RESEARCH PAPER

Estimating the flash flood quantitative parameters affecting the oil-fields infrastructures in Ras Sudr, Sinai, Egypt, during the January 2010 event

Safwat Gabr a,b, Mohamed El Bastawesy a,*

a Geology Department, The National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt
b The Hajj and Omrah Research Institute, Umm Al Qura University, Makkah, Saudi Arabia

Received 7 August 2014; revised 5 May 2015; accepted 7 June 2015
Available online 27 June 2015

KEYWORDS
GIS;
Flash floods;
Sinai;
DEM;
Oil

Abstract This paper aims to quantify the hydrological parameters for the flash flood event of 17th January 2010 in Sinai using multiple sets of remote sensing data and field work for the nongaged catchments (approximately 2100 sq km) of the wadis affecting Ras Sudr area, which is heavily occupied by numerous oil fields and related activities. The affected areas were visited, and several cross sections of the main active channels were surveyed to estimate the peak discharge rates. The Tropical Rainfall Monitoring Mission (TRMM) data have been used to estimate rainfall parameters for the catchments due to the absence of in situ data. The digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM) was used to extract the hydrographic data following standard procedures and techniques of the Geographic Information Systems (GIS). Both of the surveyed and extracted parameters for the active channels were integrated into GIS to estimate the runoff parameters using the open-channel flow equation of Manning’s. The simulated hydrographs show that the total discharge exceeded 5.7 million cubic meters and the peak discharge rate was 70 cubic meters per second. The mitigation of extreme flash flood is possible by altering the natural flow dispersion over the alluvial fan, and conveying the resulting flows into one adjusted channel.

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1. Introduction

Records of flash floods in Egypt indicate that they have been devastating. As early as 1915, trams were covered by mud in Cairo, following 43 mm of precipitation (Cooke et al., 1982). More recently, parts of Upper Egypt, Sinai and Red Sea area were hit by severe flash floods in 1976, 1982, 1984, 1994, and 1995 (El Rakaiby, 1989; El Shamy, 1992; El Bastawesy et al., 2013a). Considerable losses of lives and damage to properties and cultivated crops have occurred. The notable flash floods of January 2010 have left behind severe destruction to urbanized areas and petroleum infrastructures in Sinai as well as in Aswan. The past few decades have witnessed one of the worst incidents related to flash flood disasters in Egypt. The event of November 2, 1994 has caused widespread destruction and

* Corresponding author.
E-mail address: m.elbastawesy@narss.sci.eg (M. El Bastawesy).
Peer review under responsibility of National Authority for Remote Sensing and Space Sciences.

http://dx.doi.org/10.1016/j.ejrs.2015.06.001
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casualties in Durnka village in Assuit, which is located on the western bank of the Nile River at the footslope of the neighboring limestone plateau. However, the catchment area is only 23 km² and has not generated large volumes of flash flood water, but the absence of perceptions and the management of flash floods have ended with a catastrophe. The fuel depots constructed on the main wadi were drifted by the flash flood, and then somehow exploded. Thus, the flames from the fuel depots and the vehicles were floated on top of the flash flood water, which caused extensive fires in homes across the village and 497 people have lost their life (EGS, 1996).

In January 17, 2010, a destructive flash flood has swept the wadi floors in Northern Sinai (Wadi Al Arish) and the gulf of Suez (e.g. Wadi Wirdan, and Wadi Sudr). The urban areas erected on the downstream floor of Wadi Al Arish were the most affected by the flood, and several homes were demolished by the flood. Media reports claimed the loss of seven lives, and exact assessment of resulting fatalities was never found. Indeed the problem of flash floods is very critical to the society and economic developments, but most of the hydrological studies focusing on flash floods are based on qualitative/quantitative assessment of the lumped morphometrical parameters of the catchments, such as density of the drainage networks, basin relief. (El-Etr et al., 1990; El-Fakhirany and Dahab, 1997; El Rakaihy, 1989; El Shamy, 1988, 1992; Hegazy, 1999). However, the numerical analyses of these parameters draw the complex interplay of geological, geomorphological and climatological, which have developed the contemporaneous setting of the catchments (El Bastawesy et al., 2009). The spatial and temporal variability of flash flood events even within a single catchment clearly demonstrate the need for distributed model rather than the lumped-black box models (Helminger et al., 1993). This is because the imperfect knowledge of the characteristics of such flows, compounded by the scarcity of relevant data and observations, makes it extremely difficult to evaluate the potential magnitude and frequencies of flows (Dunne et al., 1991). In spite of the limited number of observations of flood events in drylands, the indication is that fluvial processes are significant agents of erosion and deposition and landslides, therefore, active land forming agents (Hjalmarsen and Thomas, 1992; Tooth, 2000). Therefore, due to sparse habitation as well as the random character of the prevailing climatic regime, most of the dry land catchments are of scarce hydrological data. Therefore, direct measurements of rainfall, runoff hydrographs, and associated sediment erosion/deposition in dry land catchments are very rare (El Bastawesy et al., 2009). Due to these limitations, remote sensing data have been used to directly or indirectly estimate a range of hydrological variables and parameters such as rainfall, evapotranspiration and land cover change detection (El Bastawesy et al., 2013b). The Tropical Rainfall Monitoring Mission (TRMM) is one of the key meteorological satellites, which provides free downloadable and detailed datasets on rainfall and latent heating over vastly under-sampled oceanic and continental areas between Latitudes 50° N and 50° S. TRMM data have a grid spatial resolution of 0.25° × 0.25°, and a temporal resolution of three hours (3B42.V6), which is available from 1998 to date. TRMM data have widely been used to estimate various temporal ranges of rainfall for many dryland areas (e.g. El Bastawesy et al., 2008; Milewski et al., 2009; Abou El-Magd et al., 2010; Al Mazroui, 2011).

The essence of using optical satellite images to detect changes in landcover following a flash flood in the dryland depends on the discrimination of active and non-active channels. Straightforward, the signatures of flash floods can be identified by comparing satellite images acquired before and after runoff events. This comparison is significant as remote sensing-spectral reflectance of dryland channels affected by recent flash floods exhibit a marked albedo, due to the deposition of fine sediments in these channels as the flood recedes, or to the retention of soil moisture and growth of vegetation (El Bastawesy et al., 2009). Therefore, the analyses of the available multi-temporal satellite images can be used to indirectly map the spatial and temporal distribution of flash flood events for given catchment(s).

Ideally, the delineated active channel of a given flash flood event should be integrated into hydrological models with other hydrological and topographical parameters in order to estimate the resulting runoff hydrograph. Again, the general lack of observations of dry land floods hinders the development of a physically based model that can be applied in different catchments with much confidence in results (Shentsis et al., 1999; White, 1995). The semi-distributed and distributed hydrological models have only been applied and calibrated within the very few gaged catchments in the dryland, which include the Walnut Gulch in Arizona and Nühl Yael in Israel (e.g. Borgia et al., 2008; Dayan and Morin, 2006; Yakir and Morin, 2011). Simply, the curve numbers and similar variables for these catchments cannot be verified in other un-gaged catchments as such the study area.

Consequently, deterministic models and lumped parameters are the way on forward to the hydrology of flash floods within the dryland (El Bastawesy et al., 2013a). Since the advent of GIS, conventional cartographic representation of topography has been gradually replaced by digital representation using GIS (Tribe, 1991). These drainage parameters are being extracted from the increasingly available DEM and satellite images (e.g. El Bastawesy, 2015; Li, 1992). Generally, the automatic derivation process is fast and more objective than traditional manual techniques applied to topographic maps (Tribe, 1991). The application of a uniform threshold as given below makes the delimitation process uniform throughout the network for environments where it is available. Overall, the significant influence of DEM accuracy and resolution on the representation of topographical parameters and on hydrological modeling, considerable amount of research has been conducted (Wise, 2000; Wolock and Price, 1994; Zhou and Liu, 2002; El Bastawesy, 2014).

In this paper remote sensing data, terrain analysis and field-work were integrated into GIS to assess the flash flood hazard in Ras Sudr in the Gulf of Suez area. The catchments are heavily developed for petroleum production and industries, and the flash flood event of October 17, 2010 has affected the transmission pipelines and some leaked oils reached the coastal area. Therefore, the mitigation strategies are of vital economical, societal and environmental importance in the study area.

2. Study area

The catchments of Gulf of Suez area (which are heavily developed for petroleum production) are located in the dry lands
zones where the mean annual rainfall is very low (less than 100 mm per year) with interannual spatial and temporal variability up to 100% (Shata, 1992 – Fig. 1).

Only one meteorological station is located on the coastal area of Ras Sudr (Ras Sudr meteorological station). The coastal area in Ras Sudr is composed of coalescing alluvial fans of three main wadis namely; Wadi Sudr (702 km²), Wadi Wirdan (1302 km²) and Wadi Abu Haggar (86 km²). The rock units exposed in the area of the considered drainage basins are displayed on the simplified geological map (Fig. 2).

Figure 1  Location map of the study area.
The hill slopes of the study area are carved in the Middle Eocene limestone, which caps the Egma plateau. The Eocene limestone overlies Upper Cretaceous sequence of carbonates, claystone, marl and sandstone of El-Tih plateau. The plateaus are cut by a set of NW/SE step faults constituting steep slopes bringing the surrounding alluvial plain in abrupt contact with the plateau massif (Patton, 1982). Most of Wadi Sudr and Wadi Wirdan main channels are confined to a deeply incised canyon running westward into the Gulf of Suez across the Egma plateau. The Miocene rocks (mainly evaporites, limestone and clastics) are down faulted into mesas at the western foot slopes of El-Tih – Egma Plateaus, therefore the deep incised channels emerging form the plateaus are less confined and develop broad and shallow profiles on these rock units (Said, 1962). The Quaternary deposits (alluvial fans, sabkhas and eolian deposits) flank the low relief coastal areas and at the outlets of these catchments. Reaching the alluvial plain, the wadis fans out constituting braided alluvial channels (alluvial fan of Wadi Sudr and Wadi Wirdan) draining a wide area of the coastal plain. The out-washed pebbles from the hill slopes underlain the alluvium bed of the Wadi channels and the alluvial fan.

The existence of abundant pebbles and coarse clastics implies a high rate of infiltration from occasional surface run-off in the considered drainage, and these gravels are being quarried at different localities of the alluvial fan (Saleh, 1989). Most of the petroleum sites (e.g. Matarma Station) were erected on the western most distal parts of the alluvial fan, which is drained by sets of shallow braided channels. The pipeline is also transecting most of these braided channels in the middle part of the alluvial fan, which are being active during severe flash floods such as occurred during February 1999 (Fig. 3). However, few sites are constructed on high fluvial shoulders and are naturally protected from flash floods as the neotectonic movements have re-oriented drainage pathways at certain impounded areas of the alluvial fan (e.g. Assal and Sudr Stations).

This suggests that the local geological conditions have a marked influence on the nature of the flash floods, which may affect the study area, as the generated flows tend to significantly decrease because of infiltration and channel divergence. It is also worth mention that human activities (i.e. open cast quarries, landfills, land use pattern, etc.) play an important role in the changes of the active flood pathways, where the pattern of flow dispersion and dissemination on surface of the alluvial fan can be affected by the location and extent of these factors. The alluvial fans of the study area are heavily occupied by petroleum facilities such as transmitting pipelines and storage stations. The flash flood flows are dispersed into several shallow broad channels and for example Matarma station is located in the pathway of an active flash flood-channel on the alluvial fan. Furthermore, the dispersed and braided channels of the alluvial fan transect the pipeline in several areas (Fig. 4) and deliver flows to some of the agricultural fields, settlement areas and resorts on the coast (Fig. 5).

3. Data and methods

Different sources of data have been collected, processed and integrated into a GIS following the standard technical and scientific procedures that have been applied in similar research. These datasets (e.g. multi-temporal satellite images, DEM, TRMM data, rainfall ground data, field survey, and geological
maps), ERDAS Imagine, ArcGIS softwares have been used to carry out the technical analyses of these data through applying the following specific routines, algorithms and methods.

3.1. The extraction of catchment parameters

DEM indicates that the elevation of north-east Gulf of Suez drainage basins ranges from 0 to 1384 m above sea level (a.s.l.). The elevation of Wadi Sudr sub-catchment ranges from 0 to 864 m a.s.l, Wadi Wirdan sub-catchment ranges from 0 to 1060 m a.s.l and Wadi Abu Hagar sub-catchment ranges from 0 to 422 m a.s.l (Fig. 6). DEM is significantly important to automatically extract various topographic and hydrologic parameters. The most significant topographic parameters include slopes (magnitudes and aspects), slope length and shape. The hydrologic parameters include flow direction, flow accumulation, watershed delineation, and stream networks. All these parameters were extracted according to the following steps:

Figure 3  Landsat ETM + image showing the active channel of Ras Sudr alluvial fan during the February 1999 flash flood event.

Figure 4  A Photograph shows the scouring of alluvium and asphaltic road, and the exposure of oil-transmitting pipeline due to the activity of flash flood in the alluvial fan area.
The D-8 method is the most commonly used procedure and is based on the O’Callaghan and Mark’s (1984) algorithm. Each cell is considered to flow or discharge into one of its eight neighbors (hence the name D-8), which has the steepest slope from the target cell. Points with no neighbors of lower elevation are termed a pit or sink and are given a distinctive drainage code (Mark, 1988). Once the flow direction out of each cell is known, it is possible to determine the flow path and associated drainage networks.

Figure 5 A photograph showing the flooded Ras Sudr port during the January 17, 2010 event (courtesy of the general company for petroleum (GCP)).

Figure 6 DEM of Wadi Wirdan. Note the relationship of drainage channels (solid blue lines) and the locations of main oil facilities (the yellow points and red lines).

(a) Flow direction
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and to define how many cells flow into any given cell (ESRI, 1997).

(b) Flow accumulation
Simply, flow accumulation can be expressed as the number of upslope cells that flow into each cell. Within the flow accumulation function, cells with high flow accumulation values are areas of concentrated flow and may be used to identify stream channels. Cells with a flow accumulation of zero are local topographic highs and may be used to identify ridges (ESRI, 1997). Consequently, the cumulative flow over the surface can be obtained by accumulating S over the entire grid (Burrough and McDonnell, 1998).

(c) Watershed delineation
An area that contributes water and debris to an outlet can be described by many terms, including “catchment”, and “drainage basin”. The drainage divide or watershed is the boundary between drainage basins. Using DEMs, it is possible to delineate sub-catchments of a watershed in order to examine the hydrological processes within them. The delineation process can be achieved by setting minimum flow accumulation thresholds for the desired sub-catchments.

(d) Stream networks
By applying a threshold (i.e. 100 cells) to the results of flow accumulation, streams can be delineated. The threshold value is referred to as a threshold area (A) and represents the minimum upstream area required to form a channel segment in which water starts to flow as channel runoff (Rieger, 1993). For example, all cells with more than 100 cells flowing into it are considered streams and all other cells are not associated with channeled surface flows, although they may have overland flow moving through them. The stream network is normally displayed as inter-connected linear features and these features begin where the threshold value is exceeded.

Both flow accumulation and flow length have been used to calculate the hypothetical hydrograph for the study area’s sub-catchments.

3.2. Acquisition and analysis of TRMM rainfall data
Precipitation is the main climatic parameter that initiates and controls the occurrence of flash flood events in drainage basins of all climatic zones. There is only one meteorological station in the study area (Ras Sudr meteorological station), which is installed near the coastal area. Sampled precipitation at few points cannot confidently be interpolated and/or extrapolated over the gross catchment. The storms’ magnitude and intensity are usually variable over short distances within the dry-land catchments. Accordingly, another alternative real time source of remotely sensed climatic data from the Terrain Rainfall Monitoring Mission (TRMM) has been used. The daily TRMM accumulated rainfall data were acquired, covering the last 12 years (1998–2010). Analyzing these datasets indicates the following:

- The maximum daily precipitation during this period has occurred on the January 17, 2010 with a total amount of 25 mm, which has developed a destructive flash flood in the area (Fig. 7).
- Annual rainfall patterns are almost consistent in terms of spatial coverage and spots of high precipitation and intensity. The number of rainy days over the catchment area is large when compared with those over other catchments of the Red Sea coast.
- The mean annual precipitation ranges from 58 mm to 66 mm as shown by the cumulative precipitation from 1998 to 2010 (Fig. 8). The highest amounts precipitate over the high topographic areas in the south and northeast of the catchment. The coastal areas (where the ground meteorological station exist) receive the least amount of precipitation.
- The majority of precipitation events occur in winter months (November to March).
- The total rainfall depths of single rainfall events are more relevant to the flash flood analysis than the monthly or yearly gross records.

It should also be noticed that the skewness of the recorded amounts of rainfall in the North Eastern Gulf of Suez catchment is not very large. This means that the precipitation pattern over the considered catchment does not change much in terms of spatial coverage and storms’ intensity, from year to year. This indicates that exceptional storms of abnormally high magnitudes are likely to develop on the same area.

3.3. Field work
The field work was carried out shortly after the flash flood event of January 17, 2010 to validate the Remote Sensing observations for the determined active channels, and also to survey several cross-sectional areas along the main channels from upstream to downstream in order to determine the geometrical change of the maximum wetted perimeter (i.e. peak discharge), which can be used to estimate transmission loss of flows. Quantifying the peak discharge and the total flow volumes is necessary to assess the effectiveness of the remedial measures to be taken to protect the sites from flash flood hazard.

A total station and surveying tools were used to measure the wetted perimeter and cross sections of selected areas where clear marks of the last flash flood can be easily recognized in the field (i.e. slack mud deposits, scours, channel banks, etc. – Fig. 9). The surveyed cross-sectional areas and wetted perimeters imply the field evidence of maximum peak discharge and its gradual reduction downstream. The differences between peak discharge at the cross sections indicate quantities of flows being abstracted due to transmission loss.

Therefore, the peak discharge simulated from the developed hydrological models will be calibrated with the surveyed active channels-cross sectional areas in order to determine the reduction (i.e. transmission loss) of this peak discharge downstream. This to estimate the runoff hydrograph of the January 17, 2010 storm in order to design a 50 years return period hydrograph and to estimate its maximum discharge rate as well as the required conveying channel(s) geometry to pass the flash floods away from the vulnerable sites.

3.4. Estimation of the runoff coefficient
Usually the runoff coefficient is estimated during the field work using rainfall/runoff simulators or the double rings infiltrometer. However, these experimental assessments are valid for the point scale and cannot be generalized with confidence,
particularly when geology and soil are complex as such within the study area. Therefore, the runoff coefficient were estimated from the satellite images (February, 1999) which show active channels-carried flash floods that have been totally consumed within the channel alluvium before reaching the final outlet. In approximation the active channel cross-sectional recorded on the satellite images represent the maximum discharge at that cross section. Therefore, the volume reduction of that flow in distant cross sections downstream represents the transmission loss in the channel reach during the flow time consumed between the two measurement points. Given the TRMM estimate for depth of rainfall and the peak discharge as implied by the cross-sectional areas of active channels, the transmission loss has been estimated for the active channels reaches. It was found that 25% of the total rainfall can represent the active channels appeared on the satellite images. Of course this value can be affected by several variables and it may vary spatially within the catchments, but no other field measurement or estimate is available for the study areas.

3.5. The calculation of the runoff hydrograph

Overland flow velocity requires the calculation of both magnitude and direction. Magnitudes were estimated using the Manning equation (Eq. (1)). Where the hydraulic radius was assumed to be minimal (0.05 m), the slope was derived from the DEM, and Manning’s coefficient value ($n$) was obtained from standard tables.

\[
V = \frac{R^{1/3} S^{2/3}}{n}
\]

where; $V$ = velocity m/s; $R$ = hydraulic radius (i.e. = depth); $S$ = slope percentage; $n$ = Manning coefficient.

The flow direction grid represents the direction of flow within each cell in the catchment area into one of the eight neighboring cells (D-8 algorithm) (i.e. either diagonal or orthogonal). Because the grid resolution of the DEM is known, it is possible to calculate the flow length within each cell, which is equal to the grid cell length ($L$) in case of orthogonal, or equal to $L\sqrt{2}$ in case of diagonal.

Then, the flow direction grid was reclassified to obtain the flow length within each cell. Once both the flow velocities and the flow lengths were calculated for each cell, the travel time of flow in each cell was obtained by simply dividing the flow length by the velocity. The time-of-flow grid, representing the time required for the runoff generated at each cell to reach the outlet was estimated using the flow length function in the ArcInfo package, which uses the following convolution equation (Eq. (2)).
\[ V_{ij} = \sum_{p} c p \times dp \]  

where, \( V_{ij} \) = the output result of the convolution for cell \((i,j)\); 
\( d \) = the slope distance between the centers of two adjacent cells along the minimum-path; 
\( c \) = the unit-distance value; 
\( p \) = the minimum-path.

Therefore, the cell-travel time grid was considered as the unit-distance value, and was used to calculate a weighted flow-length. The time-weighted flow-length map (time-of-flow grid) represents the time (seconds) required for flow in each cell in the catchment to reach the outlet. Finally, by dividing the time-of-flow grid by 3600, then reclassifying the resulting map, the estimated travel time is expressed in one hour intervals and then aggregated for the different zones in the catchment area (time-area zones) (Fig. 10).

4. Results

The total amounts of runoff produced from Wadi Wirdan catchments were estimated at 5.7 million m\(^3\) (Fig. 11). These calculations were carried out using GIS map algebra functions, given a uniform runoff coefficient of 25% of the 17th of Jan 2010 rainstorm over the entire catchments. The peak discharge was implied by the surveyed maximum wetted cross-sections and the estimated flow velocities in the channel reach of these different cross-sections. The transmission loss (i.e. infiltration into the channel beds) can be approximated using the surveyed decrease of maximum wetted perimeter (i.e. peak discharge) downstream and the estimated channel runoff velocities (i.e. elapsed time between successive flow peaks downstream of known flow length).

The flow generated within different time-area zones was linearly routed in a cascading way from the most upstream time-area zone successively up to the outlet zone. Flows generated within upstream zones are vulnerable to transmission loss into the alluvium channel all the way downstream (i.e. from zones 18 to 1) until they reach the alluvial fan. But the flow generated within zone 2, for example, will only suffer transmission loss into the alluvium of zones 1 and 2.

According to the above considerations, the transmission losses were subtracted from the runoff produced at different time-area zones. The transmission loss volumes depend on the total active channel surface areas within each time, the estimated channel runoff velocities and the infiltration rates into the underlying channel bed materials.

Figure 8  The daily TRMM accumulated rainfall data acquired during the last 12 years (1998–2010).
5. Discussion

The understanding of geological, geomorphological and structural control on surface channel patterns within a given catchment is very important to mitigate the impacts of flash flood hazard on required infra-structures (El Bastawesy et al., 2013a). Mapping the morpho-tectonic evolution of drainage networks is essential to identify abandoned and current channel connectivity with upslope runoff-feeding areas. For example, the radial dispersion of runoff from the apex of the alluvial fan of Ras Sudr was disrupted downstream by NW–SE faults which lifted a slightly prominent ridge that embay the most southern tip of the fan, and thus naturally protecting it from destructive flash floods (Fig. 3). Also some channel courses are chocked with sand dunes in certain areas as they were abandoned due to tectonic activity. The flow dispersion on alluvial fans can be confined into certain few channels that transport runoff and sediment loads away from developed or infrastructure areas.

Regionally, different mitigation measures are being adapted to control the flash flood hazards including, construction of protection dykes and small dams, artificial ponds and channels flow diversions and re-direction. The construction of protection dykes and dams may not be suitable in the study area except for partial water storage purposes at bedrock incised and narrow channels. The simulated flow hydrographs indicate that several millions of cubic meters of water were produced from January 17th, 2010 storm. The geomorphological setting of the drainage channels; incised narrow channels and steep slopes will not favor storing this volume of water in front of a dam on the main channel before reaching the braided channels on the alluvial fan, this is why we propose partial storage dam(s). For example, El-Rawaffa dam on Wadi El-Arish, which could store up to 5 million cubic meters of water was overflowed during January 17th, 2010 storm (Hermas and El Bastawesy, 2012). The resulting flash flood swept the urban areas downstream and produced severe destruction and fatalities in El-Arish city. Additionally, the construction of dams and protection dykes can be misleading as it may encourage the aggressive and non-planned development on the alluvial fan areas prone to flash floods, given the belief that torrential flows are fully controlled.

Herein the feeder channel to Matrama station must be blocked upstream by a diversion dyke constructed from big boulders of solid rock. Additionally, the flow dispersion will be conveyed into one single channel as indicated in Fig. 12, in order to minimize the intersection of flash floods with the path of the pipeline as well as the other sites on the coast of Gulf of Suez. This conveying channel has to be dredged (widened and deepened) in order to drain the flash flood flows.
into the Gulf of Suez. Finally, the implementation of any of the suggested mitigation measures should comply with regulations of the Egyptian Ministry of Environment, which determine the impacts of these projects on the surrounding environment. The regulations may favor storing strategies of flash flood waters in desert areas rather than wasting this water into the sea via diversion channels. Therefore, it is worth mentioning that some of the facilities (currently located within the risk zone of flash floods) could be re-placed on relatively higher grounds if feasible. The port area also need to be

Figure 10  The time-area zones estimated from the derivatives of DEM and the application of Manning’s equation.

Figure 11  The simulated hydrographs for the three main catchments using the estimated runoff coefficient, DEM hydrological parameters and surveyed cross sections.
equipped with a drainage pipe installed at the area of the lowest level to drain the collected rainstorm water as happened during the last flash flood.

6. Conclusion

The problem of flash floods in the catchments feeding the oil production area of Ras Sudr has been investigated. The most recent flash flood of 17th January 2010 was devastating and the oil infrastructure was affected. Currently, there is no adoption of any management strategies for the flash flood in the area, except the construction of small levees and earth piled dykes for conveying and collecting occasional runoff to the agricultural fields. The simulated runoff hydrograph for this event suggests that the peak discharge rates would reach 70 meters per second, for Wadi Wirdan in Ras Sudr area. The estimated flash flood hazards are likely to increase given the probability of developing much more severe storms of longer return periods (i.e. 50 and 100 years designed storms). It is highly recommended to consider the construction of proposed mitigation measures to control flash floods. Furthermore, it is recommended to construct several small dams at the fingertip channels, in order to retain considerable amount of sediments and to reduce the flow volumes reaching the outlets. These dams could be acting as a point-source recharge to the underlying alluvium aquifer, and they will contribute to the replenishment of fragile groundwater aquifers.

References

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