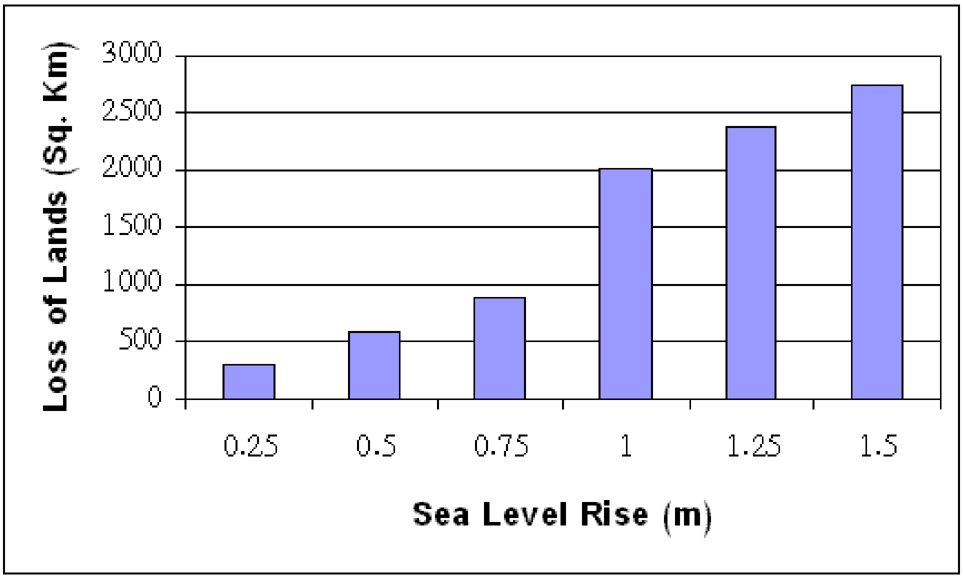

Figure 6: The expected loss of lands under several sea level rise scenarios

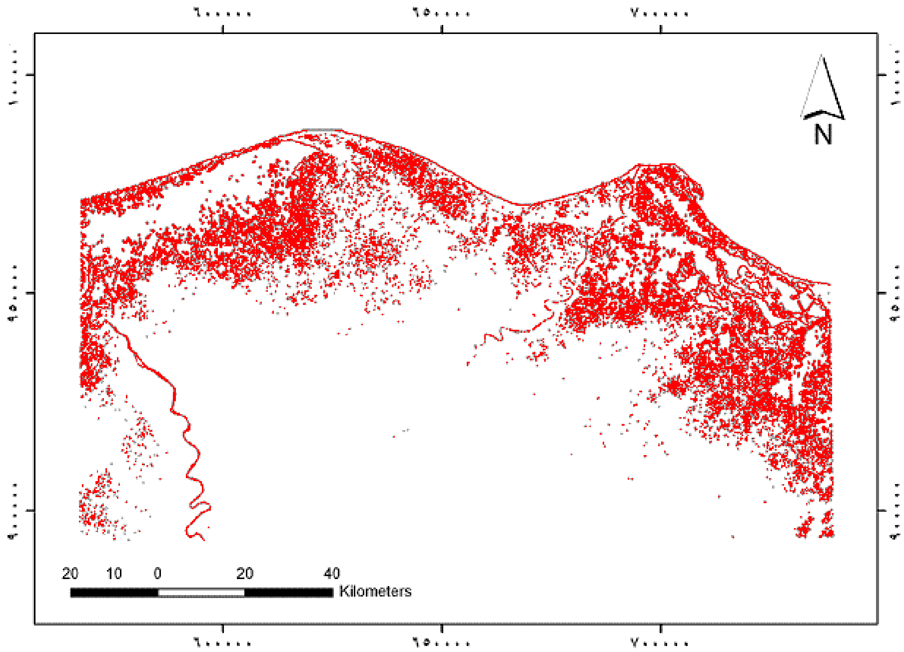

Figure 7: The expected loss of lands corresponds to sea level rise of 0.25 m

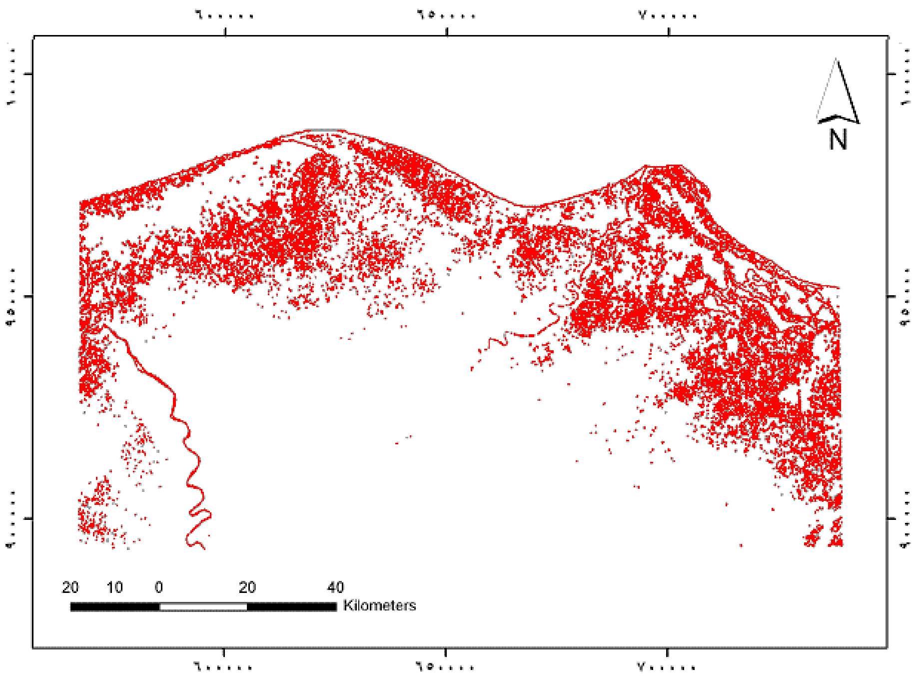

Figure 8: The expected loss of lands corresponds to sea level rise of 0.50 m

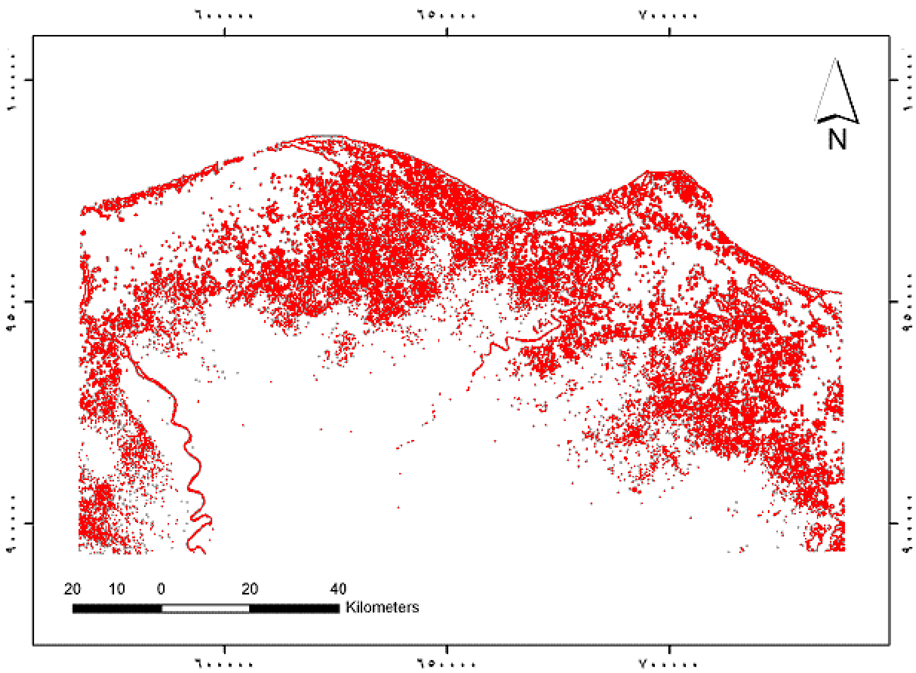

Figure 9: The expected loss of lands corresponds to sea level rise of 1.00 m

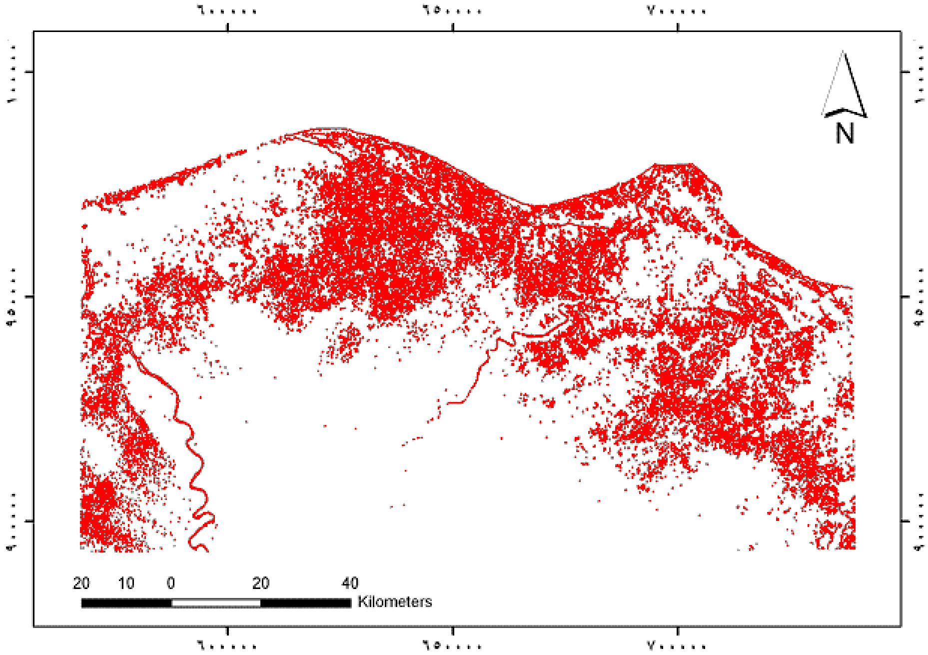

Figure 10: The expected loss of lands corresponds to sea level rise of 1.50 m

تقدير مخاطر ارتفاع منسوب سطح البحر في مصر داخل إطار نظم المعلومات الجغرافية

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الملخص العربي:

تؤدي الظواهر المناخية – ومنها ظاهرة الاحتباس الحراري – لزيادة في منسوب سطح البحر علي المستوي العالمي. أشارت الدراسات و التوقعات العالمية الحديثة لقيم ارتفاع منسوب سطح البحر إلي أن هذه الزيادة قد تبلغ أكثر من متر بحلول عام ٢١٠٠م. يؤدي ارتفاع منسوب سطح البحر إلي عدة مخاطر بيئية منها تراجع الشواطئ وفقد مناطق سكنية خاصة في المدن الشاطئية. يهدف هذا البحث لتقدير و تقييم هذه المخاطر في المناطق الساحلية في دلتا النيل بمصر وهي المنطقة البالغ أبعادها حوالي ١٧٠ × ٩٠ كيلومتر. ولعدم توفر نموذج ارتفاعات رقمي وطني فقد اختبرت الدراسة الحالية أربعة من نماذج الارتفاعات الرقمية العالمية الحديثة لاختيار الأنسب لتمثيل طبوغرافية منطقة الدراسة وذلك باستخدام نقاط تحكم أرضية. ثم مثلت الدراسة أنسب نموذج ارتفاعات رقمي عالمي (ووجد أنه نموذج "SRTM3 ذا القدرة المكانية الأفقية حوالي ٩٠ متر) في إطار نظام معلومات جغرافي مكونا من ٢٢٠٦٣٨١ نقطة. تم دراسة عدة سيناريوهات لارتفاع منسوب سطح البحر تتراوح بين ٠.٢٥ متر إلي ١.٥ متر ، ووجد أن مساحة المناطق المعرضة للغرق تتراوح بين ٢٩٢ إلي ٢٧٣١ كيلومتر مربع. كما تم تمثيل التوزيع المكاني لهذه المخاطر في كل سيناريو متوقع لتطوير خرائط رقمية للمناطق المهددة. أثبتت نظم المعلومات الجغرافية فعالية هائلة ومميزات تقنية كبيرة في مثل هذا النوع من الدراسات البيئية. توصي الدراسة بأخذ النتائج – التي تم استنباطها – في الاعتبار بواسطة متخذي القرار في وضع خطط تنمية المناطق الساحلية في مصر.

كلمات مرجعية: نظم المعلومات الجغرافية ، ارتفاع منسوب سطح البحر ، نماذج الارتفاعات الرقمية، التأثيرات البيئية ، مصر.