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Evaluation of River Nile High Flood Effects by Geographic Information System

ABSTRACT

River Nile is subjected to different floods with considerably high variations ranging from very low to very high floods. Even though low floods yield some side effects on the availability of water resources, low water levels, and navigation problems, high floods have many other critical outcomes. Recently, River Nile floods have relatively increased, which causes quite high water level upstream the High Aswan Dam. It is a matter of fact that construction of the High Aswan Dam, in 1968, has played a significant role in preventing downstream flooding. However, considerable floods have been recorded after the construction of the dam; such as the floods of 1998/1999 and 1999/2000. Therefore, it is extremely important to prepare the main Nile and its two branches for passing high releases more than the maximum current releases. This study evaluates the impacts of high water releases on the Nile water levels and bank line (terrace line) through a GIS application. A one-dimensional computer model program has been developed, by the authors, to compute water surface profiles along any river reach and, then, passes the results to a GIS package for further detailed analysis. The study area constitutes the fourth reach of the River Nile, which extends from Asyut Barrage to Delta Barrage with a length about 410 Km. The achieved results showed that the entire lands behind the high bank, at this computed discharge, are safe against flood threats, while the low lands between the terrace and channel lines need to be developed. It has been concluded that GIS is quite an effective tool in analyzing such a hazardous scenario, produces valuable pieces of information for decision makers, and also presents guidelines for development planes.

Key Words: Nile River, Water Resources, Floods Impacts, GIS

1. INTRODUCTION

River Nile is considered a very unique river since it is one of the longest rivers in the world (about 6500 kilometers long) and its discharge is very limited compared with its length (Figure 1). River Nile flood has a very great variation due to the different characteristics of the Nile Basin. The Nile flood can be as high as 150 billion cubic meters per year (year 1878/1879) and as low as 42 billion cubic meters per year (year 1913/1914). Both extreme cases, very low and very high, floods have their own side effects. While the low floods have their own consequences such as of water supply un-sufficiency, navigation difficulties, and some local sedimentation problems, high floods produce very important side effects. Some of these impacts are the flooded areas, their effects on river banks, beds an hydraulic structures. River Nile is divided into different reaches between main hydraulic structures. The river length between down stream Old Aswan Dam to upstream of Delta Barrage is divided into four reaches according to the major hydraulic structures such as Old Aswan Dam, Esna Barrage, Naga Hammadi, Assiut Barrage, and Delta Barrage. The fourth reach located from Assiut Barrage to Delta Barrage is selected to be simulated during this study. The fourth reach length is about 410.00 kilometer length from kilometer 544.00 down stream Aswan Dam (Assiut Barrage) to kilometer 954.00 down stream Aswan Dam (Assiut Barrage). This reach is selected since it has suffered from many human interventions and its banks are relatively low compared with other reaches and it contains many populated islands.

The utilization of Geographic Information System (GIS) and Remote Sensing technologies has been spread in water resources management in the last two decades. GIS models can help people understand the problems they are facing and help stakeholders to make decisions. It can be an important tool of communication and sharing knowledge, attributes which are now of high interest to international organizations. For example, in 1998 the United Nation Environmental Program (UNEP) started a project on water sharing in the Nile River basin. This project was set up to prepare an experimental methodology to identify the potential water-related issues in a watershed. Its first stage consisted of the compilation of available geo-referenced data sets for the Nile valley region to be used as inputs for water balance modelling, where these geo-referenced data sets have been stored in Arc/Info-ArcView environment [UNEP, 2000]. In Egypt, several researches have highlighted the role of GIS in a wide range of applications within the context of integrated water resources management [e.g. Yakoub and El-Kady, 1998, and Dawoud et al, 2005]. Moreover, the Nile River's flood management issue, has been investigated by many researchers [e.g. El-Sersawy et al, 2003] presenting approaches for producing digital floodplain maps, where GIS was used in the development of the base map imagery, redefinition of floodplains, manipulation of data, development of metadata, and the production of map panels.

2. OBJECTIVES

The objective of this paper is to study the effect of high floods on River Nile banks and islands using the most available recent techniques and data. Numerical model is developed and utilized, and selected study area' maps and Geographic Information Systems (GIS) have been used to identify areas subjected to flooding. Two flood values, for this study, were selected: the maximum future discharges, and the emergency flood of 7000 cubic meters per second, to indicate the effect of these damaging floods on a populated area.

3. MATERIALS AND DATA

Conventionally, three factors have to be analyzed in investigating the floods' harmful influences. These factors include: floodplain geometry (topography), flood discharge (hydrology), and flood stage (hydraulics). Topographic data describe the geometry of the physical system while hydraulic data are used to establish model boundary conditions, and to calibrate and test the model.

Figure 1. shows the Nile River and its selected fourth reach. For this specific area, many data are required. Some actual measurements were required to be able to calibrate the model. The particular inspected flow has never passed since the construction of the High Aswan Dam during the sixties. Hence, the measured records of the gauging stations for the period before the construction of the High Aswan Dam have been utilized. In order to study the flood effects on a populated area, a populated island (namely the Quarateen Island) has been chosen. This island has many buildings and factories and some other buildings. The island area is about 2 squared kilometers with a length of 3.8 kilometer.

4. PROPOSED MATHEMATICAL MODEL

Mathematical models are used to predict water levels for different flood conditions. For the current research, a mathematical model was derived based on solving the flow equations to compute water levels corresponding to different discharges. This model was developed, by the first author, using the Fortran computer language. Details of the computations are presented in the next sub-section.

Water Surface Profile Computations

Water surface profile computations for the developed model are based on solving the energy and the flow equations. The energy equation is described as follows:

$$\frac{V_1^2}{2g} + Y_1 + S_o \Delta L = \frac{V_2^2}{2g} + Y_2 + S_f \Delta L ....(1)$$

Where:

V_1	=	Average velocity at section (1)
V_2	=	Average velocity at section (2)
Y_1	=	Water depth at section (1)
Y_2	=	Water depth at section (2)
S_o	=	Bed slope
S_f	=	Energy slope
ΔL	=	Distance between sections (1) and (2)

The Manning flow equation is described as follows:

$$Q = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} A ....(2)$$

Where:

Q	=	Flow discharge,
n	=	Manning roughness,
R	=	Hydraulic radius (A / P),
S	=	Energy slope,
A	=	Cross sectional area, and
P	=	Wetted Perimeter.

The energy equation is solved numerically using Standard Step Method iterative procedure [Chow, 1957] The downstream boundary condition is pre-determined from the actual measurements and the water surface profile computations are processed from downstream to upstream.

5. MODEL CALIBRATION

The model calibration is a very essential task in any mathematical model computations. The first step for the model calibration is to determine the actual measurements related to the analyzed discharges at the gauging stations. Different gauging stations along the reach are used for this calibration water. These gauging stations are shown on Table 1.

The measured water levels related to the studied discharge (7000 cubic meters per second) are used for the selected gauging station and they are shown in Table 2 [NRI, 2007].

Table 1. Selected water level gauging stations.

No.	Site Name	Km
R4-1	Ds Assiut	544.78
R4-2	Maaabda	576.2
R4-3	Mandra	612.1
R4-4	Menia	687.55
R4-5	Fadl	735.25
R4-6	Beba	789
R4-7	Baniswafe	808.6
R4-8	Korimate	839.1
R4-9	Lethy	873.7
R4-10	Eksas	887
R4-11	Roda	927
R4-12	Usdelta	953

Table 2. Recorded levels for elected water level gauging stations.

Site Name	Km	Water Level
Ds Assiut	544.78	51.65
Maaabda	576.2	49.01
Mandra	612.1	45.71
Menia	687.55	39.26
Fadl	735.25	35.00
Beba	789	30.57
Baniswafe	808.6	28.98
Korimate	839.1	26.34
Lethy	873.7	23.69
Eksas	887	22.57
Roda	927	19.50
Usdelta	953	17.58

6. ACOMPLISHED RESULTS AND ANALYSIS

The model calibration and results are depicted in Figure 2. This figure shows the model results compared with the measured water levels for the selected discharge of 7000 cubic meters per second. It can be concluded, form this figure, that predicted simulation is very close to the measured data and the simulated results can be used for further analysis. Figure 3 shows the water level for the whole fourth reach of the River Nile, and the study island is highlighted. It can be concluded, from this figure, that the water level due to the emergency discharge is estimated by 18.00 m at the southern end of the island and 17.72 m at the northern end of the island.

The ArcGIS software has been utilized to build a GIS for flood impacts of the study area. Digital topographic and cadastral maps have been incopröprated in this system. Additionally, the attained flooding results have been diplayed as a specific layer. Comprehensive GIS analysis, through merging, intersecting and buffering GIS tools, shows a very alarming result indicating that almost the whole island is subjected to flooding due to this condition. The detailed map of the study island is shown in figure 4. These findings can be confirmed by reviewing the levels on the study area map and similar conclusion can be reached that almost the whole island will be flooded during the emergency flood conditions. From this map, it is clear that the island contains houses, different types of buildings and even some factories.

Maximum future discharges

During the previous analysis it was shown that the whole study island is subjected to flooding under emergency discharge. However, the emergency discharge is a very rare event and extreme damages could be expected during this condition. The emergency flood is only considered in Egypt for hydraulic structures. The evaluation of flooded lands in Egypt is usually performed using the maximum future discharges. The maximum future discharges in Egypt are estimated by the flood of 350 million cubic meters per day which is equivalent to 4051 cubic meters per second. These discharges are used also to define the management lines for the river. Terrace line for the river bank is defined by the line that allow to pass a flow of the maximum future discharges and it is the line of slope change of the bank. Hence another analysis step has to be carried out.

Model results for the maximum future discharges

The model results for the maximum future discharges are obtained, and being analyzed. From the model results, it has been found that the water level due to the maximum future discharge is estimated by a level equals 16.68 m at the southern end of the island and 16.46 m at the northern end of the island. Furthermore, these results have been added, as a new layer, to the developed GIS of the study area. The comprehensive examination shows that the island is safe from flooding higher than the previously defined terrace line. So it can be concluded, for this part of the research, that the study area is safe from flooding for areas with levels higher than the terrace lines. The narrow strip located between the terrace line and the water level is subjected to overtopping and under any condition, no buildings should be allowed in this strip.

7. CONCLUSIONS

The effects of high floods on River Nile banks and islands have been investigated. A numerical model was developed, by the first author, and utilized to compute and analyze the water levels related to the studied discharges. The model calibration procedure shows close computed results compared with the measured data. A study area has selected in this research to evaluate the effect of very high floods. This area consists of an Island located in the fourth reach with a length of 3.8 km and an overall area of about 20 squared km. The current emergency flood (a very rare event) was simulated by the model and the results were applied to the study area using GIS. The analysis results show that almost the whole island will be flooded during emergency flood. Another scenario has been also considered in this analysis, which is the maximum future discharges. The attained results correspond to the maximum future discharges show that the study area is safe against flooding higher than the terrace lines. More detailed analysis is recommended for the whole length of the river.

GIS utilization in such kind of studies related to water resources management is greatly valuable in capturing and communicating a great amount of information in a digital environment. A fundamental role of working in digital forms is that it allows the floodplain data to be easily incorporated with several other digital data types, such as digital orthophotos and GIS coverage of infrastructure, buildings, and land parcels. It has been concluded that GIS is quite an effective tool in analyzing such a hazardous scenario, produces valuable pieces of information for decision makers, and also presents guidelines for development planes.

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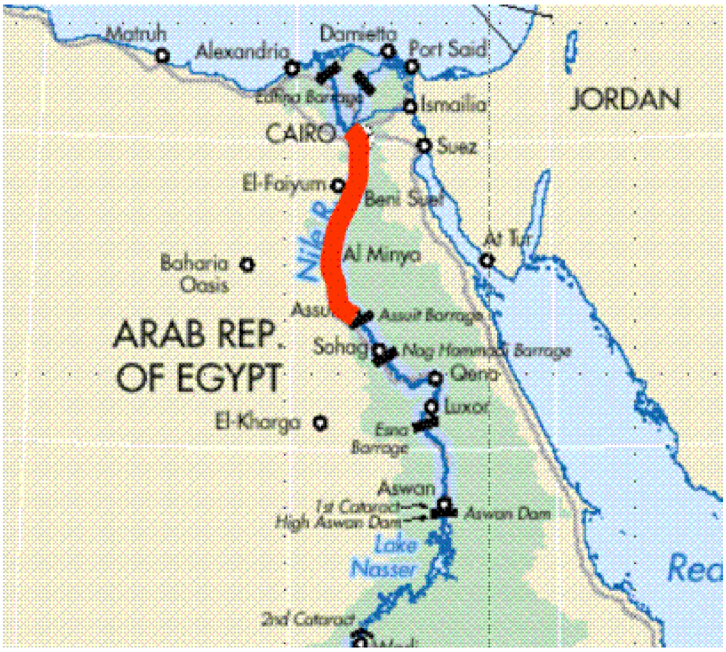

Figure 1: The River Nile Map

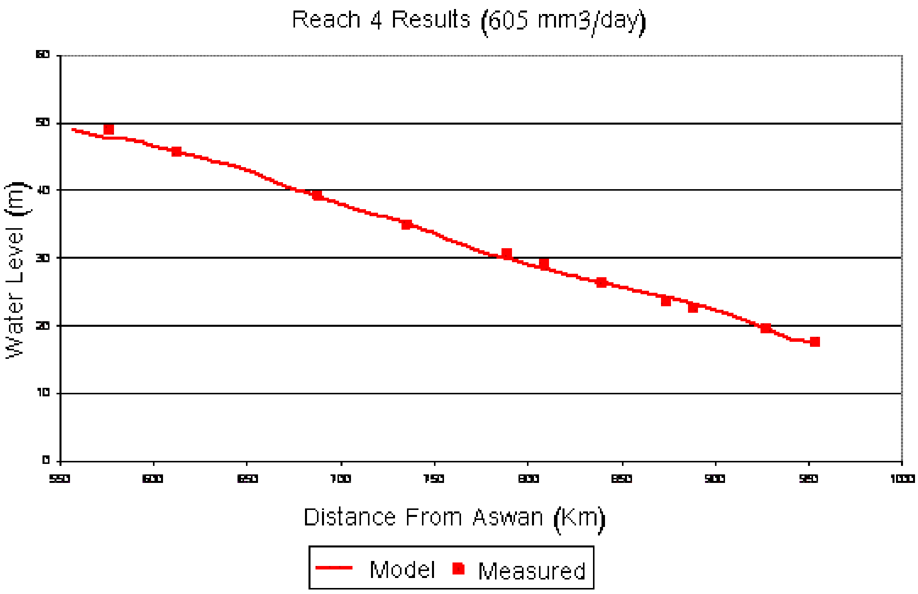

Figure 2: Model calibration and results

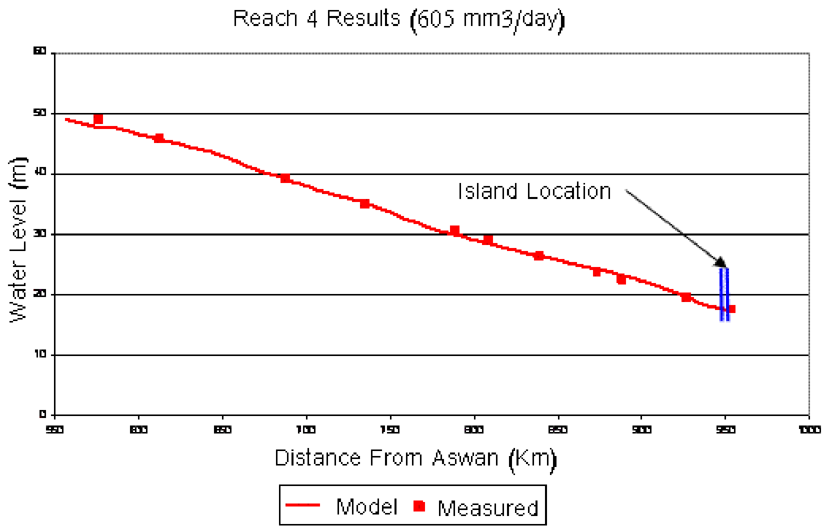

Figure 3. Model results for the study island

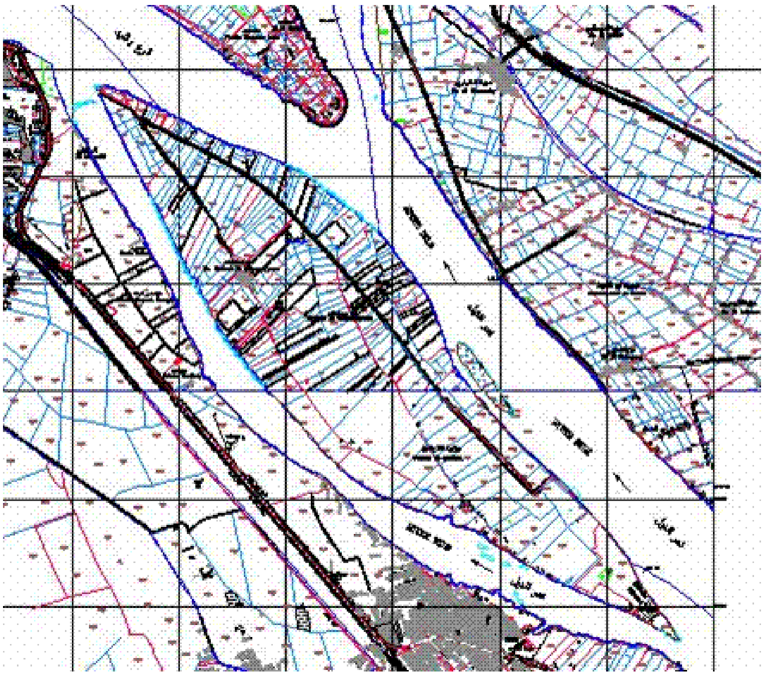

Figure 4: Map of the selected island