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Integrated Management of Flash Flood in Wadi System of Egypt: Disaster Prevention and Water Harvesting

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Synopsis

In the arid regions, flash floods are among the most devastating hazards in terms of human losses and economical damages. On the other hand, however, flash floodwater can be an important source of water in arid environments. Unfortunately, there is often a lack of data on key hydrological processes in arid areas. This limits the ability to understand the flash flood process and use this knowledge to minimize its threat. Egypt is one of arid countries that faces flash flood in the coastal and Nile wadi systems. Until today, no proper protection from flash floods proposed for all wadis basins in Egypt. This study aims to discuss challenges, impacts, previous studies and current mitigation strategy of flash floods at Egypt. Wadi Abadi in the Eastern Desert is selected as a case study for flash flood simulation. Due to the scarcity of observational data, computation are carried out using sophisticated techniques where remote sensing data used with Hydrological River Basin Environmental Assessment Model (Hydro-BEAM) to simulate several flash flood events at wadi Abadi. The paper propose an integrated management approach for flash flood at wadi system.

Keywords: Flash Flood, Wadi, Egypt, Hydro-BEAM

1. Action and Background

The United Nations Office for Disaster Risk Reduction (UNISDR) reported that recently the Arab region was affected by more than 270 disasters during 30 years, causing in more than 150,000 deaths and affecting approximately 10 million people (EM-DAT, 2015). These disasters are mainly flash floods and droughts. A flash flood is defined as a rapid developed flood in just few minutes or hours of excessive rainfall without visible signs of rain, or an accident like a dam or levee break. A flash flood can be generated during or shortly following a rainfall event, especially when high-intensity rain falls on steep slopes with shallow, impermeable soils, exposed rocks and poor or sparse vegetation (Lin, 1999).

Egypt is one of arid and semiarid Arabian countries that faces flash flood in the coastal and Nile wadi systems. Wadi (W.) is a dry riverbed that can discharge large water volumes after heavy rainfall as shown in Photo 1. Recently, Flash floods are extensively occurred in Egypt, several flood events occurred in Sinai Peninsula, Eastern Desert, Red Sea wadis such as Safaga, Ambagi, El-Baroud, and Upper Egypt such as Assiut, Sohag, Qena, and Aswan as shown in Fig. 1. Also this figure illustrate different wadi systems at Egypt based in downstream feature, where wadis discharge water either to the coastal areas or to the Nile/desert plateau. Some records about such severe floods affected Egypt from 1975 to 2014 with an estimated total economic damage of approximately 1.2 billion USD/year.

Flash floods in these wadis are produced by convective cloud mechanisms at the beginning or end of the summer and winter, as warm air masses that produce heavy rainfall associated with thunderstorms as they are pushed over the Red Sea and Mediterranean

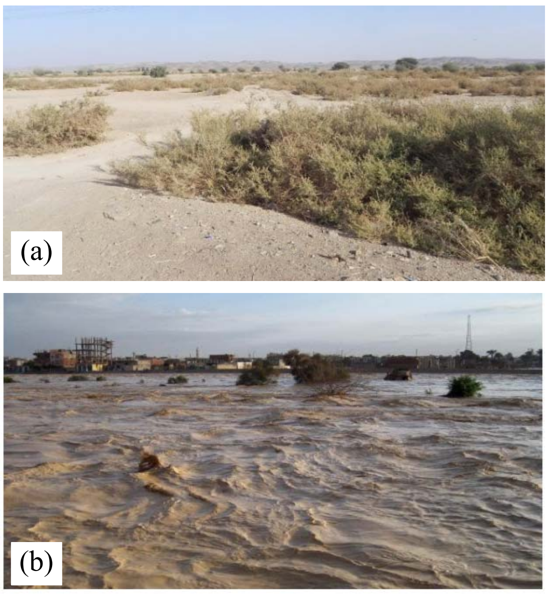

Photo 1 Wadi system in (a) dry, and (b) flash flood condition

Sea. Additionally, floods can occur over a local small wadi area, affecting the neighborhood or community, as was the case in 1992 and 1994, or the entire basin, such as the floods of 1996 and 2010, which affected not only the Egyptian Red Sea coast but also the Sinai Peninsula.

Nile water is insufficient to meet all the Egyptian demand especially in the future due to increasing of the population. According to the general census of Egypt, the population has reached 95 million inhabitants (86.8 million inside Egypt inhabitants according to population monitor (General Census of Egypt, 2014) of whom about 99% are concentrated in the Nile Valley and Delta. One of the important issues in the future development is to reallocate the population over a larger area. To reach this objective, it is essential to reclaim new lands, build new cities, hospitals, schools, create new industrial regions, etc. in order to create new jobs and provide the required food for the new communities, which makes more pressures on water resources of Egypt. Therefore, such floodwater is an important source of water to develop and create new sustainable communities in some of potential wadis.

Floods, although infrequent two or three times every decade, can be extremely damaging and represent a threat to life as well as property. Due to climate change impacts, such threats are likely to increase. In Egypt, most of practicable routes for highways roads and other infrastructures are constructed across wadi. Rapid increase of population, urbanization, economic and touristic developments has pushed people for construction in high disaster risk zones such as on wadi flood plain.

Hydrological assessment studies across vast regions of the arid world are often hindered by the inaccessibility of these areas and the paucity of data sets, as well as the high expenses and difficulties entailed in acquiring these data sets, their unpublished nature, and their varying scales, projections, and datum (Becker, et al., 2012).

The main objectives of the current study and research investigation are as following:

1. To clarify the occurrence and processes of flash floods;
2. To mitigate and utilize floodwater as a new supply for water harvesting project in rural desert areas;
3. To set-up potential hazard map with an early warning system;
4. To prioritize wadi systems based on risk assessment;
5. To define obstacles to flash flood flows and prepare protection plan.

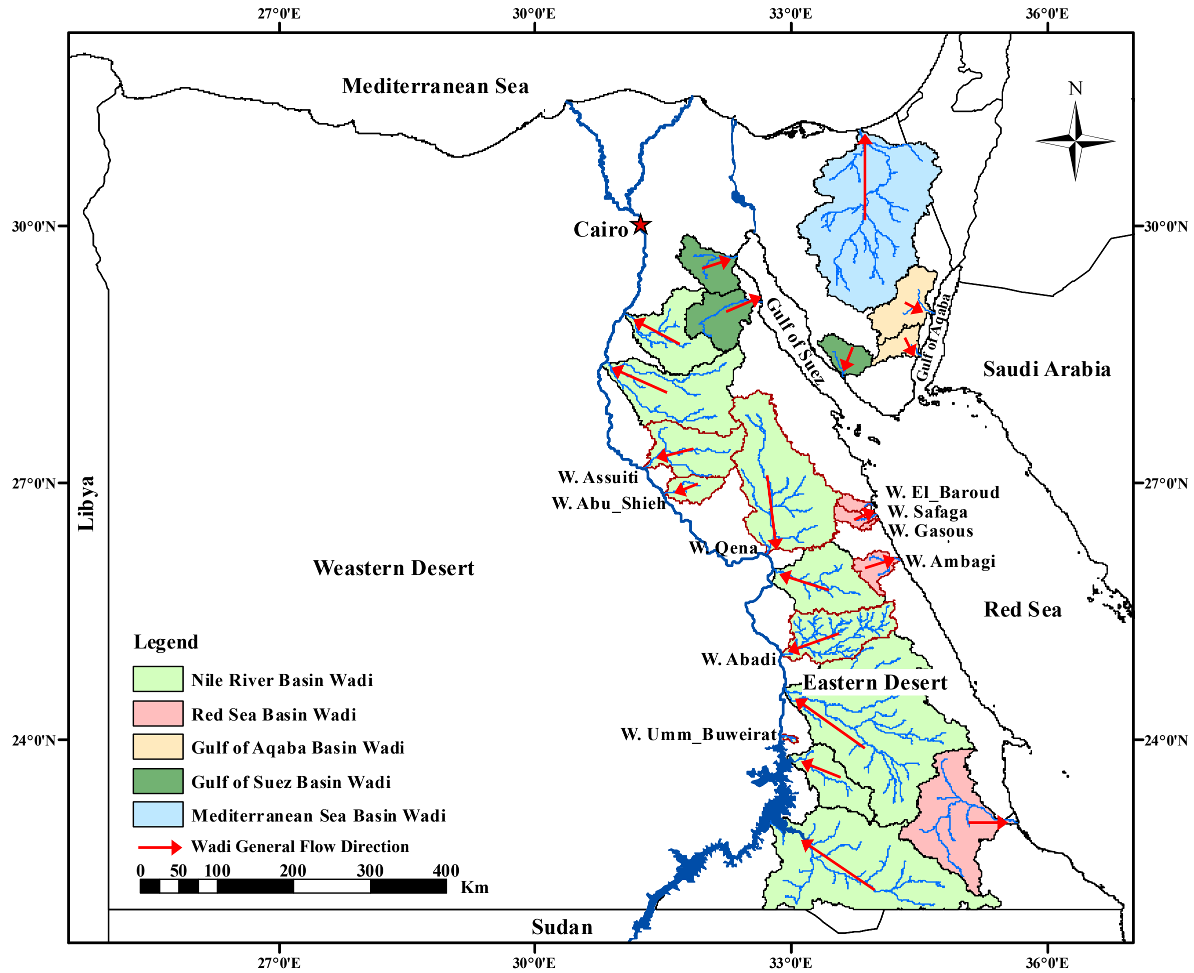

Fig. 1 Eastern Deseret& Sinai Peninsula main wadis showing different wadi systems based on the downstream feature (wadis in red outline were visited at the field investigation)

Table 1 Flash flood main events at Egypt

Date	Affected Area	Recorded Damages
Feb. 2015	Sinai, Red Sea region	Road damages
Mar. May 2014	Taba, Sohag, Aswan, Kom Ombo	Dam failure at Sohag, road damages
2013	South Sanai	2 death, road damage
2012	W. Dahab , Catherine area	Dam failure, destroyed houses
Jan. 2010	Along the Red Sea coast, Aswan, Sinai	12 death, damaged houses& roads
Oct. 2004	W. Watier	Road damage
May 1997	Safaga, El-Qusier	200 death, destroy roods, demolished houses damaged vehicles
Nov. 1996	Hurghada, Marsa Alam	
Sep. Nov. 1994	Dhab, Sohage, Qena, Safaga, El-Qusier	
Mar. Aug. 1991	Marsa Alam, W. Aawag	Destroyed houses
Oct. 1990	W. El-Gemal, Marsa Alam	
Jan. 1988	W. Sudr	5 death
Oct. 1987	South Sanai	1 death, roads damage
May., Oct. 1979	Aswan, Kom Ombo, Idfu, Assiut, Marsa Alam, El-Qusier	23 death. demolished houses
Feb. 1975	W. El-Arish	20 death, road problems
1972	Giza	Destroying houses, roads and farms

2. State-of-Art of Flash Flood at Egypt

In recent years, flash floods became more frequent causing life losses and significant damages at Egypt. Destructive flash flood frequently occurred in Egypt between 1972 to 2015 as shown in Table 1. The information included in this table were collected from available reports, newspaper, dissertations and published articles as Eliwa, et al. (2015). These floods destroyed main infrastructures as roads, buildings, power towers, villages, agricultural lands, pipelines, injured and killed human and animals. For instance economic losses due to Taba at Sinai Peninsula 2014 flash flood is 1 Billion EGP.

The geology, geomorphology, and hydrogeology of wadi system have been studied by many studies as Abdel Moneim (2005), Elewa and Qaddah (2011), Abdelkareem and El-Baz (2015). However, other wadi aspects, which more related to flash flood like hydrological modelling, risk assessment and integrated management not sufficiently covered. We will tray in the following section to summarize the literature that related to flash floods at Egypt.

There are some authors interested in groundwater recharge by surface runoff and rainfall events as Gheith and Sultan (2000, 2002) who investigate recharge of the alluvial aquifers flooring wadi El-Arish in Sinai and Eastern Desert (W. Tarfa, W. Asyuti, W. Qena, W. Hammamt). At these studies, a hydrological model that combined the spatial and temporal distribution of rainfall, suitable infiltration parameters, and appropriate sub-basin unit hydrographs used to estimate initial upstream loss, transmission losses along stream networks, and downstream runoff. The model incorporate remote sensing, meteorological, and geological data in a geographic information system (GIS) environment.

El Bastawesy et al., 2009 present an approach for modelling flash floods by integrating remote sensing and DEM data in GIS. In this research the parts of a catchment that have been affected by a recent flood event discriminated from unaffected parts, using a time series of Landsat images due to the increasing spectral reflectance of channels affected by flash floods, as result of deposition of fine sediments in these channels. This synthetic GIS-based system only, cannot be relied on to model the hydrographs reliably, but physical parameters, such as rainfall intensity, distribution, and transmission loss, must be considered.

Milewski et al. (2009) make rainfall–runoff and groundwater recharge computations for main wadis at Sinai Peninsula and Eastern Desert due to heavy rainfall events between 1998 to 2007. That study basically rely on wide-range of global remote sensing data sets. For the investigated watersheds the average annual precipitation, average annual initial losses, average annual runoff, and average annual recharge through transmission losses were estimated. Also this methodology utilized to estimate average annual recharge for the Nubian Sandstone aquifer at South Sinai wadis (Sultan et al., 2011).

At the study of Ismail et al. (2010) the Flood Routing Processing (FRP) as a rainfall-runoff model and GIS used to calculate direct runoff volume, peak discharge and morphometric parameters at W. Abu Ghusun south of the Eastern Desert. Flash flood for some rainfall events for Nile River wadis simulated by Saber et al. (2010) linking Hydro-BEAM with different satellite data.

Good example for practical and cost-effective integrated (geochemistry, geophysics, and modeling) solutions that utilize web-based GIS technologies and global remote sensing data sets is presented by Becker et al. (2012) at Eastern Desert and Sinai Peninsula wadis. This study adopted methodologies to develop a conceptual model for hydrogeological settings conducive to groundwater accumulations of meteoric origin at different aquifers types, and construct a hydrologic model to estimate average annual runoff and recharge over the major watersheds.

Fathy et al. (2014) develop a lumped model to solve the hydrologic problems in arid watershed and compared with results from Watershed Modeling System (WMS). His model is applied to W. Sudr in Sinai Peninsula.

Regarding flash flood assessment El-Shamy, (1992) develop a method to evaluate the recharge and flash flood possibility at the different sub-basins, utilizing some of the geomorphometric parameters as bifurcation ratio, drainage density and drainage frequency.

By integration of geological, geomorphological, field data and remote sensing data, a GIS-based geomorphological hazard assessment and mapping have been made at many areas in Egypt like Red Sea area between Safaga and Quseir (Youssef et al., 2009) and along the Feiran– Katherine road, South Sinai (Youssef et al., 2011). Presenting the effect of flash flood hazard on different urban infrastructures proposing dam sites to minimize the flood hazard. Hazard probability estimation of the different basins based on the morphometric parameters (El-Shamy, 1992). Moreover the morphometric analyses have been used to estimate the flash flood risk levels of sub-basins within the watersheds.

Flash flood hazards assessment also has been made in Abu Dabbab drainage basin. Remote sensing data were used to delineate the alluvial active channels, which were integrated with morphometric parameters extracted from DEM into GIS environment to construct a hydrological model that provides estimates about the amount of surface runoff and the magnitude of flash floods (Abou El-Magd et al., 2010).

Kehew et al., (2010) reconstruct high magnitude flash flood in W. Isla, South Sinai, using palaeohydrological parameters, where flood velocity and discharge is related to the size of boulders transported within the wadi though various theoretical and empirical methods. Further, the amount of rainfall necessary to generate a flood of the calculated magnitude range estimated using the calibrated Soil Water Assessment Tool (SWAT) model.

W. Abadi was studied by Ibrahim et al. (2011) targeting to assess, evaluate hydrology and flood hazard degree and including potentials of both surface and groundwater resources in the wadi. Paleo flood height measured at the field utilized with rating curve to expect peak flow at Jan. 2010 flash flood event. Then this peak flow used in hydrological modelling parameters calibration.

To determine potential sites of surface runoff recharge at Sinai, remote sensing, GIS and watershed modeling were integrated to produce a multi-criteria-decision support system of different layers like volume of the annual flood, lineaments frequency density, basin morphometric parameters, average overland flow distance and soil infiltration. These criteria were used for conducting a Weighted Spatial Probability Modeling to determine the potential areas for the rainwater harvesting. The potential runoff available for harvesting was estimated by applying Finkel-SCS rainfall runoff methods (Elewa et al., 2012). Further, the same methodology used to propose the best dams location for the surface runoff control at W. El-Arish, design criteria and technical considerations were given for the proposed control structures (Elewa et al., 2013).

For groundwater recharge estimation and surface runoff, the relation between rainfall and runoff was calculated depending on the paleo-flood hydrology information. Two models were used to calculate the rainfall–runoff relationships for El-Hawashyia basin and Ghazala sub-basin (Gulf of Suez). To evaluate the flood hazard of the studied basins, some morphometric parameters with a direct effect on flooding have been studied, and their relationship with the flash flood was analysed (Masoud et al., 2013). McLane and Wüst (2000) make a master plan to mitigate the impact of flooding on the historic tombs in the Valley of Kings watershed.

Integrated management approach proposed by Masoud (2004), which focuses on the integration of remote sensing and GIS techniques for flash flood potentiality, mitigation, and floodwater resource management in Safaga area at the Red Sea coast. Flood risk prone areas were mapped, suitable sites for building dams were detected, and highly probable sites for recharging water were located. Further, several rainfall- runoff analysis and discharge forecasting as well as flash flood inundation mapping techniques were performed to fully assess the flood potential.

Al Zayed et al. (2013) evaluated the water harvesting potential at W. Watier, South Sinai. The analysis is based on the Integrated Water Resources Management (IWRM) guidelines. Therefore, physical, social, environmental and institutional analyses were carried out. The potential runoff was estimated by applying the Soil Conservation Services (SCS) method using the Hydrologic Engineering Center (HEC-1) model, and then GIS was used to examine the potential sites by combining different geology, slope and land use layers. Eliwa et al. (2015) summarize the status of flash flood at Egypt, showing the development of management strategy.

3. Facts Findings for Wadi Flash Flood Management at Egypt

In Egypt several measures are adopted to mitigate the flash flood as a combination of obstacle dams, and detention dams at upstream and artificial lakes at downstream leads to a better management of flood retention and groundwater recharge. A group of Kyoto University and Japan Dam Engineering Center (JDEC) made preparatory field investigations for several wadis in Egypt, from 22th to 29th of November 2014, for facts findings and selecting the type of suitable integrated flash flood measures and their design criteria. The main objectives of these field investigations were to obtain hydrological, geological, structural and operational conditions of existing flood mitigation dams at wadi basins in Red Sea coast and Eastern Desert, and clarify the possible cooperation on selected pilot project. During the trip, wadi basins were surveyed along Eastern Desert between Nile River and Red Sea coast, investigating flash flood mitigation and management strategies at Egypt.

Egyptian government make flash flood mitigation and harvesting master plan: (a) short-term plan for high risk wadis and, (b) long-term plan for low risk wadis. There are different flash flood management structures at Egypt as storage dams, obstacle dam, artificial lakes, diversion dikes, embankments, and artificial drainage channel as indicted at Fig. 2.

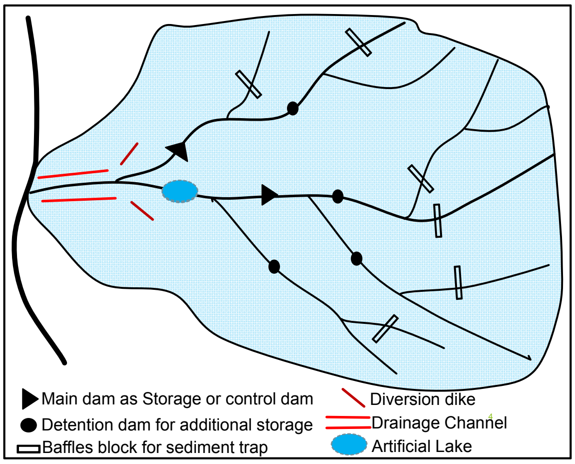

Fig. 2 Flash flood mitigation structures at Egypt

Selection and design of the best mitigation measures combination based on expected floodwater quantity, wadi risk degree, potential affected infrastructures and flash flood return period.

Photo 2 shows the main flash flood mitigation and management structures at Egypt and their characteristics:

I. Obstacle dam: low dam (less than 4-6m), only for reducing flood impact (velocity reduction),

II. Storage retention dam: middle height dam (around 10m), for flood retention and additionally water harvesting, and

III. Artificial lake: excavated, depth (2-4m), for flood retention and additionally water harvesting.

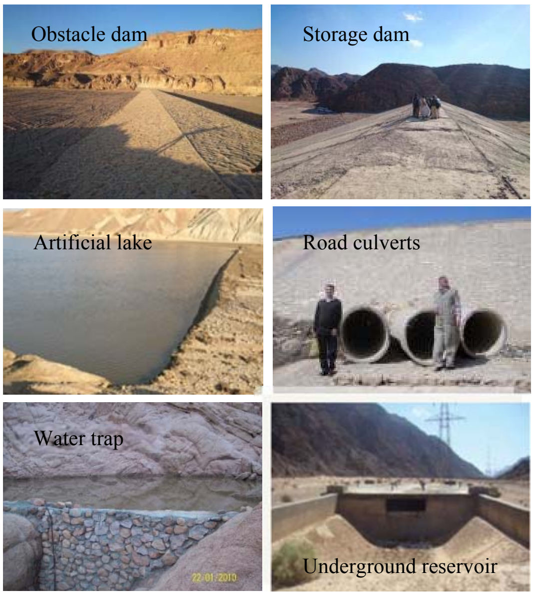

Photo 2 Flash flood management structures at Egypt

Accurate prediction and early warning for flash flood in a form that is readily understood by related authorities and common people is required so that they are prepared against such hazard before it become disasters (Khan, 2013). By doing so lives and property can be protected. However, warning system is a vital tool for forecasting the potential flash flood, there is only one system at Egypt. This system installed at W. Watier, South of Sinai Peninsula that considered as one of the most active wadis in Egypt with respect to flash floods. The Ministry of Water Resources and Irrigation in collaboration with Belgium has installed this early warning system called Flash Flood Manager (FlaFloM).

4. Flash Flood Simulation at W. Abadi Case Study

With increasing pressure due to flash flood disaster and water resources limitation in Egypt, application of rainfall-runoff models can be a part of the solution to mitigate flash flood, and at the same time manage and sustain the water resource. This paper attempts to simulate two flash flood events (January 2010 and March 2014) at W. Abadi. Those flash flood events were selected because they are the most recent events and based on the availability of GSMaP rainfall data in the target basins. Finally, we will propose different management concepts for flash flood management at wadi system.

4.1 Study Area

W. Abadi is located at the southern part of Eastern Desert of Egypt, which is bounded by Red Sea and the Gulf of Suez from the east, and River Nile valley from the West as shown in Fig. 3. W. Abadi is located between latitudes 24˚ 52' - 25˚ 37' N and longitudes 32˚53' - 34˚ 15' E with total area about 6800 Km^2. W. Abadi in some references called also W. Abbad, W. Abad or W. El-Btur.

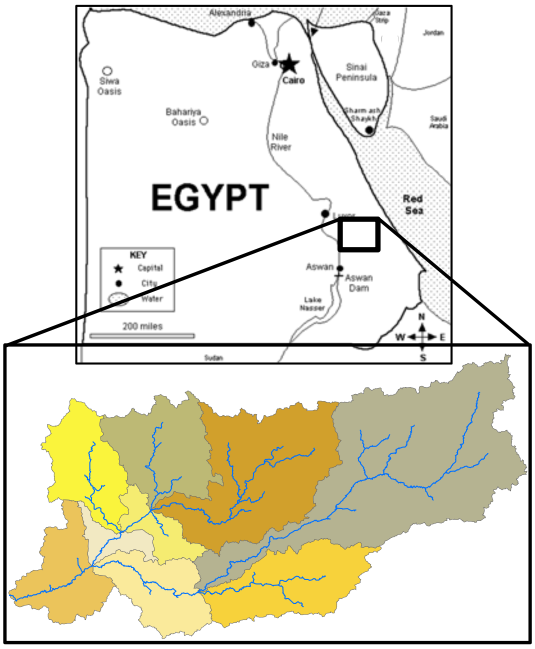

Fig. 3 Map of Egypt and location of W. Abadi

W. Abadi general flow direction is NE-SW and at the end pour into Nile River east of Idfu city. The downstream part of W. Abadi contains delta W. Abadi, where agriculture land cover about 29 km^2.

Regarding the climatology of W. Abadi, the study area characterized by an arid climate with average annual rainfall of 25 mm and high evaporation rate. The rainfall is high variable in time and space, where sometimes there is no rainfall all over the year and sometimes heavy rainfall intensity occurred in a short time. Due to sudden heavy rainfall, the study area is frequently affected by flash flood events as in October 1991, November 1994, October 1997 and January 2010 (Ibrahim et al., 2011). W. Abadi is classified as medium flash flood risk degree by Ministry of Water Resources and Irrigation at Egypt (MWRI, 2012).

The target area studied by Milewski et al. (2009) estimating the annual averages of precipitation, runoff, and recharge through transmission losses. Also flash

Photo 3 Main channel of W. Abadi and potential location of CSG dry dam

flood simulation for some rainfall event was made by Saber et al. (2010). Ibrahim et al. (2011) assess and evaluate hydrology of W. Abadi including potentials of both surface and groundwater resources in the wadi. In that, research paleo flood height measured at the field utilized with rating curve to expect peak flow at Jan, 2010 event, then this peak flow used in hydrological modelling parameters calibration. Therefore, we compare our results for Jan. 2010 event with this research.

As result of increasing pressure of population, and unmanaged development, people started reclamation of new lands for agriculture even building their houses at more prone areas for flash floods at W. Abadi. The study area is also dissected by vital roads like Idfu-Marsa Alam road as shown in Photo 3. This road frequently damaged by flash floods and the Egyptian government start to make flash flood mitigation for this important road. Due to aforementioned reasons, we will try to simulate flash floods at W. Abadi for the most two recent events, Jan. 2010 and Mar. 2014.

4.2 Methodology

To face data limitation on arid environment, different remote sensing data were utilized with a physical based distributed hydrological model (Hydro-BEAM) to simulate two flash flood events in the target basin. Data processing and modelling processes were made using in house developed programs. The watershed is divided into equally spaced cells or meshs as basic units. Different data processing have been made before the main Hydro-Beam program to identify different parameters for each mesh. For W. Abadi, watershed divided in to meshs with a resolution of 1km*1km.

(1) Hydro-BEAM Model

This approach is based on Hydrological River Basin Environmental Assessment Model (Hydro-BEAM). This model was developed by Kojiri et al. (1998). The first purpose of Hydro-BEAM is to used as a tool for simulating long-term fluctuations in water quantity and quality in rivers through understanding of the hydrological processes that occur within a watershed (Kojiri et al., 1998). It has since been used in many researches as a river basin environment assessment model through comprehensive simulation including the control of water quantity, water quality, and sediment such as reservoir operation for assessing their risk.

Many approaches were based on Hydro-BEAM, where a methodology for assessing the similarity between watersheds was proposed by Park et al. (2000), to investigate sediment transport processes in the large watershed of the Yellow River, China (Tamura and Kojiri, 2002), and to investigate pesticide levels in rivers and their effects on hormone levels in fish (Tokai et al., 2002).

The original Hydro-BEAM model that was used for the humid conditions then it was adopted for simulation in the arid areas in wadi system and has been calibrated in W. Elkhoud at Oman by Saber, (2010) indicating that proposed model can be used to simulate the flash floods in arid areas.

(2) Main Structure of Hydro-BEAM

Hydro-BEAM is a physically-based numerical hydrological model and it can be summarized as following. Surface runoff and stream routing modeling based on the kinematic wave approximation is applied, initial and transmission losses modeling is estimated by using SCS (1997) method (an empirical model for rainfall abstractions suggested by the U.S Soil conservation Service) and Walter's equation (1990) respectively. Groundwater modeling based on the linear storage model (Saber, 2010).

The watershed is modeled as a uniform array of multi-layered mesh cells, each mesh containing information regarding surface land use characteristics, ground surface slope direction, runoff, and the presence or absence of a channel. The original Hydro-BEAM model that was used for the humid conditions can be adopted for simulation in the arid areas in wadi system as described in the following sections. Basic structure of Hydro-BEAM model is shown in Fig. 4.

With Hydro-BEAM the target basin is divided into an array of unit mesh cells. Each mesh cell contain a combination surface layer and several subsurface, labeled A, B, C and D. A-Layer is composed of the surface and soil surface layer. Kinematic wave model and Manning equation are used to estimate the surface runoff and roughness coefficient in each mesh of the watershed basin. B-D-Layers are subsurface layers, which are evaluated using the linear storage model, with the assumption that both of B and C layers have flow toward the river, but D-layer is represented groundwater storage and does not has influence in river flow. When storage water content reaches to a saturated state, water content flows into the upper layer of model as returned style.

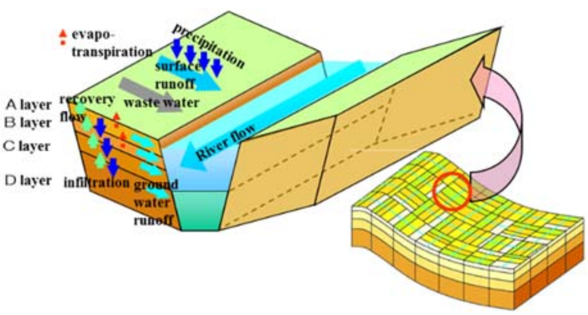

Fig. 4 Conceptual illustration of Hydro-BEAM (Kojiri et al., 1998)

4.3 Input Data

(1) Digital Elevation Model

Topographic data were obtained by the Shuttle Radar Topography Mission (SRTM), which was cooperative project between the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) to produce the near global set of digital topographic data with 16m vertical accuracy (at 90% confidence) (USGS, 2008). The used data set is SRTM void filled 3arc-second elevation data. This data are result of additional processing to address areas of missing data or voids. Global DEM data are available at this US geological survey website.

The study area is characterized by middle range of relief with elevation ranges from 1029 m above sea level (a.s.l.) at the upstream, where the basement outcrops is existed, to 78 m a.s.l. at the downstream, and generally slopes towards the west, draining into the Nile River as shown in Fig. 5.

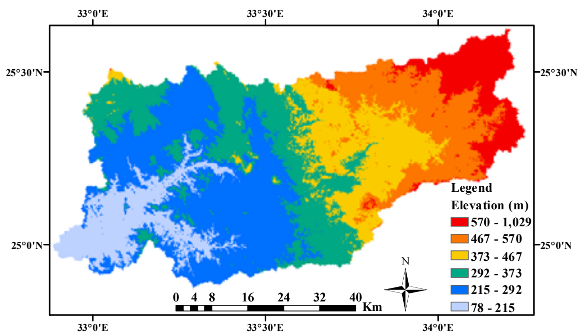

Fig. 5 Wadi Abadi Digital Elevation Model

DEM data also used for watershed delineation (including sub-basin boundaries and stream network detection), flow direction and mesh slope identification. All of that information for each mesh used as input for main Hydro-BEAM program.

(2) Rainfall data

The used precipitation data is Global Satellite Mapping of Precipitation (GSMaP) data which developed by GSMaP Project. The GSMaP project was promoted for a study "Production of a high-precision, high-resolution global precipitation map using satellite data," sponsored by Core Research for Evolutional Science and Technology (CREST) of the Japan Science and Technology Agency (JST) during 2002-2007. (TRMM Real-Time Office, 2013).

Table 2 Description of GSMaP data (TRMM, 2013)

Variable	Rainfall rate (mm/hr)
Domain	Global (60N - 60S)
Grid resolution	0.1 degree latitude/longitude
Temporal resolution	1 hour

The distribution maps of GSMaP precipitation of Jan. 2010 and Mar. 2014 events (Fig. 6 and Fig. 7) at W. Abadi catchment show that there are highly variation of rainfall distribution in space and time. The rainfall events of Mar. 2014 has more uniform distribution than Jan. 2010 event, which mainly concentrated on the upstream part especially the northern eastern part of the watershed.

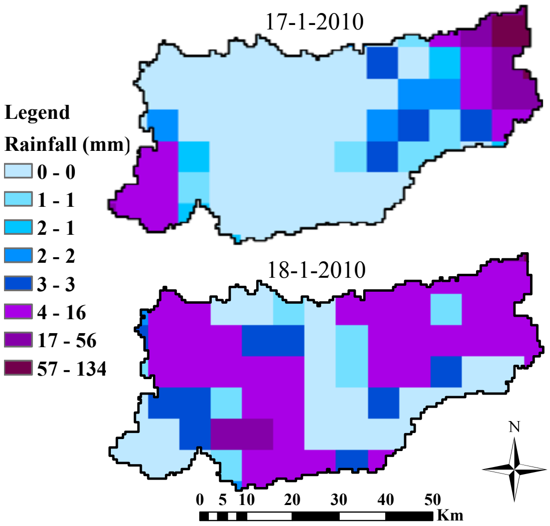

Fig. 6 GSMaP data in 17-18, Jan. 2010 at W. Abadi

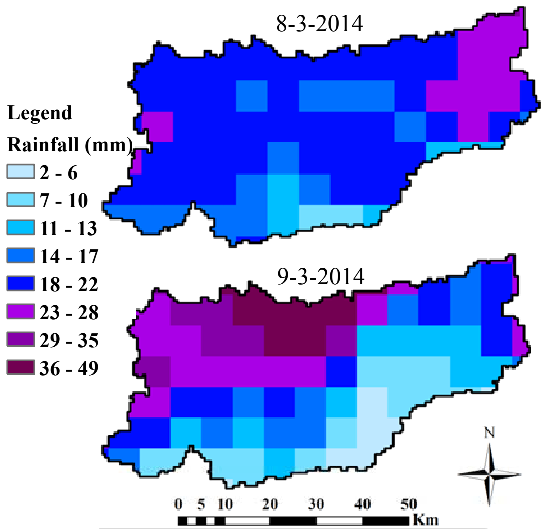

Fig. 7 GSMaP data in 8-9, Mar. 2014 at W. Abadi

(3) Land Use Data

Global Land Cover Characterization (GLCC) data were used to identify the different land use types at W. Abadi. The U.S. Geological Survey's (USGS) National Center for Earth Resources Observation and Science (EROS), the University of Nebraska Lincoln (UNL) and the Joint Research Centre of the European Commission have generated a 1-km resolution global land cover characteristics data base for use in a wide range of environmental research and modelling applications (GLCC, 2008). We just identify five land use types, desert, field, urban, water and forest as shown in Fig. 8.

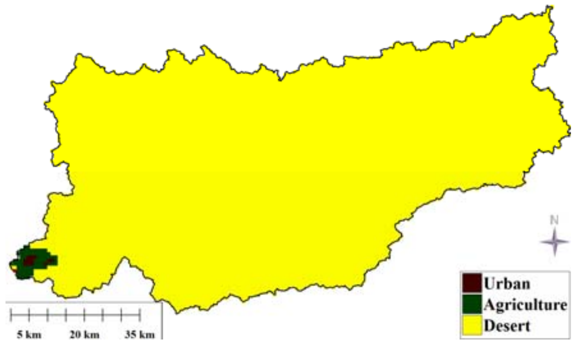

Fig. 8 GLCC land use types at W. Abadi

4.4 Watershed Delineation

The watershed delineation of the target wadi to detect the main streams network, watershed and sub-basins boundaries, was accomplished using ArcMap 10.2 GIS software and SRTM (90 m resolution) DEM as input. Watershed modelling steps are shown in Fig. 9. By comparing the generated streams to the available satellite images, Google Earth and the geological map, it is evident that the streams generation produced good results. Watershed delineation and stream network determination of W. Abadi are shown in Fig. 10.

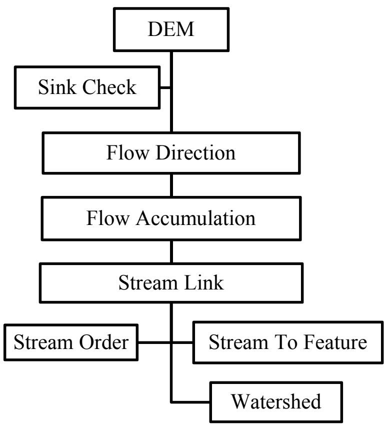

Fig. 9 Watershed modelling flowchart

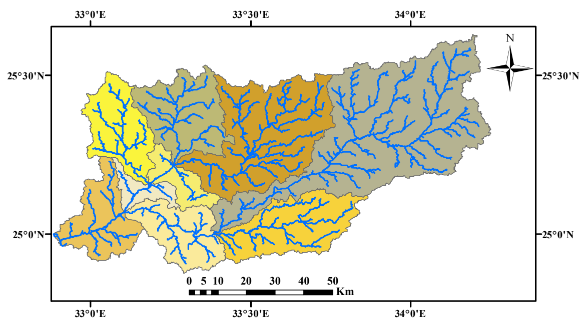

Fig. 10 Wadi Abadi Watershed

5. Results and Discussion

Two flash flood events were simulated Jan. 2010 and Mar. 2014 at W. Abadi case study. Both events are big flash flood events having high impact on many wadis at Egypt, especially Jan. 2010 event that affected a wide area of Egypt. This flash flood hit many wadis all over the Red Sea coast at the Eastern Desert and Sinai Peninsula, leaving many destroyed houses and roads. Local authorities reported more than 12 deaths and thousands of affected peoples.

Discharge of each mesh all over the basin is computed. The calculation points selected here show the location of the highest calculated discharge in 2010 (Fig. 11) and 2014 (Fig. 13) flash flood events. From calculation point distribution, variation of the highest discharge locations can be noticed from one event to another. This is due to different rainfall patterns for each event. The simulated hydrographs of flash flood events in the studied W. Abadi basin show the flow features of flash floods at wadi system, where it takes a few hours to reach to the peak discharge and then gradually decreasing until end of the event as shown in Fig. 12 and Fig. 14.

The Simulated hydrographs are compatible with Ibrahim et al. (2011) where paleo flood height measured at the field utilized with rating curve to estimate peak flow at Jan, 2010 event. Then this peak flow used in hydrological modelling parameters calibration. For 2010 event Ibrahim et al. (2011) maximum flow estimation were 58.3 m^3/s. At the same point, our simulation estimate the peak flow to be 55 m^3/s as shown in Fig. 15.

From the simulated hydrographs, it is noticed that the discharge rate at wadi system is highly variable from one point to other. For instance, in 2014 flash flood event at the upstream of W. Abadi the flow rate is about 160 m^3/s, but at the wadi downstream, the flow rate is less than 80 m^3/s. In 2010 event flow rate is equal to about 120 m^3/s at the upstream part and decrease to about 40 m^3/s at the downstream part. So not all the water reach to the outlet point due to rainfall distribution, transmition losses, slope variation and the big area of the watershed. Hydrograph shape and time to reach the peak flow are also highly variable from one point to another because of difference in precipitation, catchment area and the geomorphologic parameters of the upstream catchment.

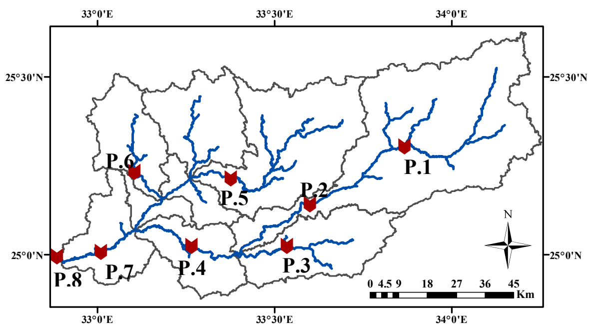

Fig. 11 Calculation points for Jan. 2010 event

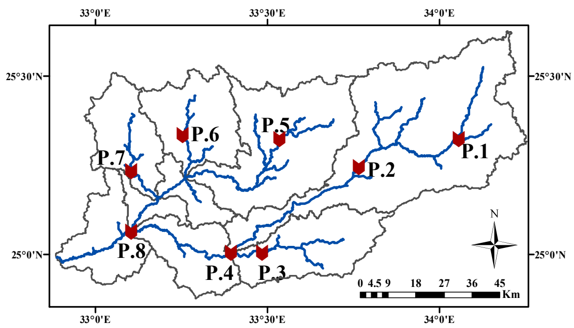

Fig. 13 Calculation points for Mar. 2014 event

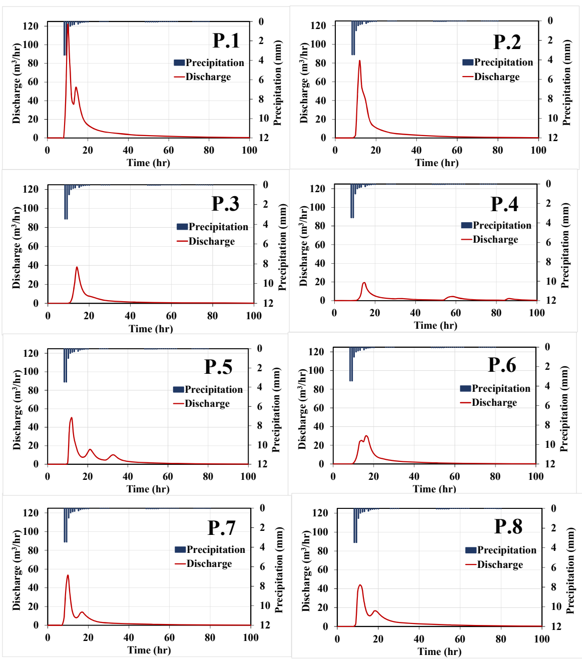

Fig. 12 Simulated hydrographs for Jan. 2010 event

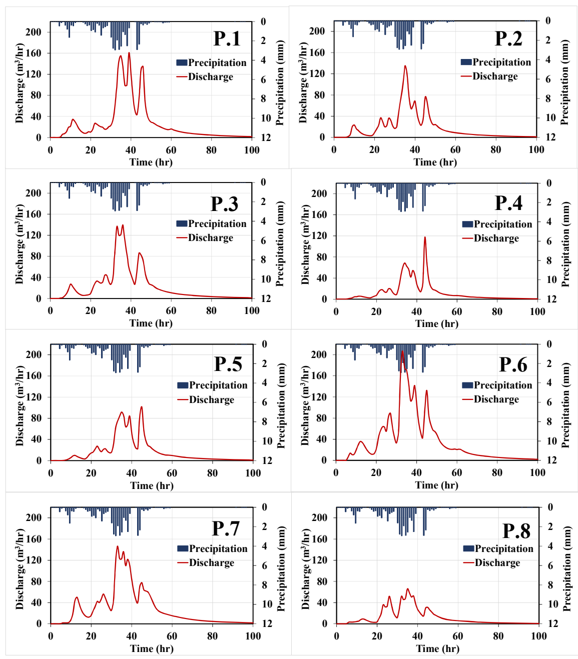

Fig. 14 Simulated hydrographs for Mar. 2014 event

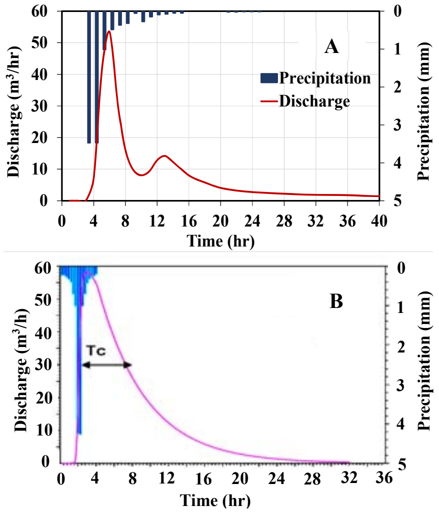

Fig. 15 Simulated hydrograph (A) compared with estimated discharge by Ibrahim et al. (2011) (B) at P.7

Geographic distribution maps of the simulated discharge for Jan. 2010 and Mar. 2014 events, Fig. 16 and Fig. 17 respectively, have been carried out to specify the locations of high and low surface flow rate and to indicate the different runoff patterns at W. Abadi. Surface runoff distribution is completely different at the 2010 and 2014 events, due to high variation of rainfall distribution in space and time. Where rainfall of Mar. 2014 event has more uniform distribution than Jan. 2010 event, which mainly concentrated on the upstream part especially the northern eastern part of the watershed, so the surface runoff distribution is highly affected by rainfall distribution.

Surface runoff distribution maps confirm that for the same rainfall event, some parts of the watershed have a flash flood and on the other hand, some locations have no flow. Where it is noticed that both of 2010 and 2014 events have more surface runoff rate at the upstream part than the downstream part, because of higher slope at upstream part than the downstream part that characterized with gentle slope. Simulated discharge distribution maps show how 2014 flash flood event is bigger in terms of maximum peak flow and surface runoff area. Where the maximum discharge is 125m^3/s and 210m^3/s for 2010 and 2014 flash floods evens respectively, and in general, the surface runoff quantity all over the watershed is much bigger at 2014 event than 2010 event.

These distribution maps can be helpful in flash flood, water resources, urban and land use management. It can be useful in detecting flash flood prone areas and consequently mitigate and mange flash floods at those areas. In addition, it can be valuable for wadi development and land use management to identify the best location for residential, touristic, industrial, agricultural activities. Surface run off zones can give signs of the potential groundwater locations, where the transmition losses and groundwater recharge is linearly related to surface runoff (Saber, 2010). Once sustainable groundwater resource is detected, especially at arid environment like wadi system, other development activities like land reclamation for agriculture can be constructed.

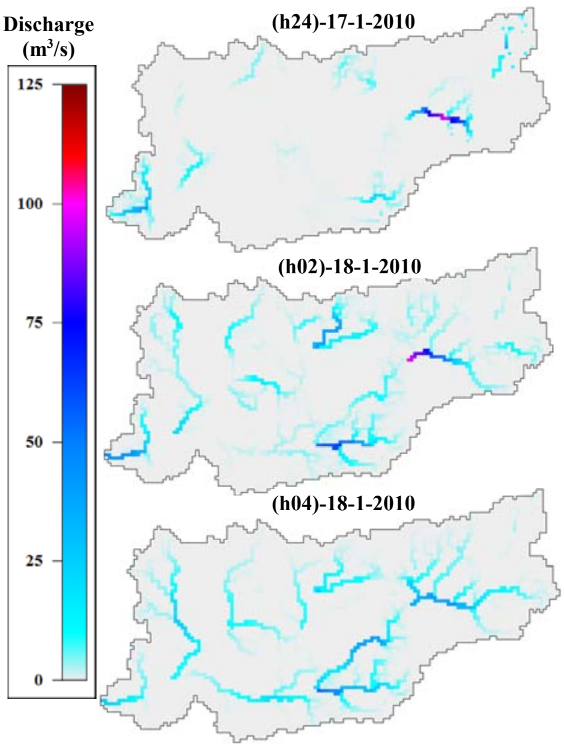

Fig. 16 Hourly distributed discharge for Jan. 2010 flash flood event (h24, 17-Jan. to h4, 18-Jan.)

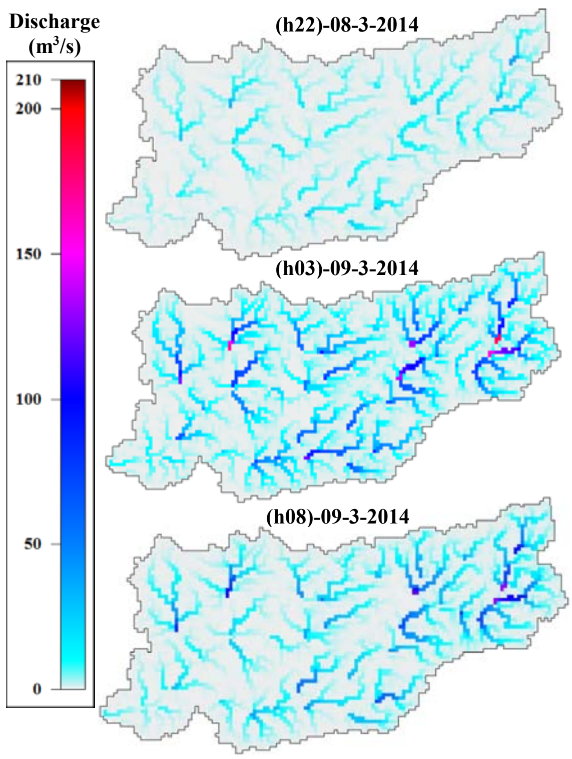

Fig. 17 Hourly distributed maps of for Mar. 2014 flash flood event (h22, 8, Mar. to h8, 9, Mar.)

6. Integrated Flash Flood Management (Flash Flood Potential, Mitigation and Harvesting)

In the arid region flash flood are in fact common, but their occurrence and processes is poorly understood. Until today, no comprehensive proper protection from flash floods proposed for wadi system in Egypt. There is an urgent need to mitigate and utilize floodwater as a new supply to sustain a minimum water resources base in rural desert areas. The proposed management approach (Fig. 18) focuses on developing a strategic methodology for evaluating wadi flash flood potential, mitigation, and floodwater resource management as well as a rainfall-runoff simulation model (Kantoush et al., 2011; Sumi et al., 2013). One of the flood mitigation measures, is constructing of flood retention structures such as dry dam by using innovative Japanese updated technology as CSG dam (Cement, sand and gravel dam) which developed by Japan Dam Engineering Center (JDEC).

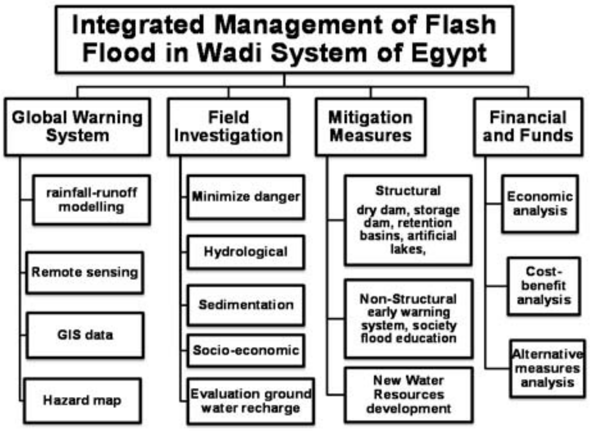

Fig. 18 Flash flood methodology and prevention strategic management approach

7. Conclusion

Effective flash flood management including flash flood mitigation and utilization of wadi surface flow is urgently needed. In this research, we try to summarize flash flood situation at Egypt, showing examples of previous studies related to flash floods, and management strategies that applied at Egypt.

The main problem at flash flood studying is obviously the lack of observations in most of the flash flood prone basins, so there is urgent necessity to adopt a new methodology to simulate and forecast flash flood in arid regions. A trail to simulate two flash flood events at W. Abadi as our target study case was implemented, where remote sensing data utilized to face the scarcity of observed data. This flash flood simulation methodology, which presented in this manuscript, should be further calibrated and validated at some wadi system in Egypt.

The flash flood hydrograph main feature is the extreme steep and rapid rising to peak flow after a few hours, which increase the degree of risk of flash flood comparing to normal flood. The distributed map of simulated discharge for flash flood events, indicating high spatial variability of runoff. Not all flash floods have a homogenous geographic distribution, due to rainfall, geomorphologic and land use variation.

The wadi's new residents, touristic developments and industry investors generally lack direct experience with flash flood hazards. Therefore, decision makers and investors of Egypt should be provided with highly accurate up-to-date digital information and a permanent database that could help in selecting cost effective measures for assessment and mitigation of potential wadis for future developments projects.

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