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Flash Flooding Simulation Using Hydrological Modeling of Wadi Basins at Nile River Based on Satellite Remote Sensing Data

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Synopsis

In the arid regions, flash floods are the most devastating hazards for human life and infrastructures. Due to the scarcity of observational data, GSMaP precipitation was applied to simulate the flash floods at wadi basins of the Nile River in Egypt. Throughout the comparison of GSMaP precipitation with the monitored data of GPCC, it is founded that GSMaP has a systematic seasonal bias as overestimated or underestimated. Hydro-BEAM (Hydrological River Basin Environmental Assessment Model) linking with the corrected GSMaP precipitation is used to simulate several flash flood events in the target basin. The simulation has been successfully carried out indicating that the proposed model can be used to predict the flash floods in such areas. The behaviors of flash floods have been depicted revealing that the warning time of flash floods is very short. Water contribution of wadi basins to the Nile River during the flash flood events was assessed as new water resource which would be properly utilized. GSMaP precipitation can be reasonably used with Hydro-BEAM to predict the flash floods at wadi system.

Keywords: flash flood, the Nile River, hydrological modeling, arid regions, GSMaP, GPCC

1. Introduction

Infrequent surface water flow in wadi system may cause natural flash flood hazards but it can be managed to be valuable water resources throughout an appropriate decision support based on effective methodologies. The term ‘flash flood’ identifies a rapid hydrological response, with water levels reaching a peak within less than one hour to a few hours after the onset of the generating rain event (Creutin and Borga, 2003; Collier, 2007; Younis et al., 2008). In other words, flash flood is a natural phenomena which occurring in arid or semi-semi arid regions within short duration (several hours to a few days) and rapidly rising water flow level (reaching maximum peak flow in a few hours) due to the causative event of intense rainfall or dam failure resulting in a greater danger to human life and severe structural damages. Responsible factors for the short duration of the flash flood include intense rains that persist on an area for a few hours, steep slope, impermeable surfaces, and sudden release of impounded water (Georgakakos, 1986). Additionally, particular hydrological characteristics such as small basins, steep slopes and low infiltration capacity combined with a meteorological event contribute to the flash flood formation.

The main problem of flash floods is that warning time is very short, leaving typically only a few hours for civil protection services to act. Moreover, the most important challenge to calibrate and simulate flash floods in arid regions is hampered by the lack of good observational networks of both rainfall and discharge. Flood occurrences are complex since they depend on interactions between many geological and morphological characteristics of the basins, including rock types, elevation, slope, sediments transport, and flood plain area. The hydrological factors, such as rainfall, runoff, evaporation, and surface and groundwater storage can also affect floods (Farquharson et al., 1992; Flerchinger and Cooly 2000; Şen 2004; Nouh, 2006). According to Few et al., (2004), each flood acquires some particular and inherent characteristics of the occurrence locality such as flow velocity and height, duration, and rate of water-level rise.

Long-term rainfall data and their analysis are limited in most of arid regions due to the lack of adequate network of monitoring stations, the paucity of high quality data, and the lack of the effective database management and analysis. The lack of observations in most of the flash flood prone basins necessitates the development of a methodology to simulate and forecast flash flood in the severe current situation. The need for water in such areas increases daily due to population growth, economic development, and urbanization. Consequently, 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.

Vulnerability to flash floods will probably increase in the coming decades due to evolving land use and the modification of the pluviometric regime associated with the evolution of the climate (Parry et al., 2007; Palmer and Raisanen, 2002; Rosso and Rulli, 2002). As pointed out by many authors, the quality of any flood prediction that is based upon hydrological simulations depends to a high degree upon the quality of the measurements and forecasts of precipitation. Also, it must be emphasized that the early warning system is indispensable for the reduction in damages associated with flash floods.

The influence of rainfall representation on the modeling of the hydrologic response is expected to depend on complex interactions between the rainfall space-time variability, the variability of the catchment soil and landscape properties, and the spatial scale (i.e. catchment area) of the problem (Obled et al., 1994; Woods and Sivapalan, 1999; Bell and Moore, 2000; Smith et al., 2004). River hydrograph forecasts are very dependent upon the input rainfall data used.

Ascribable to the aforementioned problems and characteristics of flash floods in the arid regions, effective water management and utilization of wadi surface flow of flash floods based on using remote sensing data are desperately needed. Thus, the main objectives of this research are summarized as follow: (i) Using remote sensing data for flash flood simulation at wadi basins of the Nile River to overcome the challenge of data paucity in arid regions, (ii) Assessment and evaluating of contributed water flow of wadi basins towards the Nile River during the flash flood events to utilize flash flood water as a significant water resource in the arid areas, and (iii) Determination of the prone areas for flash floods of vulnerability to the hazards and damage in the urbanized regions as trial to reduce the human being loss and damage of their properties.

2. The Target Wadi Basin

The Nile River is the longest international river system in the world. It flows about 6700 km through ten countries before reaching the Mediterranean Sea. Its headwaters are in Lake Victoria at about 4º S latitude. It has a drainage area of about 3.35 million km^2, which covers 10% of the African continent, roughly equivalent to half the area of the continental United States. Egypt and the Sudan are the two major users of this river, while Ethiopia is the primary contributor to the bulk of runoff (Beyene, et al. 2007).

The UNEP Executive Director stated that in the future, it was most likely that the complaints and problems caused by the shortage of water supplies would be a cause of conflict amongst nations. Furthermore, the world is heading towards a water crisis in several regions, notably in the Middle East and North Africa, where the available water per capita is 1,247m3/year (UNEP, 2000).

In this study, the Nile River Basin in Egypt (Fig. 1) is selected due to its significant as the main water resources for domestic and agricultural and industrial purposes. The majority of population and agriculture fields are spreading along the Nile River and at the Nile Delta. The whole selected basin is starting after Aswan High Dam to the entrance of Nile Delta. It is located between : 35°00′ E & 28°00 W′ and lat: 32°00′ N & 22°00 S′ . The total catchment area of the Nile River is 184000 km^2 and it has many sub-catchments of wadi basins which flow toward the main channel of the Nile River from both Eastern and Western deserts.

Egypt occupies a portion of the arid to semi-arid belt of Africa. The climate is characterized by a long dry summer and a short temperate winter with a rainfall period from October to March (Saleh, 1980).

3. Data Availability and Analysis

The most important factors affecting the hydrological behavior of wadi basins is rainfall, its duration, intensity, distribution, and return periods are major influences. This climate pattern can be described by considering various air masses that affect rainfall distribution (Subyani, 2009). As well known, the hydrological modeling for flash flood forecasting in arid regions has no enough data for the current research however it is urgent needed.

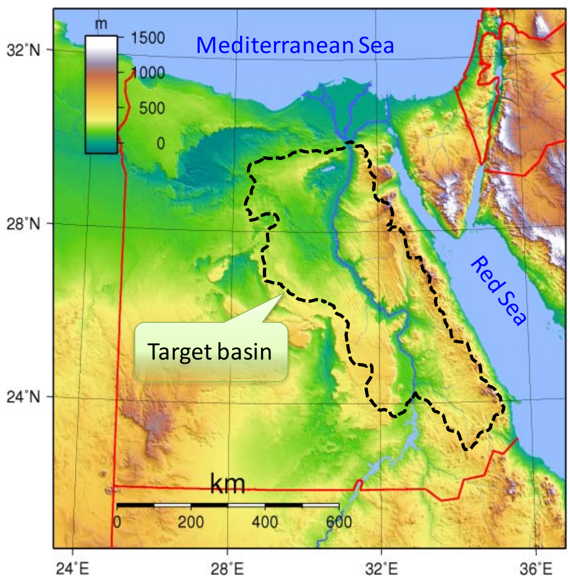


Fig. 1 Location Map of the Nile River Basin in Egypt (Source: http://en.wikipedia.org/wiki/File:Egypt_Topography.png)

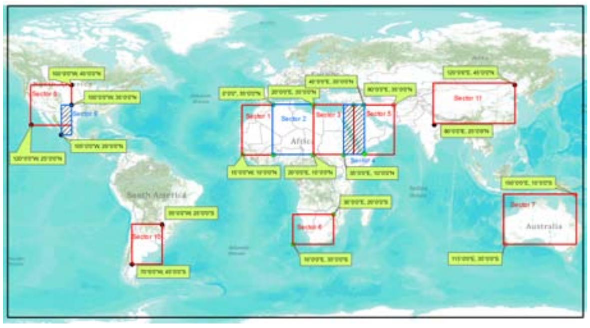


Fig. 2 Global map showing the selected sectors of arid zones

Therefore, remote sensing data is the optimal way to overcome such problems. An attempt has been done to discuss GSMaP data for its feasibility for use to flash flood simulation in such areas.

The Global Satellite Mapping of Precipitation (GSMaP) has been used in this simulation due to the paucity of data in arid regions (http://sharaku.eorc.jaxa.jp/GSMaP_crest/). There are two kinds of horizontal resolution of GSMaP product are 0.1 x 0.1 lat/lon degree grid and 0.25 x 0.25 lat/lon degree grid.

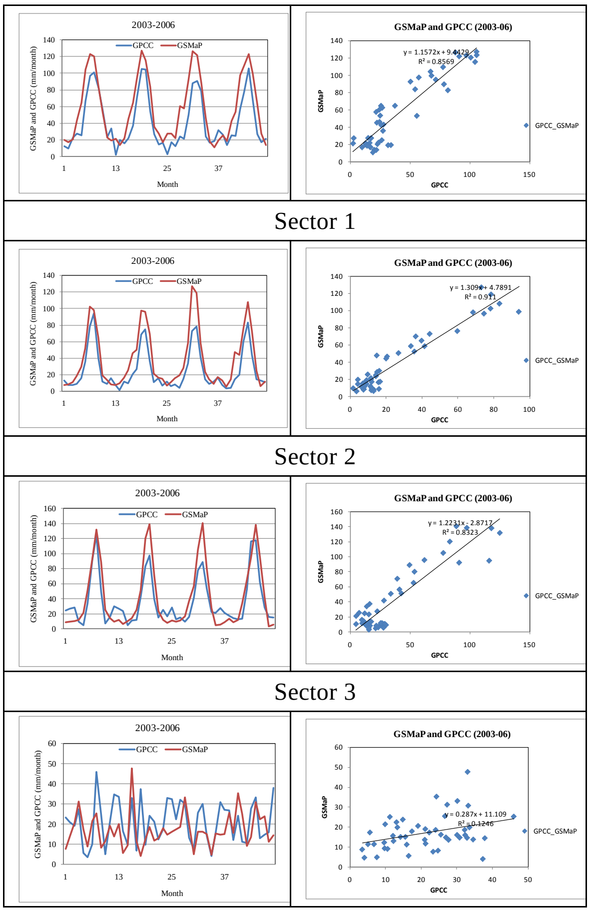
GSMaP and the monitored data of Global Precipitation Climatology Center data (GPCC; http://gpcc.dwd.de) have been compared in the arid regions all over the world to assess the bias of GSMaP product. GPCC products, gauge-based gridded monthly precipitation data sets for the global land surface, are available free for public with spatial resolutions of 0.5° x 0.5°, 1.0° x 1.0° and 2.5° x 2.5°.

Towards using of GSMaP product in this study, eleven arid-zone sectors are selected as illustrated in the world map (Fig. 2). Statistical analysis has been performed for the GSMaP data as comparison with GPCC data, both of them are monthly data and 1.0° x 1.0° spatial resolution. For this analysis the data from 2003 to 2006 has been used with considering threshold greater than 3 mm/month.

The results in most of the arid regions all over the world based on the eleven selected sectors show a systematic-seasonal bias as overestimated or underestimated based in GSMaP product. GSMaP is overestimated in the summer and in the winter, it means all the year but with different value of bias at sector number 1 (North-West of Africa) as declared in Table 1 and Fig.3. For instance, from June–Oct, the bias is 2.04 indicating that GSMaP is overestimated about 50 percent and during the period from Nov. to May, the averaged bias is 1.41.

Table 3 Statistical analysis results of bias correction of GSMaP

Sector	Months (2003-2006): J F M A M J J A S O N D	R2
1	J–M: 1.41; J–O: 2.04; N–D: 1.41	0.86
2	J–M: 1.83; J–O: 1.58; N–D: 1.83	0.91
3	J–M: 0.54; A–O: 1.65; N–D: 0.54	0.832
4	J–M: 0.70; A–O: 1.25; N–D: 0.70	0.124
5	J–M: 0.70; A–S: 1.26; O–D: 0.70	0.74
6	J–F: 1.40; M–A: 0.78; S–D: 1.40	0.837
7	J: –; F–S: 0.65; O–D: 1.18	0.91
8	J–M: 1.87; A–S: 1.14; O–D: 0.70	0.55
9	J–J: 1.84; J–N: 0.97; D: –	0.66
10	J–M: 0.89; A–J: 1.88; A–D: 0.89	0.344
11	J–F: 0.72; M–J: 0.96; J–D: 0.72	0.94



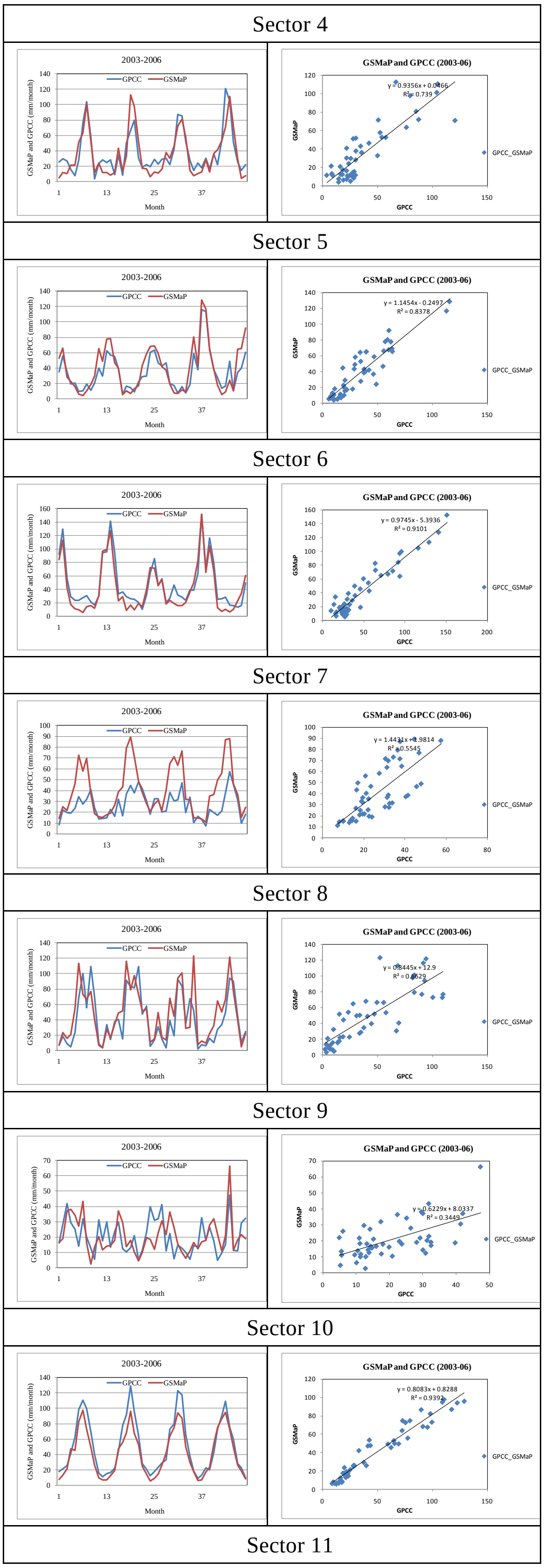


Fig.3 Hydrographs and scatter plots for the comparative between GSMaP and GPCC Data at the selected eleven sectors

In other regions, the averaged bias of GSMaP is underestimated all of the year with variable values, for example at sector number 11 (China), the averaged bias is 0.964 (very small value) during the period from March to June and the bias is 0.722 from July to Feb., it means that GSMaP has underestimated bias all the year.

Moreover, in some areas, there are bias values as overestimated in the period from April to Oct and underestimated in the period from Nov. to Mach, such as sectors 3 and 4 (Fig.3). In South Africa; sector number 6, GSMAP is averagely underestimated during the period from (Mar. to Aug.) and the bias is about 0.783 but it is overestimated during the period from Sept. to Feb. and the bias is about 1.4 as shown in Fig. 3. From these results as shown in details in Table 1 and Fig.3, GSMaP product can be used after bias correction at any arid regions with referring to the calculated results of this study.

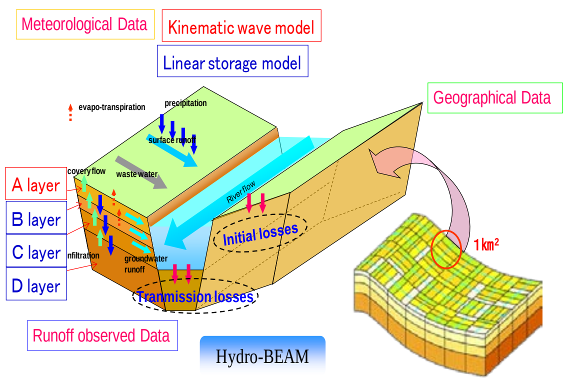


Fig. 4 Conceptual model of Hydro-BEAM

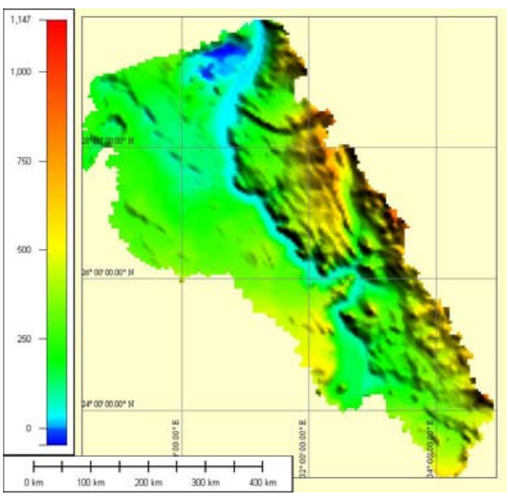


Fig. 5 Digital Elevation model of the Nile River basin

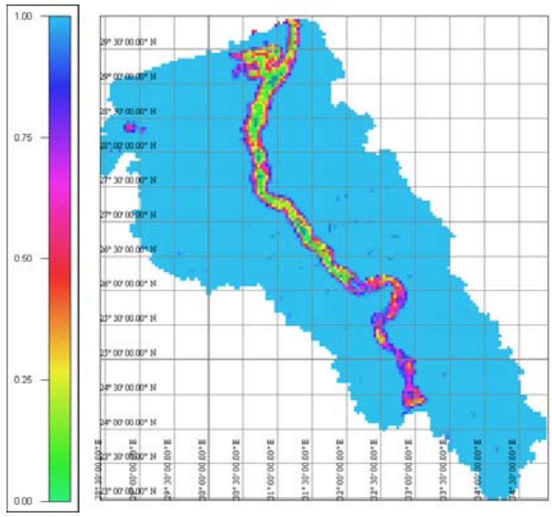


Fig. 6 Land use distribution map of desert in the Nile River basin

4. Methodology and Model components

A physical-based distributed hydrological model; Hydro-BEAM (Hydrological River Basin Environmental Assessment Model) to simulate flash floods at wadi basins has been introduced. It was originally developed by Kojiri, et al. (1998). Hydro-BEAM (Fig.4) was adopted and calibrated in the arid regions, throughout the comparative study of surface and subsurface modeling in some Arabian wadi basins such as wadi El-Khoud in Oman, wadi Assiut in Egypt, and wadi Ghat in Saudi Arabia (Saber et al. 2010).

The proposed approach can be summarized in the following main parts; the watershed modeling using GIS technique is processed, surface runoff and stream routing modeling based on using the kinematic wave approximation is applied, the initial and transmission losses modeling is estimated by using SCS (1997) method and Walter's equation (1990) respectively, and groundwater modeling based on the linear storage model is used.

4.1. Watershed modeling

Remote sensing and GIS techniques were used to assist in the modeling process as watershed modeling. In the distributed models, major input parameters are based on the spatial information of the watershed such as rainfall, land use, soils, topography etc. Therefore, based on the characteristics of constructed database, appropriate analysis techniques could be adopted to accomplish the overall goals of watershed modeling.

The data of digital elevation model (DEM); (Shuttle Radar Topography Mission), 90 m spatial resolution has been used to delineate and determine the watershed and stream networks in the studied wadi basins (Fig.5).

The data are distributed free of charge by USGS and are available for download from the USGS server at (http://dds.cr.usgs.gov/srtm/). Data are also available through the USGS seamless server at (http://seamless.usgs.gov/).The land use data of the world, GLCC (Global Land Cover Characterization, http://edc2.usgs.gov/glcc/glcc.php) and also ECOCLIMAP Data (a global database, http://www.cnrm.meteo.fr/gmme/PROJETS/ECOCLIMAP/frame_text_ecoclimap.html#licence) were used to identify the land use types. In the target basin, most of land use is desert and the others such as field, urban, water are rarely distributed in the catchment except along the Nile River as shown in Fig.6.

4.2. Climatic data

As the aforementioned descriptions of data availability and analysis part, the Global Satellite Mapping of Precipitation (GSMaP) has been used in this simulation due to the paucity of data in arid regions after the bias correction relying on its comparison with the monitored data of GPCC.

4.3. The kinematic wave model

The kinematic wave runoff model is applied for surface runoff and stream routing modeling under the assumption of the river channel triangle cross section. In Hydro-BEAM, the integrated model of kinematic wave is used for overland flow and A-layer flow as expressed in equations (1), (2), and (3).

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=r\left(x,t\right) \qquad (1)$$

$$q=\begin{pmatrix}\alpha\left(h-d\right)^{m}+ah\\ ah\end{pmatrix},\quad when\begin{pmatrix}h\geq d\\ h<d\end{pmatrix},d=\lambda D \qquad (2)$$

$$\alpha=\frac{\sqrt{\sin\theta}}{n}\left(Manning\ Eq.\right),\quad a=\frac{k\sin\theta}{\lambda}\left(Darcy\ Eq.\right) \qquad (3)$$

Where, h is the water depth (m), q is the discharge per unit length of flow [m^3/m.s], r is the effective rainfall intensity [m/s], t is the time [s], x is the distance from the upstream edge, and α, m is constant concerning frictions, λ is the porosity, D is the thickness (m), and d is the saturation pondage (m).

4.4. Linear storage model

Linear storage model as given in equation 4 is used for modeling of groundwater in layers B, C, and D layers in each mesh of the studied wadis.

$$\frac{dS}{dt}=I-O,\ \text{where,}\quad O=(k_1+k_2)\cdot S \qquad (4)$$

Where S is storage amount [m], I is inflow [ms-1], O is outflow [ms-1], k_1, k_2 are outlet coefficients.

4.5. Initial and transmission losses model

Due to the importance of the loss in the arid areas, the initial and transmission losses models were incorporated to Hydro-BEAM.

4.5.1. Initial losses

The SCS method is adopted to calculate initial losses in the target basin. Runoff in sub-basins occurs after rainfall exceeds an initial abstraction (I_a) value. Rainfall excess, P_e, is related to the effective potential retention value (S) as given in equation (7). The optimum values of λ were obtained in the least squares fitting procedure were around 0.05 for most experimental plots which were observed by Hawkins et al. 2002. Therefore, it was decided to set it as 0.05 in this study. The initial abstraction λ is a function of potential maximum retention S. S is a function in curve number (CN) which can be evaluated based on the land use or soil types as given in equations (5) and (6).

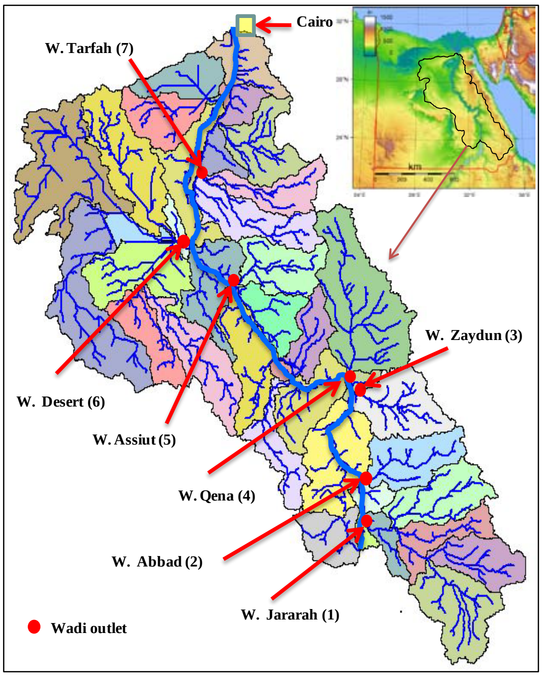


Fig.7 Wadi catchments of Nile River Basin in Egypt showing the target wadi outlets for flash flood simulation

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (5)$$

$$CN = \frac{25400}{254 + S} \quad (6)$$

$$I_a = \lambda S \quad (7)$$

Where P is the depth of rainfall (mm), P_e is the depth of runoff or excess rainfall (mm), I_a is the initial abstraction (mm), S is the maximum potential retention after runoff begins (mm), λ is a dimensionless parameter varying from 0 to 1, and CN is the curve number.

4.5.2. Transmission losses

A regression model form was developed to assess transmission losses) as given in equation (8). Unit of the equation was converted from (acre-ft) into metric unit (cubic meter). The equation was adopted in this study to estimate transmission loss in each mesh based on the flow direction from the upstream to the downstream point.

$$V_1 = 0.026 V_A^{0.872} \quad (8)$$

Where V_1 is the transmission loss for first kilometer (m^3), V_A is the upstream flow volume (m^3).

5. Flash floods Simulation

GSMaP precipitation has been used with Hydro-BEAM to simulate the flash floods at the wadi basins of the Nile River (Fig.7). The simulation has been done to the flash floods events of Feb., 2003; Dec., 2004; Apr., 2005, and Jan., 2010, using spatial resolution 10km×10km because GSMaP Product is only available in this resolution.

The calculation processes for accomplishment of hydrological simulation of flash floods are summarized as follow: (1) picking up of GSMaP data of the target basins, (2) determination and delineation of the catchments and setting of the spatial resolution of modeled meshs, (3) Statistical analysis for bias correction of GSMaP product using GPCC product, and (4) using Hydro-BEAM for simulation, as depicted in the flow chart of

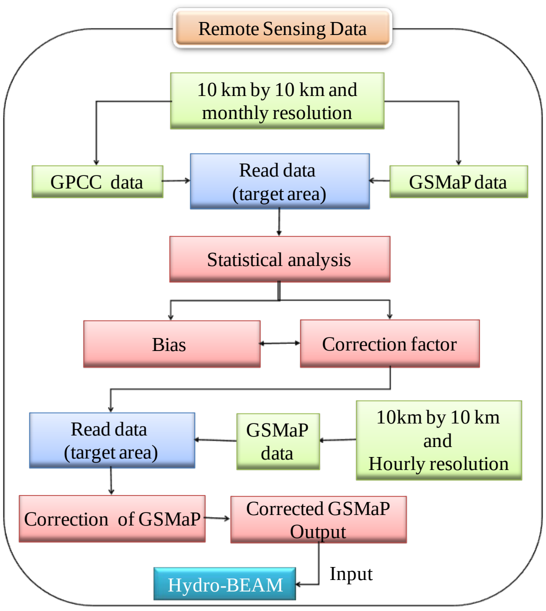


Fig. 8 Flow chart for linking GSMaP with Hydro-BEAM

calculation processes (Fig.8).

The simulated results of flash flood events in the studied wadi basins exhibit the following characteristics of flash floods: i) it takes a few hours to reach to the maximum peak and then gradually reducing until cessation of the event. In other words, it is showing extremely steep and rapid rising to maximum flow within a few hours, ii) Duration of the flash flood is short, and iii) the discontinuity of flow in the target basins.

The results of simulation of the event of Jan. 18-20, 2010 show that flash flood characteristics are highly variable from one location to the others in terms of flow rate and time to reach the maximum peak. For instance, at the outlet of wadi Qena, the flow is very severe flow about 502.7m^3/s and the time to reach to peak is 11 hours. The flow at wadi Assiut outlet is about 2.9m^3/s and the time to peak is 5 hours.

On the other hand, there are some others wadis which have no flow at the same event such as W. Tarfah as shown in Fig.9. In terms of evaluation of wadi basins as water contribution into the Nile River, the flow volume of water which can reach to the downstream point of each wadi during the flash flood event has been calculated and listed in Table 2. Moreover, because the significant of time to peak and flow duration in flash flood analysis, they have been listed in Table 2.

The simulation results of the event of Feb.11-14, 2003 exhibit that the occurrence of variability of flow rate in space and time in the target wadi basins of the Nile River as well as the time to reach the maximum peak of discharge is also changeable from one position to another. In this event, wadi Assiut show discharge about 103.4m3/s and time to peak is 15 hours but in wadi Qena it is about 69.5m3/s which means that it is smaller than that of W. Assiut however the same time to peak as declared in details in Fig.10.

Contribution of wadi basins water into the Nile River, the flow volume of water which can reach to the downstream point of each wadi has been calculated and listed in Table 3. The time to peak and the flow duration of water flow have also been listed in Table 3.

Additionally, the simulation of the flash flood event of Dec.18-22, 2004 is also carried out (Fig.11) and it shows that wadis of Jararah, Abbad and Zydun have no flow in this event but they have flow in the other events of 2003, and 2010, and 2005. This is an implication for the effect of spatiotemporal variation of rainfall in arid regions. The time to reach the maximum discharge peaks is changeable in the range of 11 in Assiut to 15 hours in Qena. Time to peak and flow duration and contribution of wadi basins water into Nile River have been calculated (Table 4).

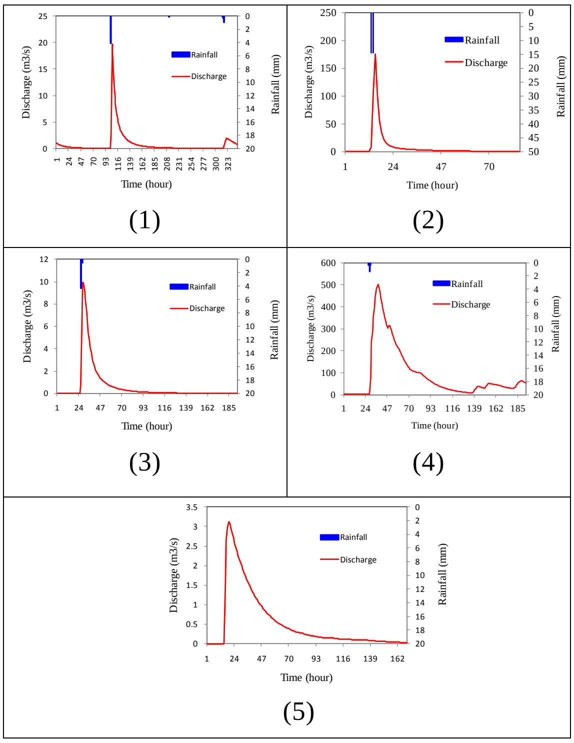


Fig. 9 Simulated flash flood of event (2010/Jan.18-20) at several wadi outlest; 1) w. Jararah; 2) w. Abbad; 3) w. Zaydun; 4)w. Qena; 5)w. Assiut; 6)W. Western Desert; 7)w. At-Tarfah

Table 2 Simulation results of event (2010/Jan.18-20)

Wadi Name	Location	Time to peak (hours)	Peak disch. (m^3/s)	Flow Volume (m3)
Jararah (1)	32.9E, 24.5N	4	19.7	8.01921E+05
Abbad (2)	32.9E, 24.9N	3	174	2.27200E+06
Zaydun (3)	32.8E, 25.9N	3	9.97	4.24185E+05
Qena (4)	32.7E, 27.3N	11	502.7	6.85286E+07
Assiut (5)	31.3E, 27.2N	5	2.9	3.02180E+05
W. Desert(6)	32.0E, 26.1N			
At-Tarfah (7)	30.7E, 28.4N			
Total				7.23289E+07

The flash flood event of Apr.22-26, 2005 is also simulated (Fig.12) for more discussion of flash flood events in the target basin. The time to reach the maximum discharge peaks is changeable in the range of 9 at W. Zaydun to 15 hours in Qena. Time to peak and flow duration and contribution of wadi basins water into Nile River have been calculated and listed in Table 5. From the results of simulation, most of the wadis have flow due to the overall distribution of rainfall effect during this event.

The distribution maps of daily accumulated GSMaP precipitation (Figs. 13, 14, 15, 16) of the events of (Feb., 2003; Dec., 2004; and Apr., 2005, Jan., 2010;) in the whole catchment of the Nile River in Egypt part show that there are highly variation of the rainfall distribution in space and time. The rainfall events of Feb., 2003 and Dec., 2004 are mainly concentrated on the downstream part of the whole catchment but the event of Apr., 2005 is more spreading on the middle and downstream of the catchment. The last event of Jan., 2010 affects the upstream area near to Aswan Dam.

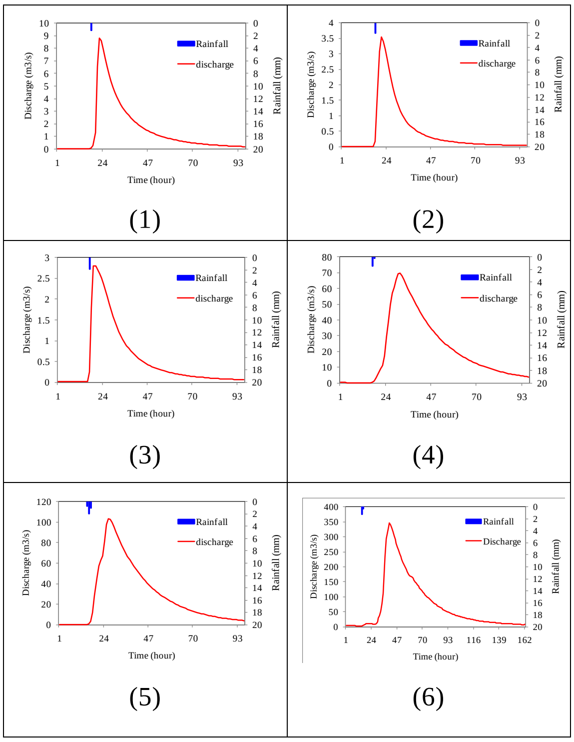


Fig. 10 Simulated flash flood of event (Feb.11-14, 2003) at several wadi outlest; 1) w. Jararah; 2) w. Abbad; 3) w. Zaydun; 4)w. Qena; 5)w. Assiut; 6)w. Western Desert.

Table 3 Simulation results of event (Feb.11-14, 2003)

Wadi Name	Location	Time to peak (hours)	Peak discharge (m^3/s)	Flow Volume (m3)
Jararah (1)	32.9E, 24.5N	5	8.8	4.889609E+05
Abbad (2)	32.9E, 24.9N	5	3.5	1.581304E+05
Zaydun (3)	32.8E, 25.9N	3	2.79	1.819197E+05
Qena (4)	32.7E, 27.3N	15	69.5	7.137293E+06
Assiut (5)	31.3E, 27.2N	12	103.4	9.437274E+06
W. Desert (6)	32.0E, 26.1N	23	333.4	4.016920E+07
At-Tarfah (7)	30.7E, 28.4N			
Total				5.75728E+07

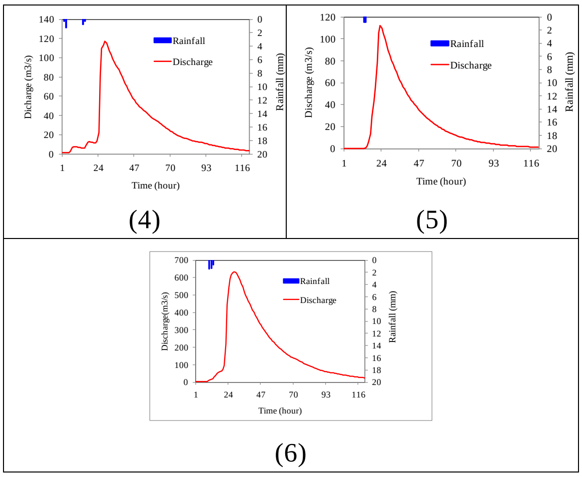


Fig. 11 Simulated flash flood of event (Dec.18-22, 2004) at several wadi outlest; 1) w. Jararah; 2) w. Abbad; 3) w. Zaydun; 4)w. Qena; 5)w. Assiut; 6)w. Western Desert; 7)w. At-Tarfah

Table 4 Simulation results of event (Dec.18-22, 2004)

Wadi Name	Location	Time to peak (hours)	Peak discharge (m^3/s)	Flow Volume (m3)
Jararah (1)	32.9E, 24.5N			
Abbad (2)	32.9E, 24.9N			
Zaydun (3)	32.8E, 25.9N			
Qena (4)	32.7E, 27.3N	17	114.9	1.278597E+07
Assiut (5)	31.3E, 27.2N	11	112.1	9.288250E+06
W. Desert(6)	32.0E, 26.1N	18	632.9	7.436089E+07
At-Tarfah (7)	30.7E, 28.4N			
Total				9.64351E+07

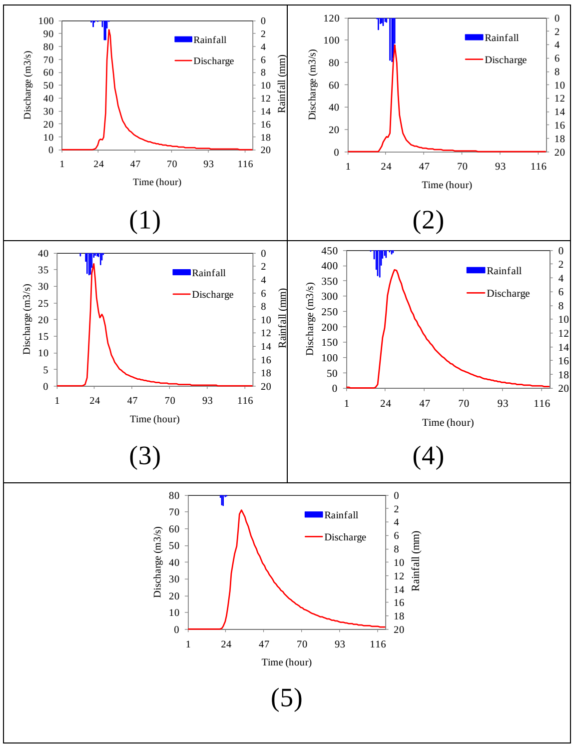


Fig. 12 Simulated flash flood of event (Apr.22-26, 2005) at several wadi outlest; 1) w. Jararah; 2) w. Abbad; 3) w. Zaydun; 4)w. Qena; 5)w. Assiut; 6)w. Western Desert; 7)w. At-Tarfah

Table 5 Simulation results of event (Apr.22-26, 2005)

Wadi Name	Location	Time to peak (hours)	Peak disch. (m^3/s)	Flow Volume (m3)
Jararah (1)	32.9E, 24.5N	12	93.0	3.432220E+06
Abbad (2)	32.9E, 24.9N	12	95.6	2.215871E+06
Zaydun (3)	32.8E, 25.9N	9	36. 9	1.457313E+06
Qena (4)	32.7E, 27.3N	15	385.8	3.781495E+07
Assiut (5)	31.3E, 27.2N	14	71.0	6.675108E+06
W. Desert(6)	32.0E, 26.1N			
At-Tarfah (7)	30.7E, 28.4N			
Total				1.95474E+08

As consequence of rainfall distribution, the flash floods distribution in the target basin is mainly affected by the wadi catchments characteristics such as area, slope, geology, soil types and land use as well as the rainfall distribution. The event of Jan 18-20, 2010 is concentrating in the upstream part of the whole catchments near to Aswan and Qena cities. It reveals the high variability of discharge distribution due to the spatiotemporal variability of rainfall during the four events as depicted in Figs. 17, 18, 19, and 20 are illustrating the hourly distribution of flash floods of the four events (Feb., 2003; Dec., 2004; and Apr., 2005, Jan., 2010;). Moreover, the flow distribution in the target basin is affected by catchments areas and geomorphologic conditions of wadi catchments. Also, it can show discontinues surface flow in the whole catchment, especially during the beginning and ending of the flash flood event.

It is obvious from these distribution maps of rainfall and corresponding discharge in the whole catchment that they are scattering with highly variation in space and time. For instance both of the events (2003 and 2004) are spreading in the northern and middle of the catchment as shown in Figs.13, 14 for rainfall and Figs.17, 18 for discharge. The event of 2005 is scattering in the whole basin as illustrated in Figs.15 and Fig.19 representing of rainfall and discharge. The event of 2010, it concentrating in the southern part near to Aswan and Qena cities as shown in Fig.16 for rainfall and Fig.20 for discharge.

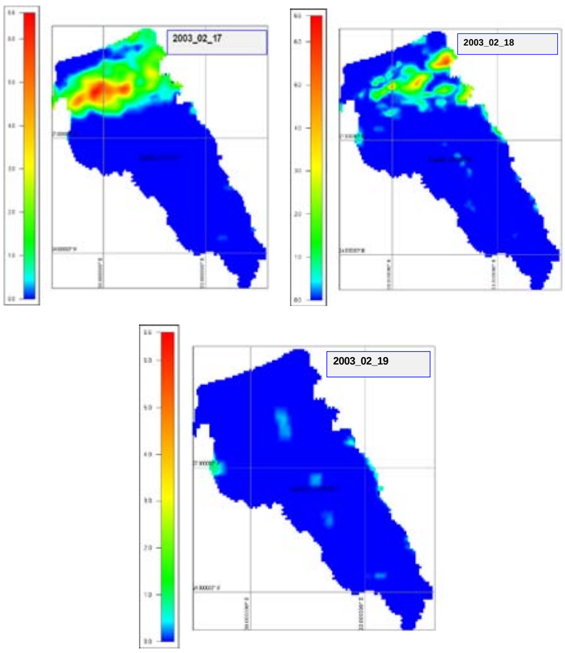


Fig. 13 Distribution maps of rainfall GSMaP (mm/h) product at the Nile River basin in Egypt during the two event of Feb (11-12) and (17-18) of 2003.

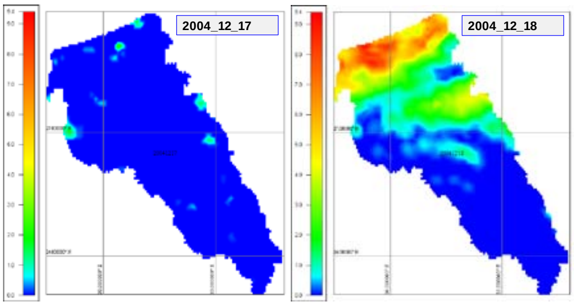


Fig. 14 Distribution maps of rainfall GSMaP (mm/h) product at the Nile River basin in Egypt during the event of Dec (17-22) of 2004.

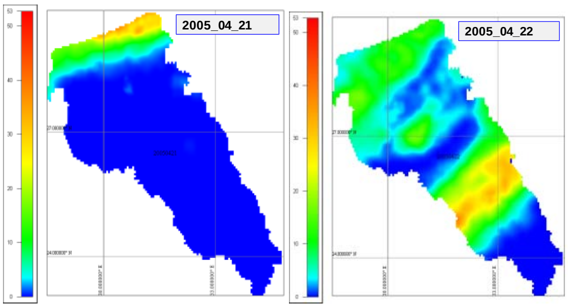


Fig. 15 Distribution maps of rainfall GSMaP (mm/h) product at the Nile River basin in Egypt during the event of Apr. (20-23) of 2005.

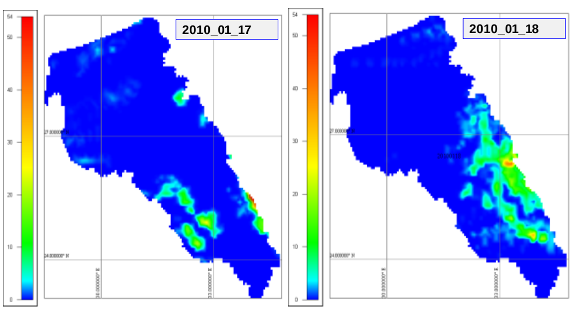


Fig. 16 Distribution maps of rainfall GSMaP (mm/h) product at the Nile River basin in Egypt during the event of Jan. (17-18) of 2010.

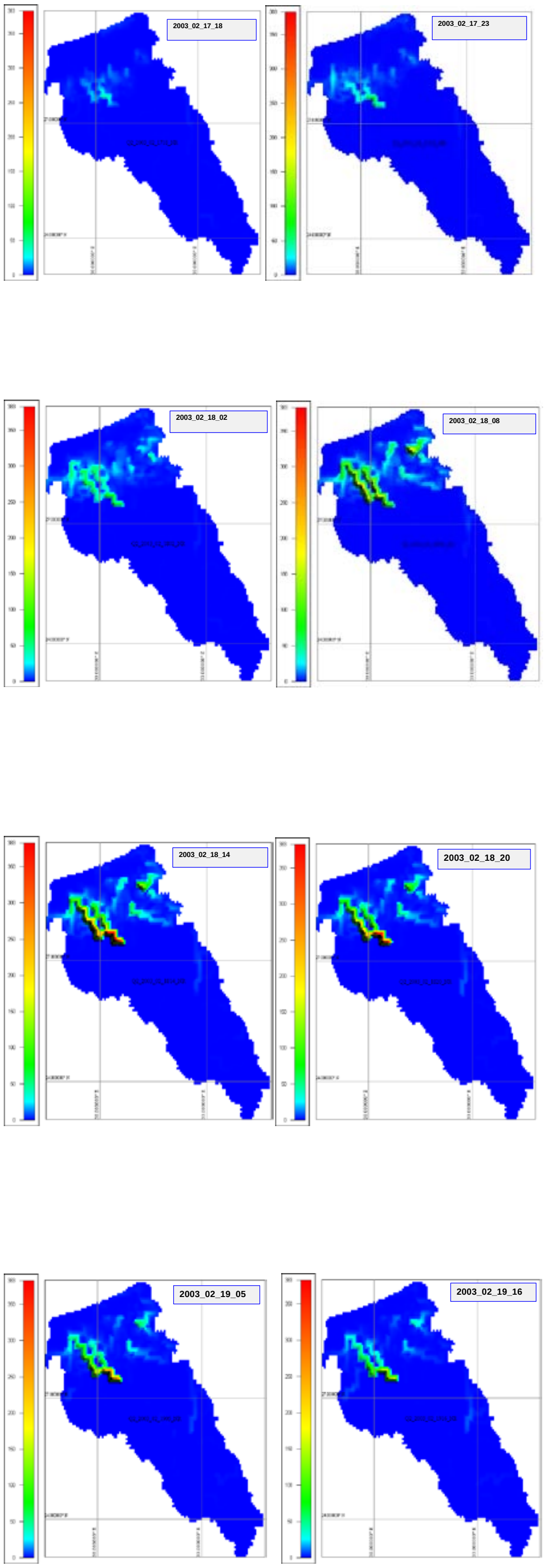


Fig. 17 Distribution maps for discharge (m^3/s) at the Nile River basin in Egypt during the event of Jan 17-19 of 2003 showing the high variability of surface runoff in space and time.

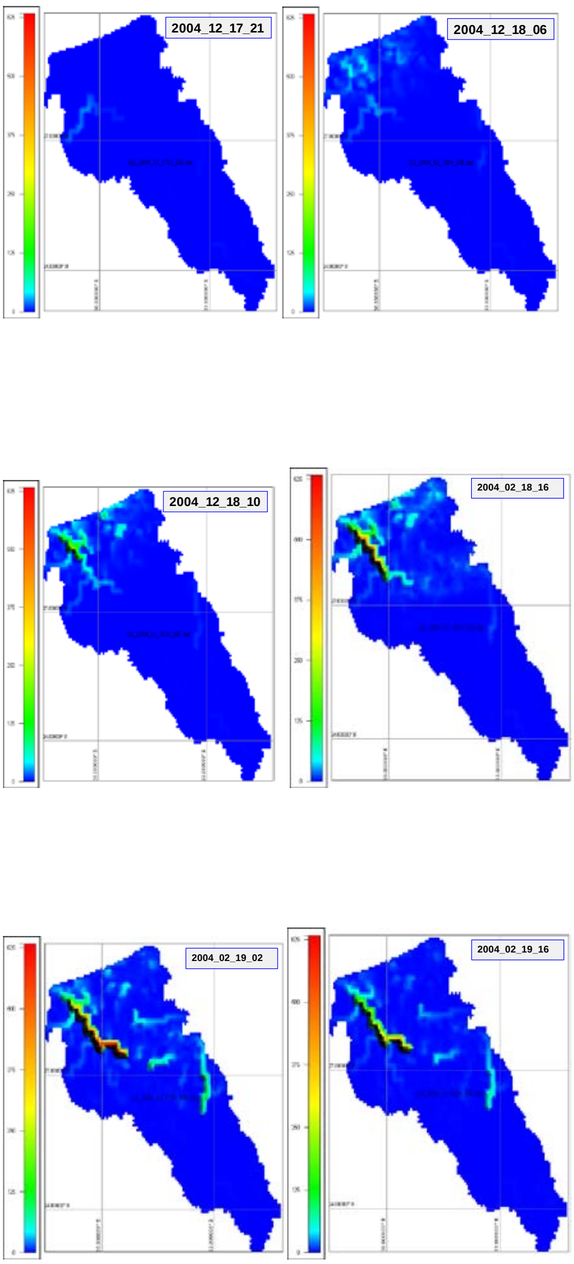


Fig. 18 Distribution maps for discharge (m^3/s) at the Nile River basin in Egypt during the event of Jan 17-19 of 2004 showing the high variability of surface runoff in space and time.

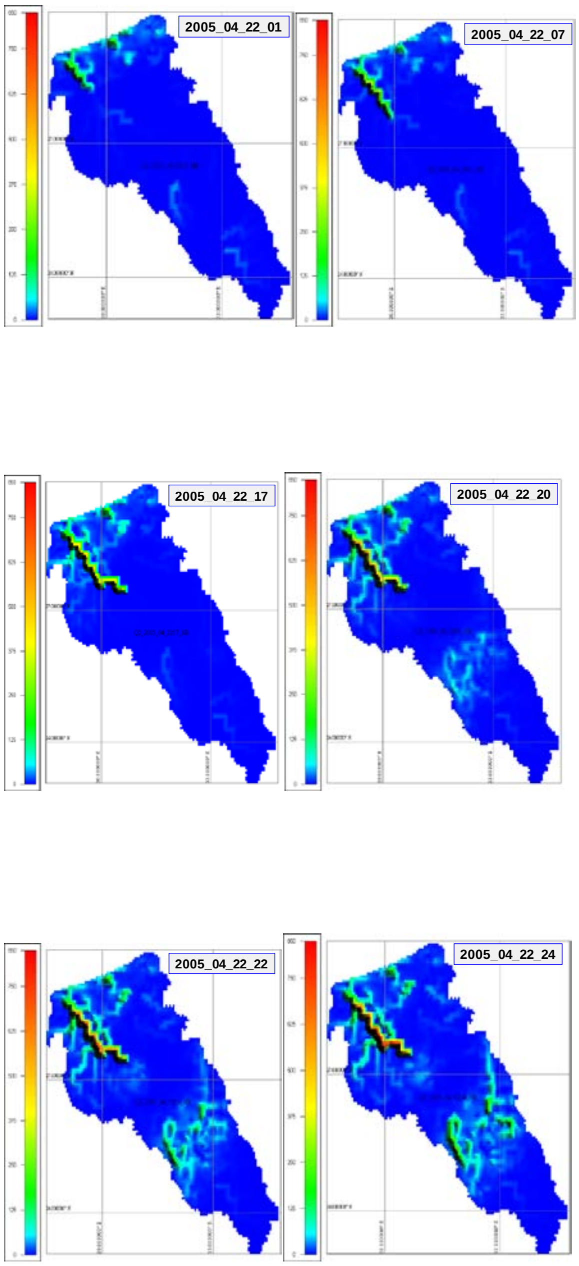


Fig. 19 Distribution maps of discharge (m^3/s) at the Nile River basin in Egypt during the event of Jan 20-22 of 2005.

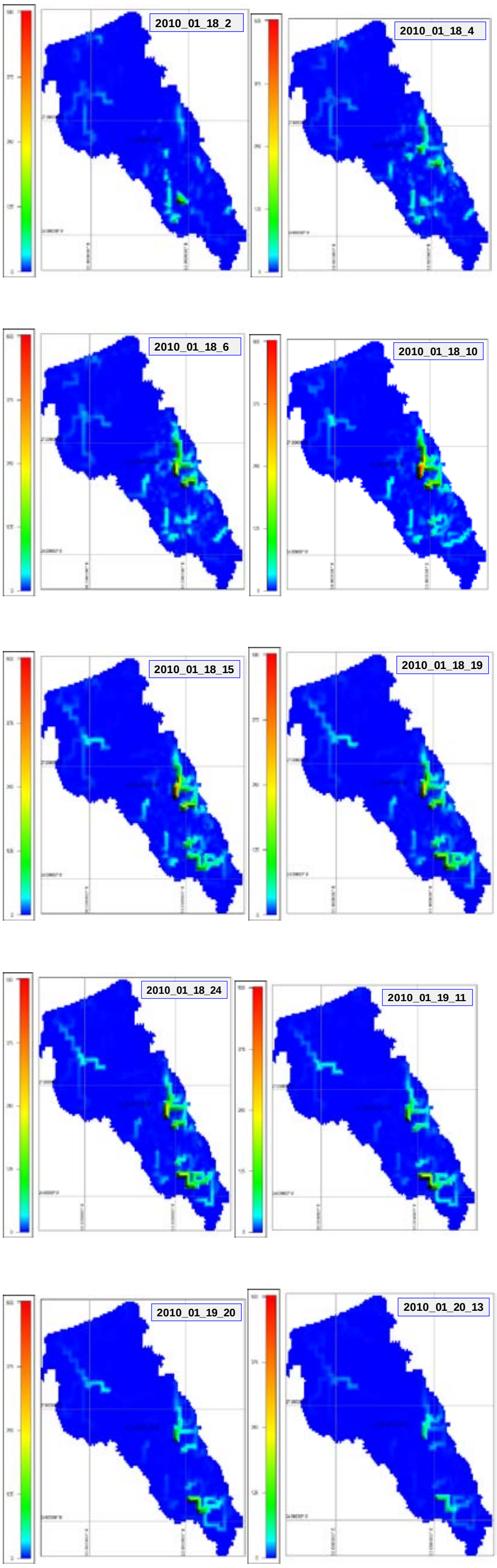


Fig. 20 Distribution maps for discharge (m^3/s) at the Nile River basin in Egypt during the event of Jan 18-20 of 2010.

6. Flash flood as new water resources

Water resources management are so crucial and important in arid regions due to the shortage of rainfall and high evaporation an transmission losses, that is pushing us to think about a practical way to solve this problem as well as protecting people form flash flood and proposing good management system for water resources evaluation and the best way for utilization it. Egypt is one of several arid and semi-arid countries that suffer from the flash flood threat and water resources scarcity. It is beginning to outstrip available water supply due to its increasing population, coupled with civilization. There is an urgent need to secure and utilize new supplies of water in order to sustain the minimum water base.

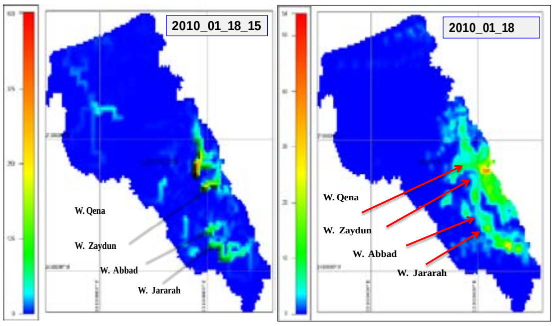
However, flash floods are devastating and represent as a big threat for human live and their properties, flash flood water can be utilized and managed in a proper way to be useful as water resources in arid regions with proposing the powerful management system or scenarios. The main water resource in Egypt is the Nile River. In this study, one of our significant targets is to evaluate the flash flood water as water resource by assessment wadi basins contribution of water to the Nile River. The water contribution of some wadi basins into the main channel of the Nile River is numerically estimated during the event from (Jan., 2010; Feb., 2003; Dec., 2004; and Apr., 2005) are listed in Tables 2, 3, 4, and 5 with identification of the outlet points and wadi names. It is varying from one wadi to the others. From these results, it is clear that how much of flash flood of wadi can contribute into the Nile River as additional water resources however its difficulty to control and management it to avoid or avert the devastating effect at the downstream areas along the Nile River.

7. Flash flood threat evaluation

Simulation results of flash flooding in the Nile River basin show how much the big threat of flash flood in wadi basins. It is investigated that form the distribution maps of flash floods is highly variable from one wadi to another, relying on the rainfall events spatial and temporal distribution, geomorphologic and topographic conditions in wadi catchments. It seems that the most affected region in every wadi basin is the downstream area while the flash flood water is accumulated in that regions and the flow volume is so big.

The remarks of the spatial variability of flash flood occurrence is illustrated in the flash flood event of Jan, 2010 where only wadi Qena, wadi Zaydun, wadi Abbad, and wadi Jaraah as shown in Fig.21. The most affected areas in this event are the downstream outlet of wadi Qena, wadi Zaydun, wadi Abbad, and wadi Jaraah as illustrated in Fig.22. Most of downstream regions are urbanized cultivated regions which have been suffering from this flash flood. The reasons why these regions at the downstream are vulnerable to the flash floods are the steepness slope of the catchments which make the travel time is short to the downstream area. The wadi bed channel is not so permeable which does not give a chance for infiltration process during the flash flood event due to the high velocity of flow. The last reason is the effect of heavy rainfall throughout short period affecting on this regions. In the real situation, the area around Aswan city which is representing in wadi Abbad and wadi Jaraah have been affected by this flash flood. The Egyptian government announced that more than 14 persons have been killed in Aswan and Sinai Peninsula as well as thousands of people becomes homeless. The results of this work illustrate that the proposed model can successfully predict the flash floods in such regions as well as the evaluation of the most affected regions as depicted in the results of distribution maps.

The simulated results dedicate that wadi Qena and wadi Abbad show flow rate about 502 (m^3/s) and 174 (m^3/s) and total flow volume about 6.85286E+07 m^3 and 2.27200E+06 m^3 which can reach to the downstream area during the flash flood event, but the flow rate and flow volume at wadi Jararah and wadi Zaydun less than those of the other two wadis. Therefore, these results indicate that the possibility of estimating spatiotemporal flow volume of the flash flood affecting the target regions and consequence, the risk maps and the prone areas of flash flood can be easily detected in wadi basins as illustrated in this work.



(a) (b)

Fig. 21 Distribution maps of flow discharge (m3/s) (a) and rainfall (mm/h) of the event of Jan, 2010 at the Nile River Basin showing the affected regions.

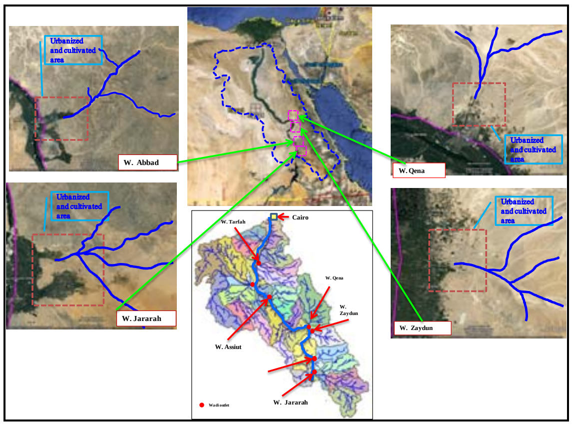


Fig. 22 The Nile River Basin and downstream areas of the affected wadis maps during the flash flood of Jan, 2010 showing the most prone regions for flash floods.

8. Conclusion

Referable to the scarcity of high quality observations, an attempt is made to use Global Satellite Mapping of Precipitation (GSMaP) for flash flood simulation in the wadi basins at Nile River in Egypt. GSMaP product has been compared with the monitored data of Global Precipitation Climatology Centre (GPCC). The results of the comparison between GSMaP and GPCC reveal that an overestimated or underestimated systematic seasonal bias is occurred. Hydro-BEAM as a hydrological physical-based model is used to simulate various flash flood events at wadi outlets of the Nile River using GSMaP data.

The simulation has been carried out to the flash flood events of Feb. 2003, Dec. 2004, Apr. 2005, and Jan. 2010. The simulated results present remarkable characteristics of flash flood hydrograph as reaching to maximum peak flow within a few hours. Additionally, the distribution results 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 follow: i) Simulation of flash flood has been successfully achieved in wadi basins in the Nile River basin, Egypt, ii) GSMaP is analyzed and calibrated in order to simulate the flash floods to overcome the problem of data paucity in arid regions, and iii) The contributed water from the wadi sub-catchments towards the Nile River during the flash floods has been estimated.

In conclusion, GSMaP precipitation is very effective in use with the physical-based hydrological model (Hydro-BEAM) to predict the flash floods at wadi basins of the Nile River. It could be applied in wadi basins at different arid regions. Currently, developing of a comprehensive flash flood warning system to minimize the human life loss and infrastructure damage causing by flash floods is desperately needed.

Acknowledgment

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衛星観測データを基にしたワジ水文モデリングによるナイル川流域の鉄砲洪水シミュレーション

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要 旨

乾燥地において，鉄砲洪水は人間生活や生活基盤に最も甚大な被害を及ぼす災害である。しかし降水の地上観測データが乏しいため，衛星観測データのGSMaPを利用して，エジプト・ナイル川にある複数のワジ流域での鉄砲洪水シミュレーションを行った。そのデータはGPCCの観測データとの比較から統計解析されてきたものである。続いて，2003年2月・2004年12月・2005年4月・2010年1月に起きた4つの鉄砲洪水シミュレーションを水文モデルであるHydro-BEAMで計算した。シミュレーション結果から，短時間で最大ピーク流量に達する鉄砲洪水の顕著な特徴が見て取れる。加えて，流量や降雨の分布結果から，１つのワジ流域から他のワジ流域へ時空間に大きな変動が発生しているのが見える。最終的に鉄砲洪水発生時のワジ流域からナイル川への流出量まで算出している。以上から，ワジ流域の鉄砲洪水を予測する際，GSMaP降水量はHydro-BEAMで使うには大変効果的であると言える。

キーワード： 鉄砲洪水，ナイル川，水文モデル化，乾燥地, GSMaP, GPCC