INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

Mitigation Strategies Based on Flash Floods Simulation Considering Water Resources Management at Wadi El-Arish, Sinai Peninsula, Egypt

M. Saber
Geology Department, Faculty of Science, Assiut University, Assiut, 71516, Egypt
msaber_75@yahoo.com

T. Hamaguchi & K. Tanaka
Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan

S. A. Kantoush
Civil Engineering Department, Faculty of Engineering and Material Science, The German University in Cairo – GUC, Cairo – Egypt

T. Sumi
Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University, Japan

ABSTRACT:
In arid regions, flash floods are the most devastating hazards in terms of loss of human lives and infrastructures. The main goal of this paper is to simulate flash flood and to propose mitigation strategies in order to reduce the threat of flash floods and utilize its water in the proper way at Wadi El-Arish, Egypt. Global Satellite Mapping of Precipitation (GSMaP) is integrated with Hydro-BEAM (Hydrological River Basin Environmental Assessment Model) for flash floods simulation. The simulation has been successfully carried out to the flash flood event which hit Egypt on Jan. 18-20, 2010. The simulation results exhibit reasonable results coinciding with the actual situation. The contributed water of Wadi sub-catchments has been estimated and some mitigation strategies have been proposed leading to future risk reduction in such regions. The developed methodology to forecast flash floods considering mitigation strategies can be applied effectively at different arid regions.

Keywords: Flash flood simulation, GSMaP, flash flood mitigation, Wadi system, arid regions

1. 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 (Fattorelli, et al., 1999). The main obstacle to study flash flood is clearly the lack of reliable observations in most of the flash flood prone basins, thus, there is urgent necessity to develop a new methodology 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 Michaud and Sorooshian, (1994). Rapidly increasing availability of good quality weather radar observations is greatly expanding our ability to measure and monitor rainfall distribution at the space and time scales which characterize the flash-flood events (Borga et al., 2007). Hydrological models of varying complexity approaches are applied to provide detailed estimates of flow processes for ungauged regions (Sangati, et al., 2009; Bonnifait, et al., 2009; Bloschl et al., 2008; Reed et al., 2007; Bohorquez, et al., 2008). A method for estimating flash flood peak discharge, hydrograph, and volume has been presented by Aristeidis, and Ioannis (2010).

Ascribable to the aforementioned 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 hydrological behaviors 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.

Thus, the main objectives of this paper are: (i) Adopting of an effective approach to simulate the flash floods at wadi system with taking in our consideration the distribution behaviors of flash floods (ii) Using remote sensing data after bias correction for a flash flood simulation at wadi basins to overcome the challenge of data paucity in arid regions, (iii) Assessing and evaluating of contributed water flow of wadi basins during the flash flood events to be utilized as a significant water resource, (iv) 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.

2. THE TARGET WADI BASIN

Wadi El-Arish is located in Sinai Peninsula, Egypt, it flows toward the Mediterranean Sea and its downstream part is El-Arish City, as shown in Fig. 1. This wadi infrequently receives flash flood water from much of northern and central Sinai which make a great threat for the human life and their properties of El-Arish City residents. It is the largest ephemeral stream system of the Sinai Peninsula. Its catchment area is calculated about 20,700 km^2 throughout GIS processing of DEM. The growing population and increasing industrial and agricultural activities create a large demand for water resources for people need as well as a flash flood protection warning system.

El-Arish area has the highest annual precipitation all over Egypt, where it receives about 300mm/year. Therefore, the city depends on its fresh shallow groundwater that is produced from Quaternary aquifers of delta Wadi El-Arish (Dames and Moor, 1985). Wadi El-Arish morphology is characterized by steep slopes in the upper part of the basin, decreasing while approaching the sea as investigated in the watershed model of the basin. Average annual precipitation in the interior of the basin is less than 30 mm as compared with the average annual rainfall along the eastern Egyptian Mediterranean coast of about 90 mm (Smith, et al., 1997).

3. METHODOLOGY

A physical-based distributed hydrological model and remote sensing data as well as GIS technique have been integrated to simulate flash floods in arid regions. Hydro-BEAM (Hydrological River Basin Environmental Assessment Model) which was first developed by Kojiri, et al. (1998), and it was also adopted as Hydro-BEAM-WaS (Hydrological River Basin Environmental Assessment Model Incorporating Wadi System) by Saber et al. (2010) and Saber (2010) to be applicable at wadi system in arid regions. It is used as physical-based model with GSMaP (http://sharaku.eorc.jaxa.jp/GSMaP_crest/) as remote sensing data which was calibrated with Global Precipitation Climatology Center data (GPCC: http://gpcc.dwd.de) in order to overcome the lack of observations in such areas.

Hydro-BEAM-WaS consists 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 (SCS, 1985) and Walter's equation (Walters, 1990), and groundwater modeling based on the linear storage model (Fig. 2).

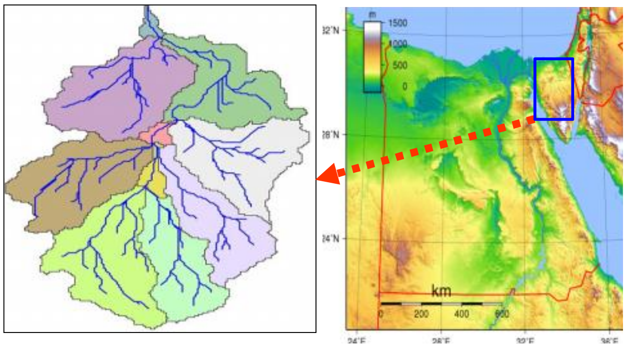

Figure 1. Location map of Wadi El-Arish, Sinai Peninsula, Egypt

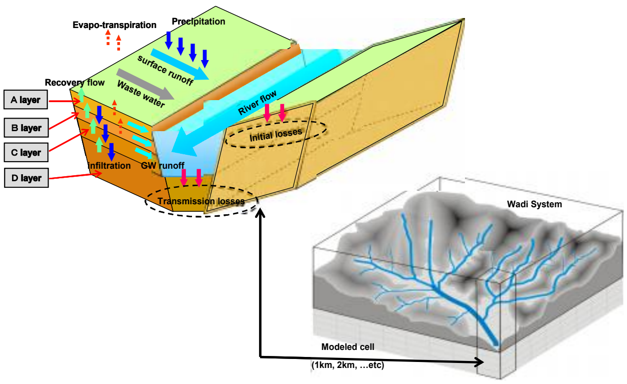

Figure 2. Conceptual model of Hydro-BEAM (Saber, 2010)

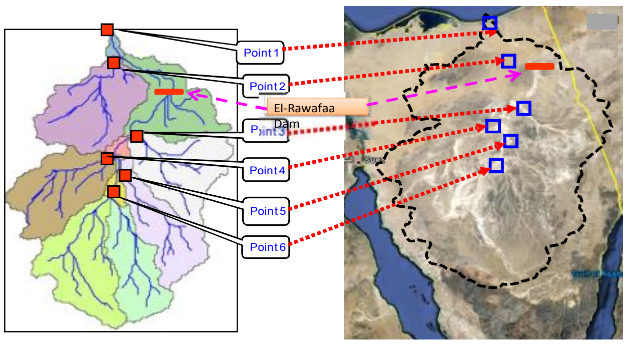

Figure 3. Wadi El-Arish catchment, Sinai Peninsula, Egypt, showing the target outlets for flash flood simulation as well as the location of El-Rawafaa Dam

4. FLASH FLOOD SIMULATION

GSMaP data of precipitation has been used with Hydro-BEAM for flash flood simulation at Wadi El-Arish, Sinai Peninsula, Egypt. The simulation of flash flood event of January 18-20, 2010 was discussed because it has a big effect on residents and their properties at Wadi El-Arish as well as other regions at the upstream of the Nile River. Six outlet points have been selected based on the sub-catchments of the target wadi for this simulation as depicted in Fig. 3. The results of simulation of this event show that flash flood characteristics are highly variable from one outlet to the others in terms of flow rate and time to reach the maximum peak within the whole watershed (Fig. 4).

Furthermore, at the downstream outlet at the Mediterranean Sea of Wadi El-Arish, the flow was very severe; about 2864.84m3/s. At W. Abu-Tarifieh, one of the sub-catchments of Wadi El-Arish, the discharge was calculated about 240.52m3/s, and the discharge of all sub-catchments was also calculated and listed in Table 1. The time to peak and the flow duration in flash flood simulations have been estimated (Table 1). Time to peak is averaged between 8 hours at the upstream regions to17 hours at the downstream outlets, which means that the alarming time very short. In other words, evacuating the people is very difficult in such arid regions. In terms of evaluation of sub-catchments water contribution towards the Wadi El-Arish, the flow volume of water which can reach to the downstream point of each sub-basin have been calculated and listed in Table 1.

From the distribution maps of flash floods (Fig. 5) in the target wadi, the discontinuously flow is perfectly depicted as one of the characteristics of ephemeral streams, revealing that the proposed model can depict these important surface flow behaviors in arid environment.

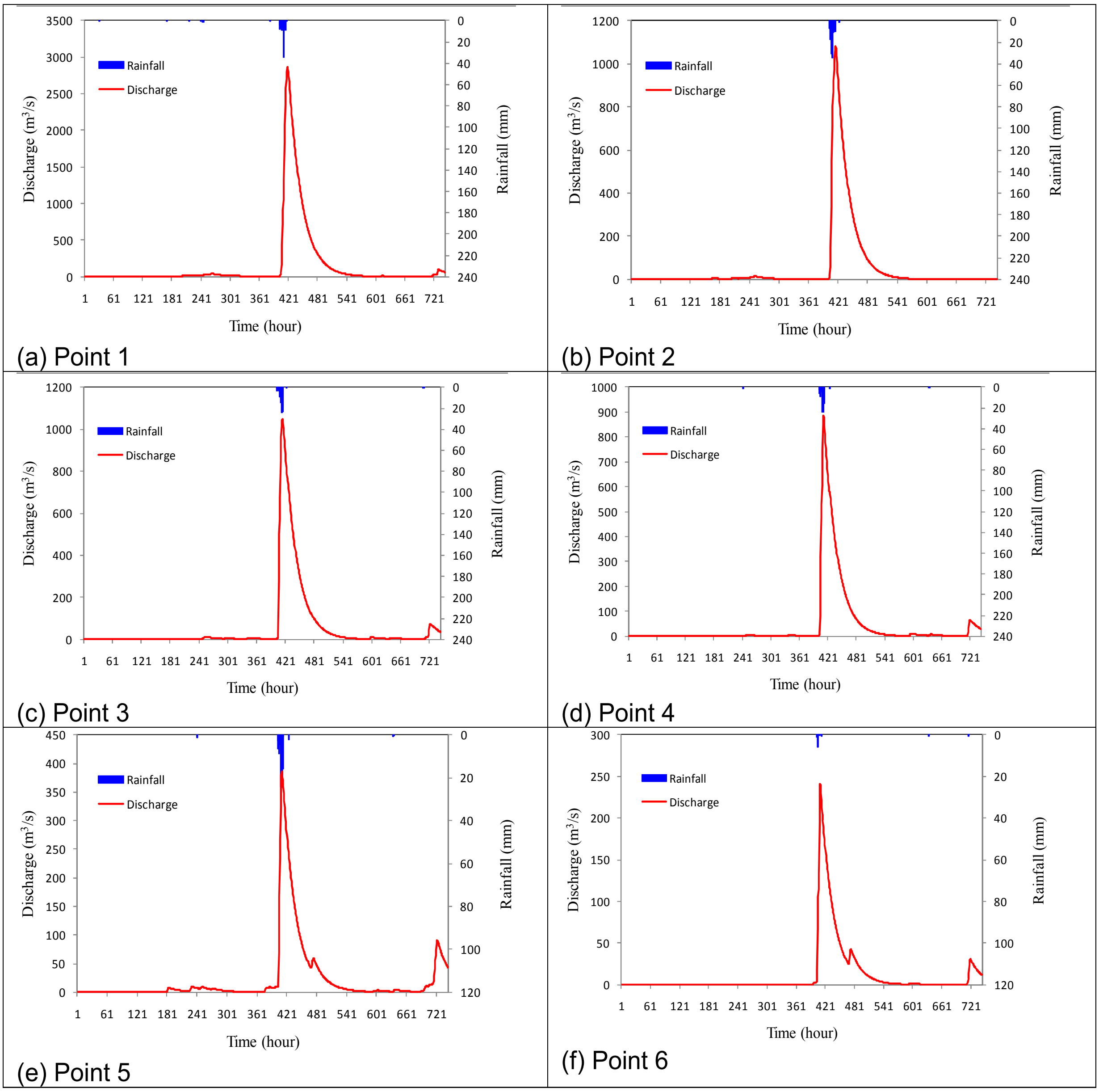

Figure 4. Simulation of flash flood event of (Jan.18-22, 2010) at several sub-catchment outlets of Wadi El-Arish: a) Point 1, b) Point 2, c) Point 3, d) Point 4, e) Point 5, and f) Point 6

Table 1. Simulation results of event (Jan.18-22, 2010) at Wadi El-Arish

Sub-catchments of Wadi El-Arish Outlets	Location	Time to peak (hr)	Peak discharge (m3/s)	Flow Volume (m3)
W. El-Arish (Point 1)	33.8E, 30.7N	17	2864.84	3.54 × 1008
W. El-Arish (Point 2)	33.8E, 30.4N	14	1080.38	1.26 × 1008
W. Griha (Point 3)	33.9E, 29.9N	13	1050.41	1.26 × 1008
W. Elbarok (Point 4)	33.7E, 29.8N	10	885.38	9.9 × 1007
W. Eqabah (Point 5)	33.8E, 29.5N	7	386.66	4.5 × 1007
W. Abu-Tarifieh (Point 6)	33.7E, 29.4N	8	240.52	2.7 × 1007

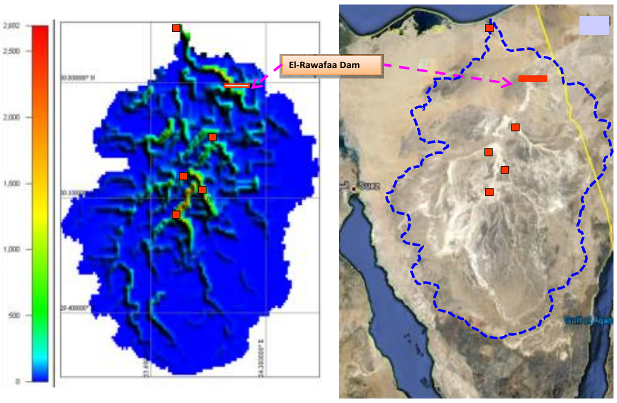

Figure 5. Distribution maps of discharge of Jan. 2010 flash flood event at Wadi El-Arish, Sinai Peninsula, Egypt, showing discontinuous flow of discharge (red marks are the position of sub-catchments outlets of simulation)

5. FLASH FLOOD AS SIGNIFICANT WATER RESOURCE

Water resources management is crucial and important issue in arid regions due to the shortage of rainfall, high evaporation and transmission losses, as well as increasing population, coupled with limited water resources and attendant increases in need for water. However, flash floods are devastating and representing a big threat for human life and arid environment, it can be utilized and managed in a proper way to be useful as water resources. Thus, in this study, one of the significant targets is to evaluate the flash flood water as additional water resources. The contribution of some wadi sub-basins into Wadi El-Arish is numerically estimated during the simulated event as listed in Table 1.

The water contribution from sub-catchments towards Wadi El-Arish during the flash flood has been recorded. Also, it is noticed that the contributed water flow volume at the downstream point of wadis is varying from one wadi to the others depending mainly on the watershed characteristics, rainfall distribution, and hydrological conditions of these sub-catchments as depicted in the distributed maps of discharge (Fig. 5). Throughout the study of the effect of flash floods on the aquifer of Wadi El-Arish Delta, it was found that there is deterioration in the groundwater levels and increasing of water salinity due to the exceeding of abstraction comparing with the recharge to the aquifer (Shawki, 2011). To this extend, it means that there are no reasonable strategies for how to utilize and manage the water of flash floods properly to be useful in a conjunctive use of surface and subsurface water to cover the water demands.

6. FLASH FLOOD MITIGATION

Simulation results of flash flooding at Wadi El-Arish in Sinai Peninsula show how the extent of the threat of flash floods in wadi basins. It was investigated that from the distribution maps, flash floods are highly variable from one wadi to the others, relying on the rainfall events in spatial and temporal distribution, and geomorphologic and topographic conditions at wadi catchments. The remarks of the spatial variability of flash flood occurrence are illustrated in the flash flood event of Jan, 2010 where the most affected regions at the middle of the catchment and around EL-Rawaffa Dam as shown in Fig. 5.

In the real situation, the downstream area after El-Rawafaa dam has been affected by this flash flood. The government announced that more than 14 persons were killed in Aswan and Sinai Peninsula as well as thousands of people becoming homeless during this event. These results exhibit the extent of the performance of the proposed model to predict flash floods in such regions. It shows the most affected regions as depicted in the results of distribution maps Fig. 5 and Table 1. Estimating of spatiotemporal flow volume of the flash flood affecting the target regions have been estimated and depicted, and consequently, the risk maps and the prone areas of flash flood can easily be illustrated. El–Rawafaa Dam (Fig 6) was constructed on 1946 at North Sinai peninsula, Egypt, for the purpose of flash flood mitigation to protect the downstream regions from the flash flood and its storage capacity about 5.8 million m3. Its width is about 350 m and its height is about 15m. Also, it is located about 40 km distance from Al-Arish City along Wadi El-Arish. The current simulation of flash flood of Jan, 2010, shows that the water volume which can reach to El-Rawafaa Dam is more than 100 million m3 that means it is very greater than the actual capacity of the dam, and hence, the big damage was occurred in this region leaving human loss and infrastructure damage.

Relying on the simulation results of this event, two scenarios have been recommended, the first one is to construct five dams at the outlets of the sub-catchments (W. Griha (Point 3), W. Elbarok (Point 4), W. Eqabah

(Point 5), and W. Abu-Tarifieh (Point 6)) as shown in Fig. 3, in order to reduce the flow volume of flash flood water which is expected to reach to the downstream regions at El-Rawafaa Dam, by which, the water flowing towards the Mediterranean Sea without utilization, could be managed as a resource of recharge to the groundwater aquifer and the threat of flash floods will be alleviated in this area.

Figure 6. El-Rawafaa Dam before the flash flood (a), and during the flash flood event of Jan, 2010, showing how much of the water is overflowing the dam

The second scenario is to construct a rechargeable dam after El-Rawafaa dam while the accumulated water will be used in two options, the first one as surface water for agriculture purpose because the region after El-Rawafaa dam is plain and it can be reclaimed for cultivation purpose. The second option is to be recharged to the subsurface aquifer of Wadi El-Arish Delta. Accordingly, the problem of groundwater level decreasing and salt water intrusion increasing will be solved at Wadi El-Arish Delta and securing flash flood water to be utilized properly as a means to overcome the problem of water scarcity in such regions.

7. CONCLUSION

An integration of using remote sensing data and the distributed Hydrological model of Hydro-BEAM has been proposed for flash flood simulation at Wadi –El-Arish, Egypt. GSMaP product has been compared with the monitored data of GPCC, revealing that an overestimated or underestimated systematic seasonal bias is occurred. The simulation has been carried out to the flash flood event of Jan. 2010. The simulated results present remarkable characteristics such as time to peak is very short resulting in a difficulty to evacuate the people from the prone regions. Additionally, the distribution maps of flash flood corresponding to rainfall data show that there are high variability in occurrence of flash flood in space and time in terms of wadi characteristics and the time of the flash flood event.

The findings and advantages of this study are summarized as follows: i) Simulation of flash flood has been successfully achieved at wadi sub-basins of Wadi El-Arish, ii) GSMaP is calibrated and used to simulate the flash floods to overcome the problem of data paucity in arid regions, iii) A commendable contribution of wadi sub-basins as water resources towards Wadi El-Arish during flash floods has been recorded. and iv) Proposing some mitigating strategies for flash flood risk reduction at Wadi El-Arish, the results exhibit that flow volume which reach to El-Rawafaa dam is higher than its capacity, resulting in failure of the dam, loss of human lives, and infrastructure damage. In spite of the fact that mitigating strategies for flash flood risk reduction are difficult to be applied, strategies for flash flood mitigation have been proposed. In conclusion, the developed methodology to forecast flash floods considering proposing mitigation strategies and water resources management has been accomplished. Consequently, taking the emergency actions for evacuating the people in advance can be done so that their lives and properties may be saved and minimized. Further studies concerning flash flood simulation and mitigation in arid regions, will be considered in our next turn based on detailed field works and observations.

REFERENCES

Aristeidis G. K. and Ioannis K. T. (2010) : A method for estimating flash flood peak discharge in a poorly gauged basin: Case study for the 13–14 January 1994 flood, Giofiros basin, Crete, Greece, *J. of Hydrology* 385 (2010) 150–164.

Bloschl, G., Reszler, C., and Komma, J. (2008): A spatially distributed flash flood forecasting model. *Environ. Modell. & Softw.,* 23, 464–478.

Bohorquez, P. and Darby, S.E. (2008): The use of one- and two-dimensional hydraulic modelling to reconstruct a glacial outburst flood in a steep Alpine valley. *J. of Hydrology* 361 (3–4), 240–261.

Bonnifait, L., Delrieu, G., Le Lay, M., Boudevillain, B., Masson, A., Belleudy, P., Gaume, E., and Saulnier, G. M. (2009): Distributed hydrologic and hydraulic modelling with radar rainfall input: reconstruction of the 8-9 September 2002 catastrophic flood event in the Gard region, France. *Adv. Water Resour.,* 32(7),1077-1089.

Borga, M., Boscolo, P., Zanon, F., and Sangati, M. (2007): Hydrometeorological analysis of the August 29, 2003 flash flood in the eastern Italian Alps. *J. of Hydrometeorology* 8(5): 1049–1067.

Dames and Moor (1985): Sinai development study-phase 1, water resources volumes II-A and II-B, submitted to the advisory committee for reconstruction, ministry of development, Cairo, Egypt.

Fattorelli, S., Dalla Fontana, G. and Da Ros, D. (1999): Flood hazard assessment and mitigation. In: Casale, R. and Margottini, C. (Eds) Floods and Landslides – Integrated Risk Assessment, *Springer Verlag, Berlin-Heidelberg*, 19–38.

GPCC: *http://gpcc.dwd.de*

GSMaP: *http://sharaku.eorc.jaxa.jp/GSMaP_crest/*

Kojiri, T., Tokai, A. and Kinai, Y. (1998): Assessment of river basin environment through simulation with water quality and quantity. *Annuals of DPRI, Kyoto Univ.*, Vol. 41, pp. 119-134, (in Japanese).

Michaud, J. D. and Sorooshian, S. (1994): Effect of rainfall-sampling errors on simulations of desert flash floods. *Water Ressour. Res.*, 30, 2765-2775.

Reed, S., Schaake, J., and Zhang, Z. (2007): A distributed hydrologic model and threshold frequency-based method for flash flood forecasting at ungauged locations. *J. of Hydrology* 337 (3–4), 402–420.

Saber, M. (2010): Hydrological approaches of Wadi system considering flash floods in arid regions. Ph.D. thesis, Kyoto University.

Saber, M., Hamagutchi, T., Kojiri, T., and Tanaka, K. (2010): Hydrological modeling of distributed runoff throughout comparative study between some Arabian wadi basins. *Annual J. of Hydraulic Eng., JSCE*, Vol.54, pp. 85-90.

Sangati, M., Borga, M., Rabuffetti, D., and Bechini, R. (2009): Influence of rainfall and soil properties spatial aggregation on extreme flash flood response modelling: an evaluation based on the Sesia river basin, North Western Italy. *Adv. Water* Resour., 32(7), 1090–1106.

Shawki, S. H. (2011): Impact of flash floods on the hydrogeological aquifer system at delta Wadi El-Arish, Sinai,5th Int. Water tech. conf., IWTC-15, Alex., Egypt.

Smith, S. I., EL-Shamy, and El-Monsef, H. (1997): "Locating Regions of High Probability for Groundwater in Wadi El Arish Basin, Sinai, Egypt". *J. of African Earth Sci.*, Vol. 25, No. 2.

Soil Conservation Service (SCS) (1985): National Engineering Handbook, section 4: hydrology, US Dept. of Agriculture, SCS, *Engineering Division, Washington, DC*.

Walters, M. O. (1990): Transmission losses in arid region. *J. of Hydraulic Engineering*, Vol.116, 1, pp. 127-138.