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GIS-Based Hydrological Modeling of Atbara Area, Sudan

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Abstract

In this paper the authors discuss the digital elevation model based arc GIS applicable for automatic generation of input data needed by hydrological models. The digital elevation model was visually inspected to study the general characteristic of the geomorphology of Atbara area. Firstly the digital elevation data was mosaicked using Global mapper10 and saved as DEM format, it has to be cleared from errors such as sink which was filled-in and prepared for standard hydrology usage. The digital elevation model was used as input data to Arc GIS software to create the surface analysis (hill shade) and then used the hydrology under the spatial analyst to delineate the hydrological models such as flow direction and flow accumulation. From flow accumulation image the surface drainage network is extracted. Finally the authors used kriging method to interpolate the depth to the groundwater table level from borehole data in the study area. This paper clearly demonstrates the use of digital elevation models to create hydrological model in Atbara area. The model shows weak zones around the River Nile and Atbara River that are vulnerable to physical and climatic hazards.

Keywords

Atbara, Digital Elevation Model, Hydrologic Models, Boreholes Data, Earthquake

1. Introduction

Hydrologic models are simplified conceptual representation of a part of the hydrologic cycle. They are primary used in surface water management and ground water recharge processes. Hydrologic response to earthquakes was also investigated by many researchers.

Generally the occurrence of liquefaction depends on many factors, such as earthquake magnitude, shaking duration, peak ground motion, depth to the groundwater table, basin structures, site effects, and liquefaction susceptibility of sediments (Youd, 2003).

One of the most spectacular surface hydrologic responses to earthquakes is large changes in stream flow. Because stream flow responds to precipitation in the drainage basin, earthquake-induced changes are best recorded and studied during the dry season or during dry periods when there is little or no precipitation. Explanations for changes in stream flow can be divided into five categories: expulsion of deep crustal fluids resulting from coseismic elastic strain (Muir-Wood and King, 1993), changes in near-surface permeability (Briggs, 1991) consolidation or even liquefaction of near-surface deposits (Manga, 2001; Manga et al., 2003; Montgomery et al., 2003), rupturing of subsurface reservoirs(Wangetal.,2004c).

The water level in wells measures the fluid pressure at depths the well is open to the surrounding formations. Several types of coseismic and postseismic responses are observed: water-level oscillations coseismic changes in water level, and delayed changes in water level.

Water wells can act like seismometers by amplifying ground motions, in particular long-period Rayleigh Waves. Water-level fluctuations as large as 6m (peak to- peak amplitude) were recorded in Florida, thousands of kilometers away from the epicenter, during the 1964 Alaska earthquake (Cooper et al., 1965).

An earthquake cause strain and strain changes fluid pressure and alters hydro geologic properties such as permeability, which controls the rate of fluid flow. And so the seismic waves cause spatial variations in strain and hence spatial variations in pore pressure, seismic wave speeds in saturated rocks will thus differ from those in unsaturated rocks.

The main aims of this study are to generate the hydrological models and stream network of Atbara area and determine vulnerable zones to earthquakes based on physical characteristics of the model.

The study area is located in the River Nile state, It is located between latitudes 16˚ 10` to 18˚ 10` N, and longitudes 33˚ to 34˚ 30` E. The area lies about 300 km approximately, north of Khartoum. The area belongs to the desert - semi desert climatic regime. Geologically the study area is consisting of superficial deposits, Umm Ruwaba formation, Cainozoic volcanic (baslt), Hudi chert formation, Nubian sandstone formation and Precambrian basement complex rocks (Whiteman, 1971). The main hydrological features in Atbara area is the River Nile and River Atbara beside the other seasonal khors such as khor Hudi and khor Kenawi on the northern bank of River Atbara.

Atbara region is one of the most important areas of the country since a lot of industrial plants are located within this region. Numerous earthquake events are observed in and around the state fig (1) revealed that most of the earthquake activity concentrated near the streams and khors in the study area. Therefore the present generated hydrologic model will thus enable the delineation of the most vulnerable areas.

2. Data

The present study is based on different types of data such as remotely sensed digital elevation model (90 m grid) obtained from the SRTM (USGS) and provided by the Remote Sensing and Seismology Authority of the National Center for Research, Sudan. The depth to groundwater table level (boreholes data) was obtained from the Arab Authority for Agricultural Investment and Development report (2006) while the seismicity data was obtained from International Data Center Catalog (ISC), UK.

3. Material and Methods

Analysis of data include mainly, the digital elevation model, was performed using global mapper and ARC GIS software. Performance and reliability of hydrological models are highly dependent on the quality of terrain elevation representation, in terms of accuracy and resolution. Most physical processes (such as surface flow depend on terrain slopes, sun exposure and absolute terrain height. The methodology of DEM creation is too complex (USGS). However, the authors are convinced that the used DEM is of reasonable quality and resolution for the purpose of the study. For representation of the terrain heights in digital form, a number of techniques can be used. The DEM were visually inspected to study the general characteristics of the geomorphology of the study area. Firstly the digital elevation data was mosaicked using (Global mapper10) and saved as dem format. The digital elevation model (DEM) data was used as input data to Arc GIS software to create the surface analysis (hill shading and then the spatial analyst was used to delineate the hydrologic models such as flow direction, flow accumulation, stream net work, stream link and stream order. Also kriging interpolation method was used in the current study to interpolate the depth to groundwater table level from boreholes data.

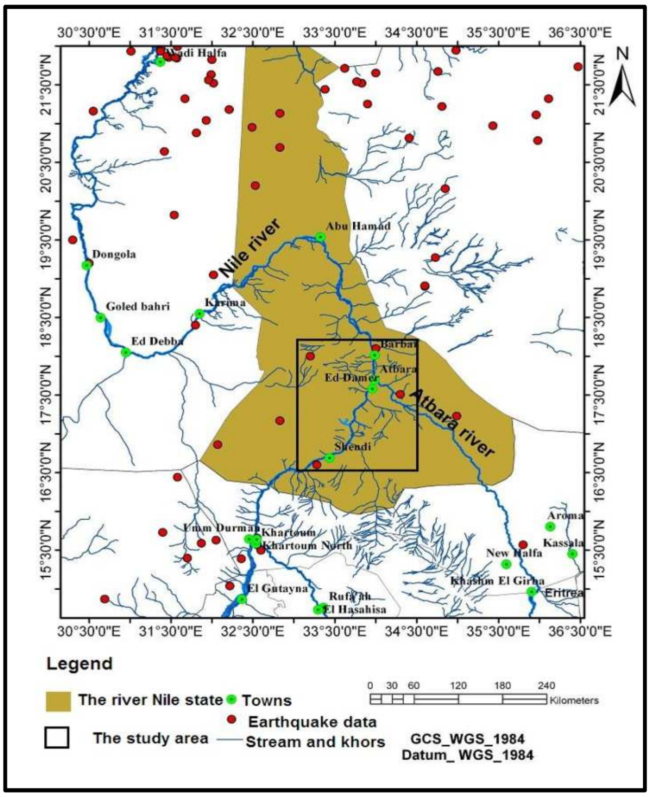

Fig. 1. Reveals the seismic activity in and around the study area.

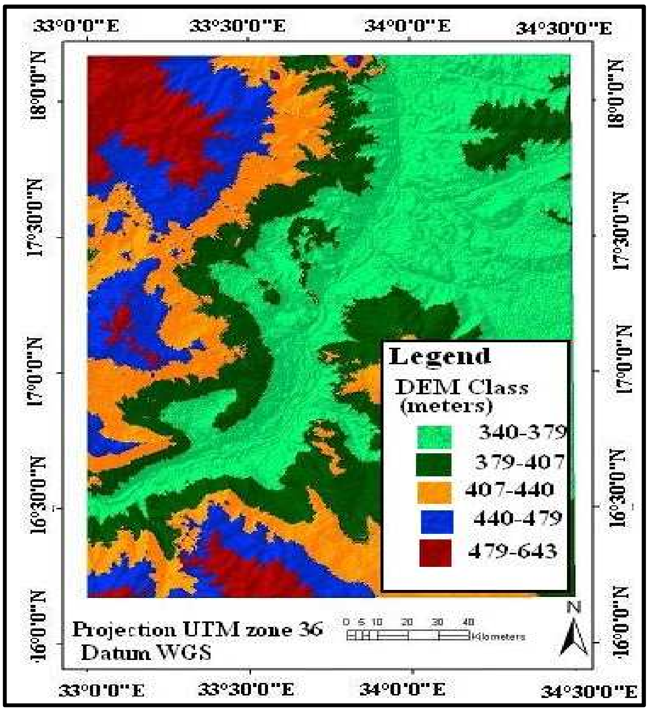

Fig. 2. Represents digital elevation model of the Study area.

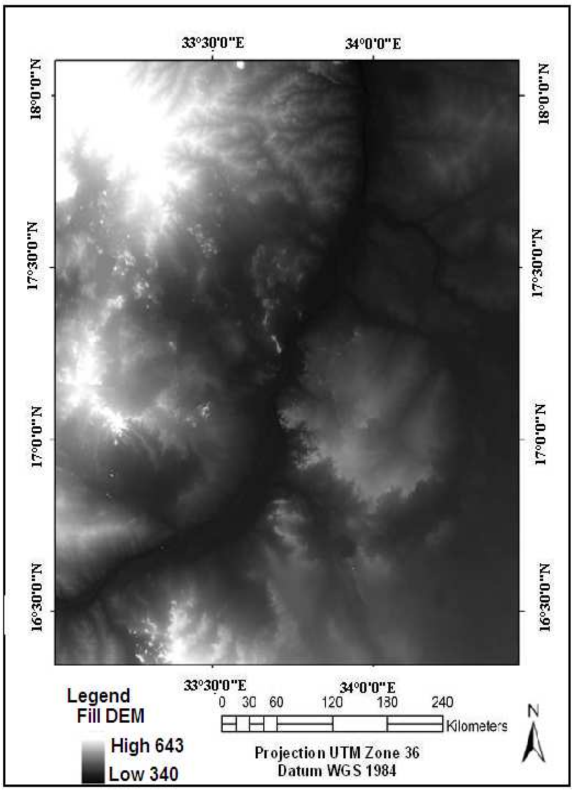

Fig. 3. The digital elevation model after filling sinks.

4. Result

Generally, the River Nile has a watershed extending into a very large region from Sudan into Egypt and running from south to the north. The watershed of the River Nile is defined by the area upstream from its outlet. But the River Nile has many tributaries such as River Atbara which is running from southeast to the northwest and meets the River Nile in Atbara town and other Khors which have the same flow direction of Atbara River are scattered in the study area. As an example of DEM fig (2) present the topographic features of Atbara area, where the area was classified into five classes described as follow (340-379, 379-407, 407-440, 440-479 and 479 to 643 m) above sea level.

Fig (3) explains the digital elevation model after sink filling, it indicates the lowest elevation in the study area is 340m and the highest elevation is 643m. Fig (4) shows the flow direction of the study area where the cells flowing to the north are displayed in yellow color, the cells flowing to the south are displayed in red color, the cells flowing to the east are displayed in dark green color, the cells flowing to the west are displays in light green color, the cells flowing to the northeast, the northwest, south east and southwest are display in brown, pink, blue and violet respectively. The obtained results were accordance with the general flow of the Nile River and tributaries.

Fig (6) represents the stream links which explains that the higher links are found in the southern part of the study area reaching 8331 indicating that the overall flow direction of the basin (from south to north). Fig (7) shows the stream orders for the study area where the main stream in the study area is shown in black (order seven) representing the River Nile after Atbara. The River Nile before Atbara and Atbara River have order number six. Generally, the ordering gradient ranges from seven to one.

Close to the Nile River and tributaries, strong relation exists between surface and groundwater. The River Nile and tributaries represent recharge sources to the groundwater. Fig (8) reveals that shallow groundwater level is located in the southern and western parts of the study area, while the deep groundwater level is located in the eastern part of the study area.

Fig (5) reveals the flow accumulation of the study area after filling the sinks of DEM in which the higher flow cells have white color (lighter tone). It is clearly confined to the main streams of the Nile River and Atbara River.

5. Conclusion and Discussions

The digital elevation model (DEM) data contributed greatly in this study to the generation of the hydrological models.

The flow direction, flow accumulation and stream order were obtained in order to anticipate potential seismic risk on regional stream flow. The seismic risk is expected to increase around the streams of higher orders (Nile River and Atbara River) where hydrologic response in the form of post-seismic changes may take place (increase in the amount of stream flow (Wang et al., 2004b).

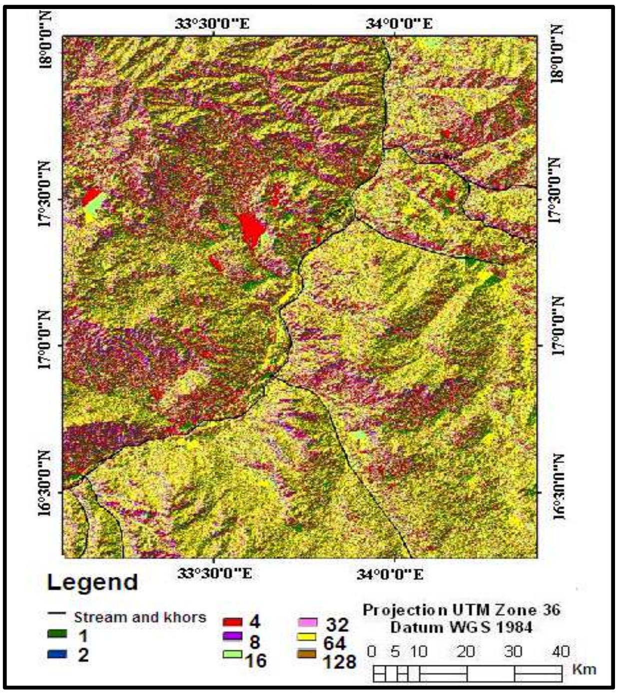

Fig. 4. The flow direction of the study area.

The depth of the groundwater table level indicated that the alluvial aquifers of the River Nile and River Atbara are of shallow depth (5~9m) extending to about 5 kilometers from the River bed. The depth to groundwater table gradually increases with distance away from Atbara river channel being

18 m. Therefore, this region of shallow groundwater depth is probably subjected to high seismic risk. Such risk will cause water-level oscillations in response to coseismic and post seismic changes. Finally, it is conclude that the GIS-based hydrological models were useful for the determination of weak zones in terms of floods, earthquakes, groundwater level rise and other physical and climatic hazards.

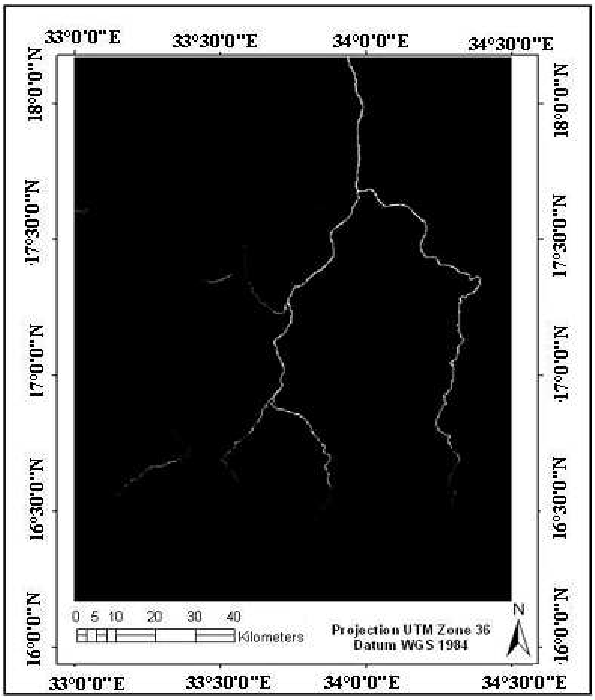

Fig. 5. Flow accumulation of the study area.

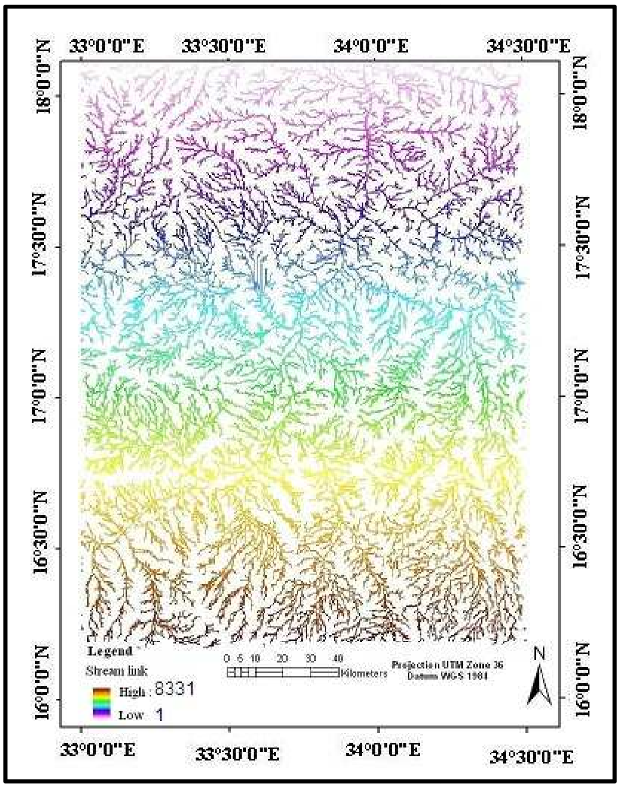

Fig. 6. The stream links of the study area.

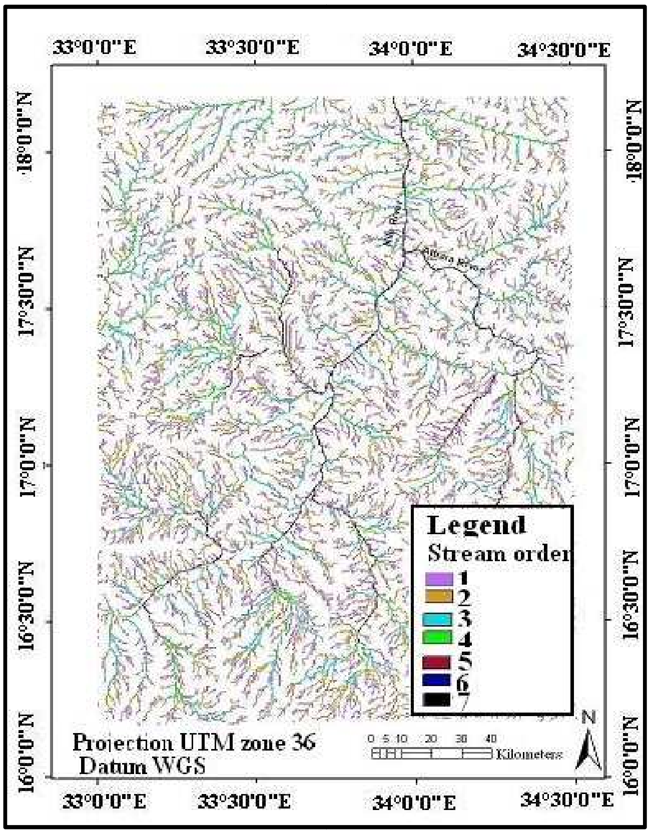

Fig. 7. The stream orders of the study area.

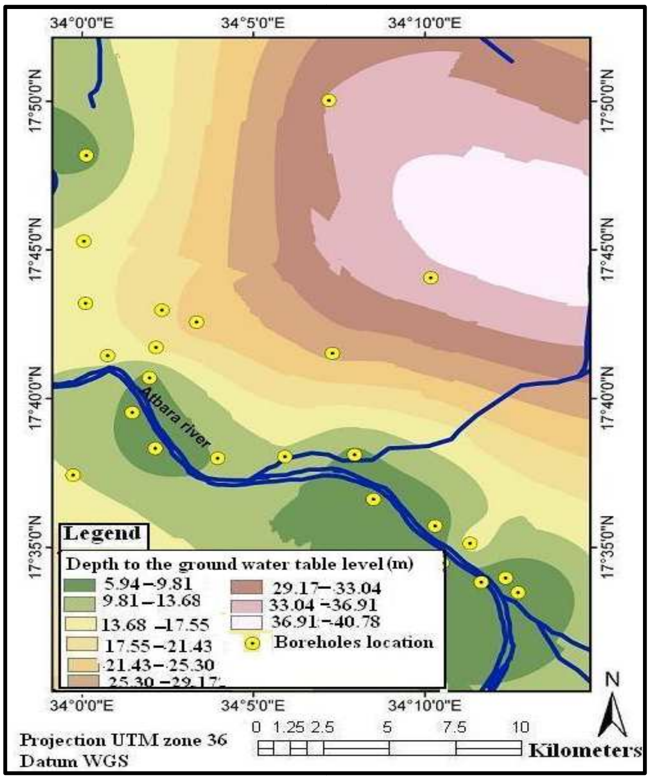

Fig. 8. Depth to groundwater table level in the study area.

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