7th International Conference on Water Resources and Arid Environments (ICWRAE 7): 60-67
4-6 December 2016, Riyadh, Saudi Arabia

Flash Floods Modeling at Wadi Basins in the Eastern Nile Basin: Applications Forwadiel-Assiuti, Egypt and Wadigumara, Lake Tana, Ethiopia

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Abstract: Flash flood is a natural hydrological phenomenon which affects many regions of the world. The behavior and effect of this phenomenon is different from one region to anotherdepending on several issues such as climatology and hydrological and topographical conditions. WadiEl-Assiuti, Egypt as arid environment and Gumara catchment, Lake Tana, Ethiopia, as humid condition were selected for the application. The main target of this work is to simulate flash floods at both catchments considering the difference between them on the flash flood behaviors based on the variability in climate, hydrology and topography. In order to simulate the flash floods, remote sensing data and a physical-based distributed hydrological model, Hydro-BEAM-WaS (Hydrological River Basin Environmental Assessment Model incorporating Wadi System) were integrated. Based on the simulation results of flash floods at the two basins, it was found that the time to reach the maximum peak is very short and consequently the warning time is very short as well. It was observed that the flash floods starts from zero flow in arid environment, but on the contrary in humid arid, it starts from base flow which is changeable based on the simulated events. Such variabilities and behaviors of flash floods provide important information about flash floods characteristics. The model application at Gumara basin shows that the simulated daily flow estimated from hourly simulation agree with the observed estimates. However, the hourly simulation are more reasonable as exhibiting the occurred flash floods. Consequently, some mitigation strategies relying on this study could be implemented by the decision makers in such regions. The proposed methodology can be applied effectively for flash flood forecasting at different arid regions as well as humid regions, however the paucity of observational data.

Key words: Flash Floods ・ Humid regions ・ Physical based models ・ Arid regions ・ Wadi basin ・ Mitigation ・ Egypt ・ Ethiopia

INTRODUCTION

In many countries and regions of the world, flash floods are the most deadly hazards in terms of both loss of human lives and material damage. The main obstacle to study flash flood is clearly the lack of reliableobservations in most of the flash flood prone basins, thus, there is urgent necessity to simulate and forecast flash flood in arid regions. The water demand in such areas increases daily due to population growth, economic development and urbanization, thus, water management using all the available resources is becoming crucial. Furthermore, the danger also comes from the rarity of the phenomenon, which demands a new observation strategy, as well as new forecasting methodology.Various problems associated with forecasting flash floods caused by convective storms over semi-arid basins have been studied by [1], (1994). Rapidly increasing availability of good quality weather radarobservations is greatly expanding our ability to measure and monitorrainfall distribution at the space and time scales which characterize the flash-flood events [2]. Hydrological models of varying complexity approaches are appliedto provide detailed estimates of flow processes for

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ungauged regions [3, 4, 5, 6, 7]. A method for estimating flash flood peak discharge, hydrograph and volume has been presented by Aristeidis andIoannis (2010). Due to the these problems and characteristics of flash floods in arid regions, an efficient integration of using remote sensing data and the distributed hydrological model have been proposed for flash flood simulation in order to understand the characteristics and hydrologicalbehaviors of flash floods. Consequently, proposing the appropriate strategies of mitigation in arid regions as well as flash flood water management to overcome the scarcity of water resources in such regions.

Flooding, as a natural phenomenon is occurring in both arid and humid environments, Ethiopia is one of the countries which is suffering from flooding threat. They have been occurring at different places and times with varying, but often at manageable or 'tolerable', magnitude. In the recent years however, the country has been threatened by quite unprecedented flooding of abnormal magnitude and damage. Much of these flood disasters are attributed to rivers that overflow or burst their banks and inundate downstream plain lands. The torrential rains falling for long days on the upstream highlands cause most rivers to swell and overflow or breach their courses, submerging the surrounding floodplains, which are mostly located in the outlying pastoralist regions of the country.GumaraRiveris one of these prone regions to the flooding effect, especially at the downstream plain area closed to Lake Tana. The river builds up from continuous rainfall on the catchments and local rainfall on the flood plain to result in flooding problems. During the flooding events, people have to live in chest-high water levels for short periods, roads become impassable and communication between affected people gets limited to swimming. In spite of the recurrent flood problem however the existing disaster management mechanism is primarily geared towards strengthening rescue and relief arrangements during and after major flood disasters with no systems to minimize the incidence and extent of flood damage. This necessitates the development of Flood warning decision tools.

Developing the comprehensive physical-based modelsbased on the best available understanding of the physics of hydrological processes of Wadi system is highly recommended [8]. Also, the collaboration research throughout a global network to develop the tools and approaches for wadi flash floods is one of the key factors to overcome their challenges in arid and semi-arid regions as the JE-HydroNet (Japan-Egypt Hydro Network) that developed in kyoto university [9], Thus, the main objectives of this work are: (i) using a physical based hydrological model to simulate the flash floods at arid and humid regions (ii) Using remote sensing data such as GSMaP data of precipitation for this application in order to overcome the challenge of data paucity in both arid and humid catchments, (iii) Determination of the prone areas for flash floods or vulnerability to the hazards and damage in the urbanized regions as trial to reduce the human being loss and damage of their properties and (v) proposing mitigation strategies to reduce the threaten effect of flash floods in such areas.

Methodology and Model Components: Due to the severe problems in wadi system in arid areas, it is important to use distributed hydrological models to understand the runoff characteristics and surface water/groundwater interactions in arid regions. These are challenging studies, with particularly challenging logistical problems and require the full range of advanced hydrological experimental methods and approaches to be applied. A distributed hydrological model in wadi system was proposed. This model is based on the modification of Hydro-BEAM (Hydrological Basin Environmental Assessment Model) which has been chosen for simulation the surface runoff model and estimation of the transmission losses.

A physical-based distributed hydrological model and remote sensing data as well as GIS technique have been used to simulate flash floods in arid regions. Hydro-BEAM (Hydrological River Basin Environmental Assessment Model) which was first developed by [10] and it was also adopted as Hydro-BEAM-WaS (Hydrological River Basin Environmental Assessment Model Incorporating Wadi System) by [11, 12, 13];to be applicable at wadi system in arid regions, then to understand the flash floods behaviors based on a comparative study at different wadi basins (Saber *et al*., 2013). The model of HydroBEAM along with GSMaP [14, 15], remote sensing data was used in this study to simulate flash floods at the target basins. GSMaP was calibrated with Global Precipitation Climatology Center data (GPCC) [16] in order to overcome the lack of observations in such areas.

Hydro-BEAM-WaSconsists mainly of: watershed modeling using GIS technique, surface runoff and stream routing modeling based on using the kinematic wave model, the initial and transmission loss modeling is estimated by using SCS method [17] and Walter's equation [18] and groundwater modeling based on the linear storage model (Figure 1).

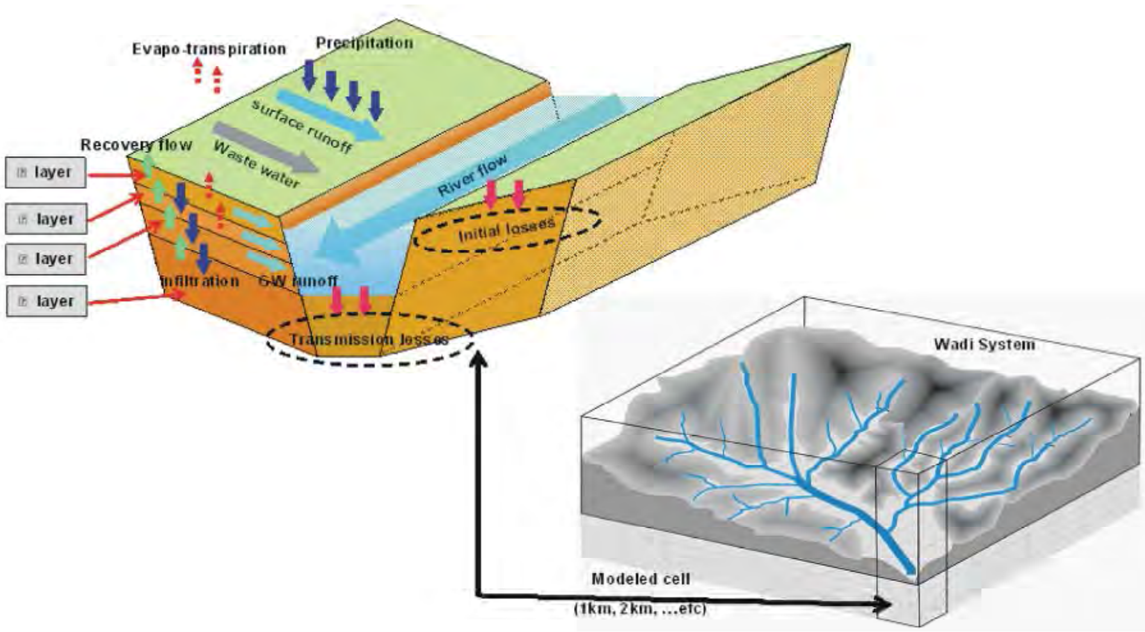

Fig. 1: Conceptual model of Hydro-BEAM (Kojiri 1998, Saber, 2010)

Target Basins

Aridbasin Application: Wadi El-Assiuti in Egypt: Wadi El-Assiuti watershed (Figure 2) is located in the Eastern Desert of Egypt. It is one of the most populous countries in Africa. The great majority of people estimated 80 million people live near the banks of theRiver Nile and in the Nile Delta, in an area of about 40, 000 square kilometers, where the only arable agricultural land is found. Thus, the finding and proposing of new and appropriate regions to overcome the ever-increasing population is urgently needed. Wadi El-Assiutiwatershed is located between Long. 32°30' E& 31°12' W and Lat. 27°48' N & 27°00' S and it is one of sub-catchments of the River Nile.

The total area of Wadi El-Assiuti (Figure 2) catchment is 7, 109 km^2, the perimeter is 496.91 km and the length of the main channel is 165.09 km. Most the area is a desert except some part of urbanization and very small areas of agriculture which are closed to Assiut city along the River Nile Basin. Study area is important due to the propagation of populations and consequently the demand of water resources for agricultural, domestic, social and industrial activities.

Wadi El-Assiuti catchment has undergone a number of improvements over the past centuries, where many of the past studies were applied and many of projects established there due to its importance. Presently, the establishment of new town, which will be in the near future crowded by populations and consequently the importance of hydrological modeling for water resources management and flood threat control, is essential.

Wadi El-Assiuti Simulation: The simulation has been done for the event of November, 1994 at W. El-Assiuti, Egypt (Saber, 2010). Simulation results exhibit that surface runoff hydrographsacting assteep rising and rapid ascending where the maximum peak of discharge is 12.52m3/s (Figure 3). The runoff behaviors arehighly affectedby factors such as the catchment area and slopewhich havea significant effect on the peak of discharge, the time to the peak and the duration of flow.

Slope and elevation have an important role on the flash floods features. At W. El-Assiuti, the maximum elevation is approximately 900m and consequently the slope will be gentle. That reveals the effect of slope on surface runoff where with increasing the maximum elevation and slope, the flow rate will be high. Consequently the surface water will be increased. As well known, the effect of rainfall rate and frequency are very observable as they are the main input resources of water in such regions. The rainfall duration is very short but causing high peak of discharge.

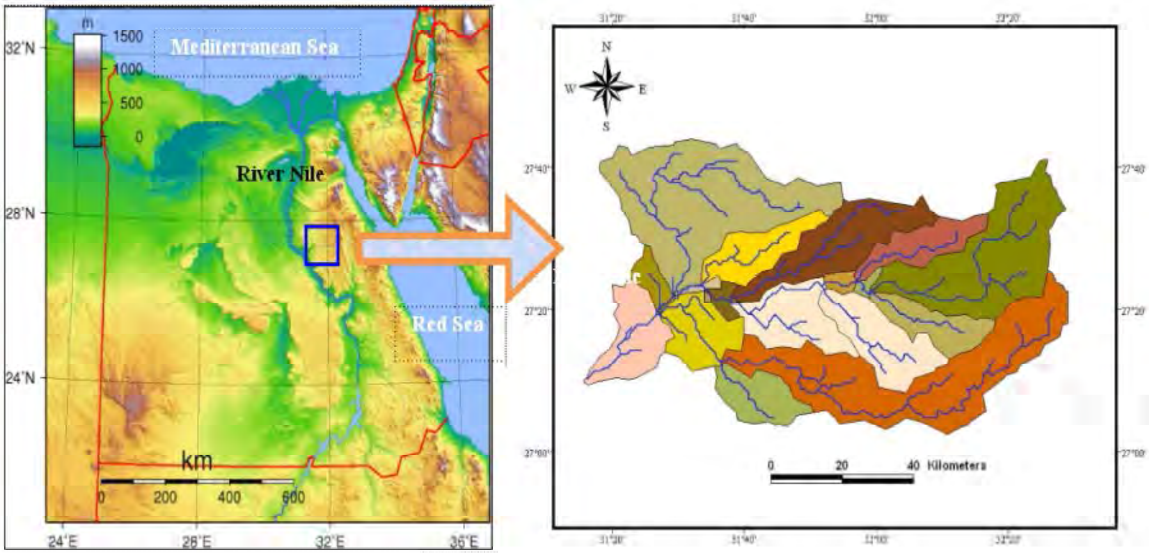

Fig. 2: Location map and watershed catchment of W. El-Assiuti, Eastern Desert, Egypt [19]

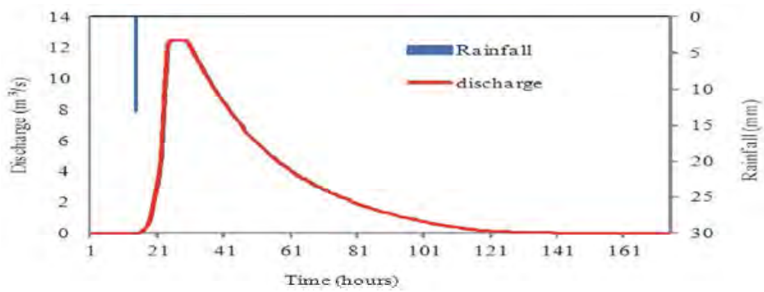

Fig. 3: Hourly hydrograph of simulated discharge in W. El-Assiutifor the flash flood event of Nov. 2-5, 1994 [19]

Humid Basinapplication:gumara Catchment, Lake Tana, Ethiopia

Location Map and Topographical Conditions: The study area is Gumara catchment, which is located in the east of Lake Tana, the area of this catchments is about 1281km^2 (Figure 4). Lake Tana is a fresh water lake and is the source of Abay River (Blue Nile), which is the biggestand the longest river in Ethiopia. Tributaries from the North, East, South and west direction feedthe lake. Lake Tana sub-basin occupies an area of 15, 046 Km^2. Out of this; Lake Tana occupiesan area of 3600 Km^2. The study area lies between 11.5 to 12 North and37.5 to38.5 East. Gumara catchment elevation ranges from 1785 m at Lake Tana up to 3500 m above mean sea level. There is large part of the downstream of Gumra is flat flood areas as depicted in the DEM of this catchment.

The climate of the region is ‘tropical highland monsoon’ with unimodal rainy season between June and September. The seasonal distribution of rainfall is controlled by the northward and southward movement of the inter-tropical convergence zone (ITCZ). Moist air masses are driven from the Atlantic and Indian Oceans during summer (June–September). During the rest of the year the ITCZ shifts southwards and dry conditions persists in the region between October and May. Generally, the southern part of the Lake Tana sub-basin is wetter than the western and the northern parts [20].

The soils in most of the Tana basin are derived from the weathered basalt profiles and are highlyvariable. In low lying areas particularly north and east of Lake Tana is developed on alluvialsediments. The Major Soil Groups characterized by Abay basin master plan study include Euteric Fluvisols, Chromic luvisols, Haplic Luvisols, Euteric Leptosols, Eutericvertisols and Haplcic Nitosols. According to [21], Luvisols are soils that are derived fromvarious volcanic and undifferentiated lower complex rocks. They are common on flat and gentlysloping topography in cooler climates of west Gojam and North Gonder. They are identified incolor as Brown /reddish brown with clay to silty clay texture. These soils are Friable to firm, sticky and slightly plastic. Land use condition of the area is dominated by cultivated land while, there is some grassland andshrub land north of Yifag and Addis Zemen.

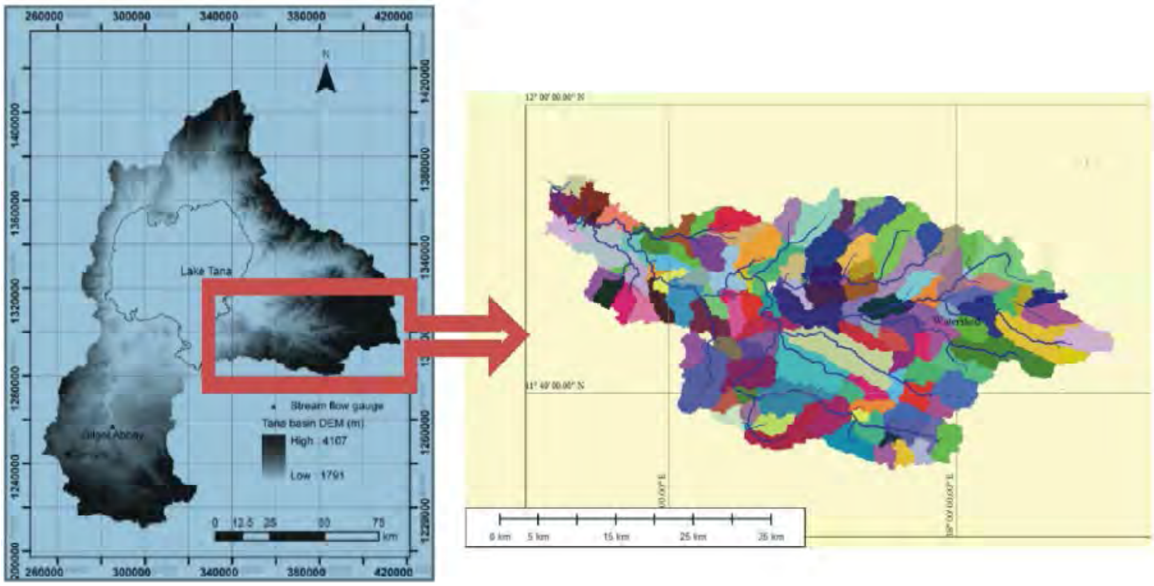

Fig. 4: The location map of Gumara catchment, Lake tana, Ethiopia

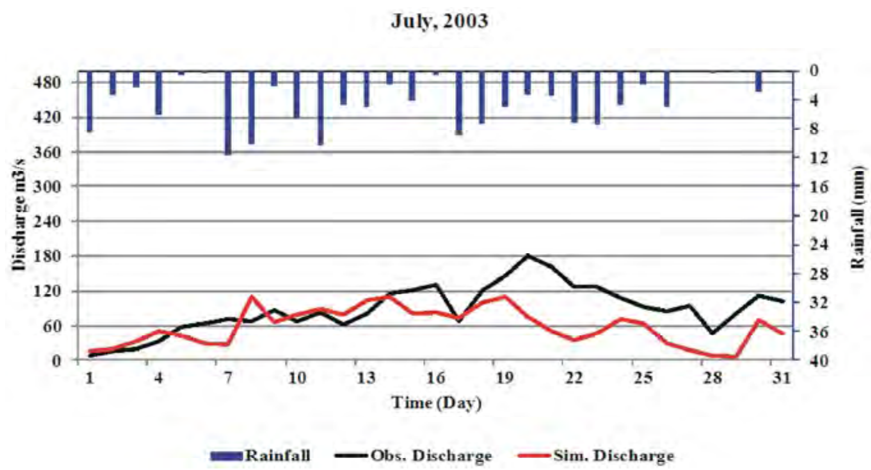

Fig. 5: Calibration results of daily discharge of July, 2003

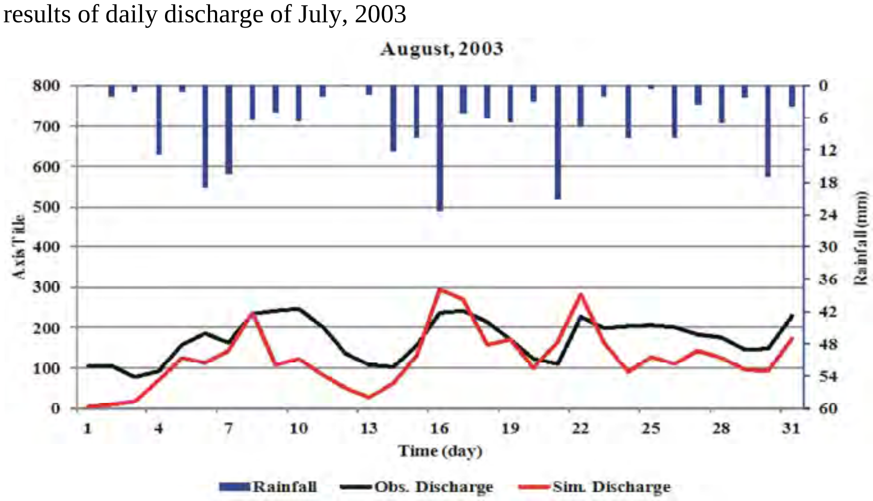

Fig. 6: Calibration results of daily discharge of August, 2003

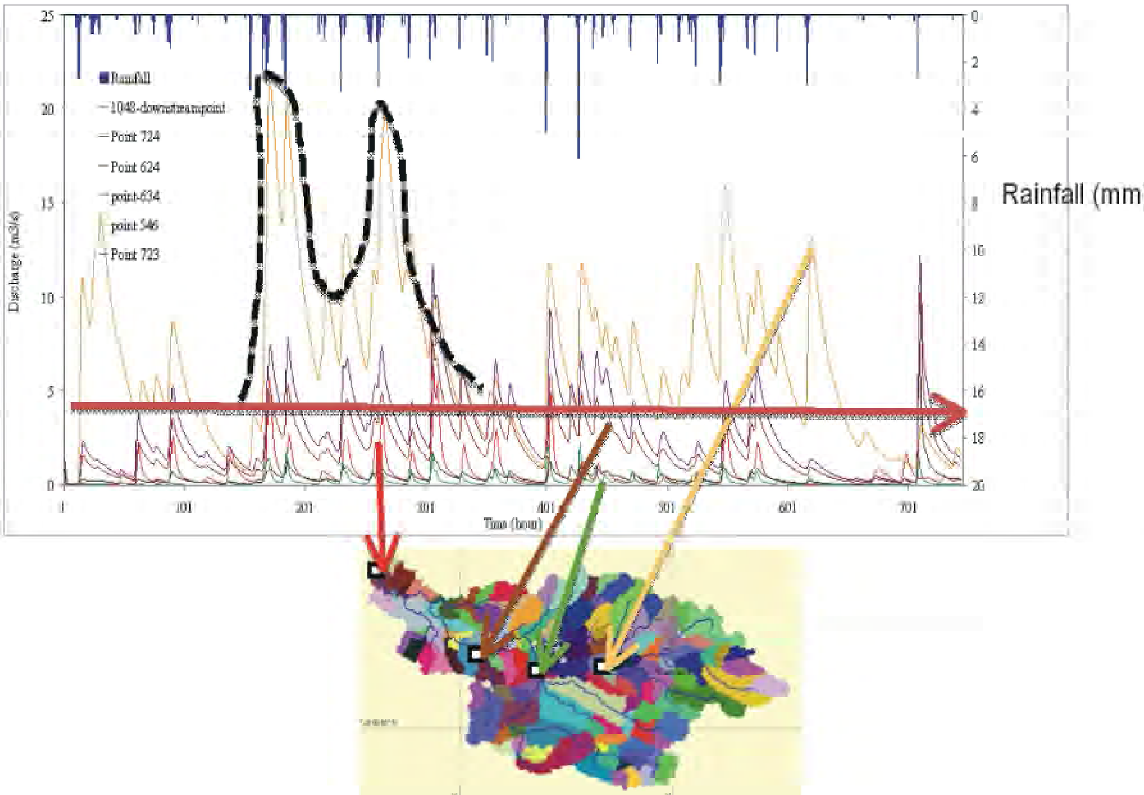

Fig. 7: Calibration results of the rainy events of July 2003

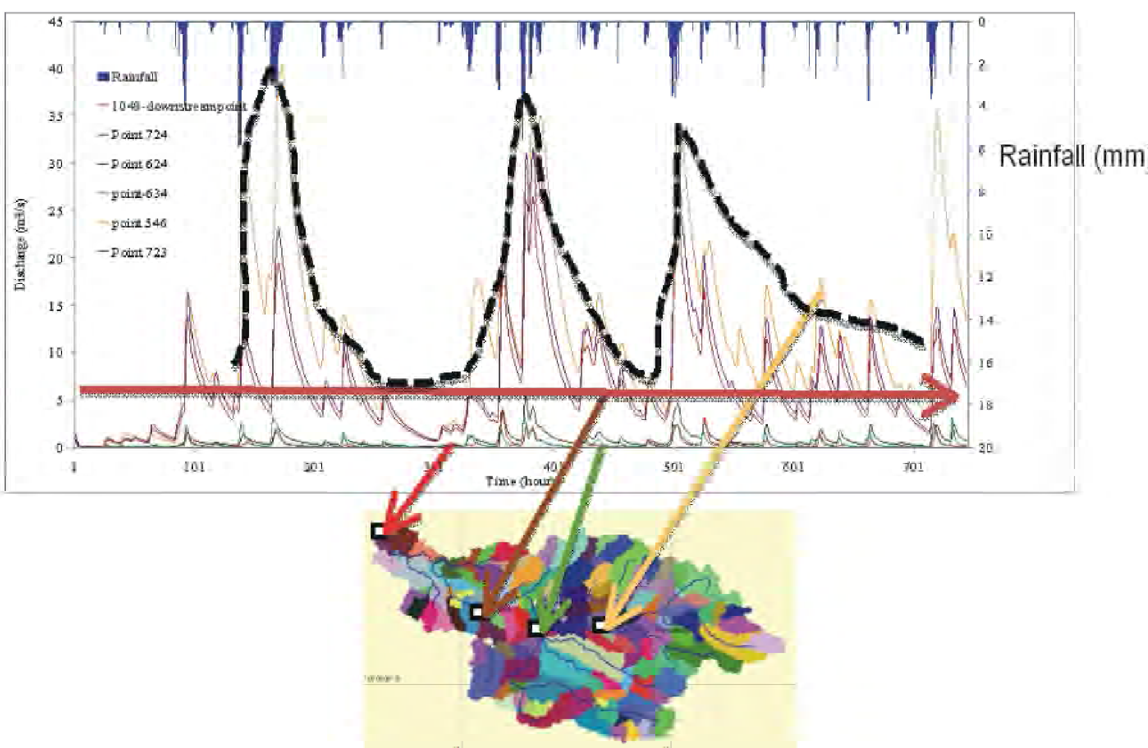

Fig. 8: Validation results of the rainy events of August 2003

Evaporation and evapotranspiration are some of the factors that influence the water balance of agiven landscape. Evaporation of surface water or groundwater increases the concentration ofsuits of minerals in the soil water [22] including isotopic content. However, evapotranspiration increases only the concentration of minerals in the ground without affectingisotopic content. It is presumed that both processes have a role to play in this basin even if it isvariable. The evaporation from the lake has been estimated using different methods and authors, for instance, the lake potential evaporation has been calculated to be 1563 mm/yr [23].

Flash Flood Simulations: As explained in the previous parts, the model was developed to the arid environments, which means that it should be calibrated at the humid regions as in Gumara catchment. Based on the availability data of stream flow, daily, at the Gauging station of Gumara, Lake Tana, the calibration has been done for two months, July and August, 2003, showing a reasonable agreement between both of Observed discharge and simulated ones as depicted in Figure 5 and Figure 6.

The simulation has been done for the rainy season of July and August, 2003 at Gumara catchments. The hydrograph of July Simulations (Figure 7) show based flow as normal conditions and there is high peak of discharge which is about 30 m^3/s comparing with base flow which is about 4 m^3/s. it means, in July, only one event of flash flood has been detected and simulated in this month. For August, the hydrograph (Figure 8) show average base flow about 3 m^3/s and the maximum peak of discharge is a range of 35-40 m^3/s, which are indication of catching three flash floods events in this month.From these calibrated results in Figures 5 & 6 comparing with hourly simulation Figures 7 & 8, the hourly simulation can reveal and catch the flash flood events but in Daily calibration, the flash flood events is not so strong and high peak of discharge comparing the base flow. These means that the need of hourly observational data of discharge is entirely required for better calibration of the model at the humid regions.

CONCLUSIONS

The simulation has been done for the event of November, 1994 at W. El-Assiuti, Egypt. Simulation results exhibit that surface runoff hydrographsacting assteep rising and rapid ascending where the maximum peak of discharge is 12.52m3/s. The runoff behaviors arehighly affectedby factors such as the catchment area and slopewhich havea significant effect on the peak of discharge, the time to the peak and the duration of flow

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The most important difference between the arid and humid flash floods characteristics are, the occurrence of multiple flash floods peaks in in the humid regions comparing with the arid regions. Also, the period of rainy season is longer than in arid environments. The hydrograph in arid environment is steeper rising and ascending in arid areas than on the humid regions. Further application is needed in semi-arid regions as Sudan to complete the story of comparison between the different catchments considering hydrological conditions, climatology conditions, as well as topographical conditions. The near future study will focus on the comparison of flash floods at different basins along the River Nile due to the high variabilities between the different basins in terms of topography, climate conditions, rainfall frequency and distribution.

ACKNOWLEDGMENT

This research was funded by the Nile Basin Initiative (NBI), the Eastern Nile Technical Regional Office (ENTRO) and Ethiopia.We also acknowledgethe Ministry of Water Resources, Irrigation and Energy of Ethiopia for providing us some of daily flow data for WadiGumara.

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