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Assessment of Water Erosion Hazards by Flash Floods Using Remote Sensing and GIS: A Case Study of Wadi Alhaytah Watershed in Wadi Natrun, Egypt

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ABSTRACT

Water erosion by flash floods is one of the major threats to the sustainable development and the environment. Recently, in Egypt, flash floods occurred frequently, causing loss of life and destruction of ecosystems. The objectives of this study are to assess the hazards of the November 5, 2015 flash flood in wadi Alhaytah watershed in Egypt using GIS and remote sensing, and develop a flood control strategy that reduces an unexpected flood risk. Two Sentinel-2 satellite images were selected for the study, which acquired on August 16 and November 14, 2015. The maximum likelihood supervised classification technique was applied on the two images to produce temporal land use/cover (LULC) maps. The hazards of the flash flood and water erosion were assessed through monitoring of LULC changes between the two dates. A flood control strategy was proposed for the watershed through a developed GIS procedure. Results indicated that the catchment area is characterized by remarkable variations in elevations and slopes. Assessment of flood hazards revealed that 32.23 km² (3223 ha) and 1.04 km² (104 ha) of the cropland and fish farms, respectively, were removed or destroyed, which would affect the national agricultural production and food security. Therefore, fifty six suitable locations of storage dams were spatially proposed in the catchment area to mitigate unexpected floods, prevent loss of human and animal lives, decrease soil erosion, enhance soil moisture, and increase the yield of the existing aquifers, especially ground water is the only water resource available for agricultural development in the region.

Keywords: Water Erosion; Flood hazard, LULC; Wadi Natrun, Egypt.

INTRODUCTION

Water erosion is considered as the major land degradation process which accounts for the greatest loss of soil throughout the world compared to other land degradation processes (Panagos *et al.* 2015). Water erosion is a natural phenomenon, occurring by the action of water.

It reduces soil productivity by removing plant and fertile topsoil, reducing rooting depth, and removing soil nutrients (Merzouk and Dhman, 1998; Gitas *et al.*, 2009).

The main factors affecting the rates of soil erosion by water are precipitation, soil type, slope length and degree, land use and land management (Panagos *et al.* 2015). Water erosion by flash floods mainly occurs due to thunderstorms and torrential rainfalls. They are very dangerous due to peak discharge received within a few hours. Flash floods are generally defined as a rapid onset flood of intense rainfall in a short duration with a relatively high peak discharge of water in a particular place (Ali *et al.* 2017; UCAR 2010). Water erosion by flash floods is not only an environmental issue, but also a socioeconomic, since it causes damage to agricultural areas and infrastructures, as well as it may result in loss of human and animal lives (Merz *et al.* 2010 b). In Egypt, flash floods frequently occur in many regions, including wadis in the coastal areas and the Nile valley.

During the period from 1972 to 2016 different territories in Egypt were subjected to heavy rain storms

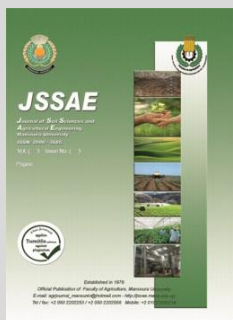
which led to flash floods and landslides and many other impacts including the killing and loss of hundreds of human lives, the damage to property, and destruction of infrastructures. Recently, it was observed that Egypt has witnessed more frequent flash floods such as flash floods of 2013, 2014, 2015 and 2016 (DREF 2010; Moawad *et al.* 2014; Eliwa *et al.* 2015; Hadidi, A. 2016; Saber *et al.* 2017; Ogiso *et al.* 2017; Saleem 2017).

Like many areas in the Northwestern region of Egypt, wadi Alhaytah watershed was subjected to an extreme rainfall storm in November 5, 2015, which resulted in an extreme runoff, loss of top soil, removal of several cropland and fish farms, as well as loss of many human and animal lives in Afunah village which locates in the downstream of the wadi. According to the state-run Ahram news report (<http://english.ahram.org.eg>), fourteen people have been killed in Afunah village by the November 5 flood which occurred in this watershed area, with several others injured or lost (Ahram 2015; Saleem 2017). These challenges increased the need to control soil erosion in wadi Alhaytah watershed through the assessment and mapping of flood hazard in order to reduce catastrophic outcomes and enhance watershed management. GIS and satellite remote sensing data and techniques offer a very decent display by combining, manipulating, managing and analysing the information for the assessment of flash risk extents very swiftly and more proficiently (Ali *et al.* 2017). Therefore, the objectives of

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this study are to identify and mapping the areas affected by flash floods and water erosion in wadi Alhaytah watershed using GIS and remote sensing data, and to propose a flood control strategy which reduces unexpected future flood risk in the watershed area.

MATERILAS AND METHODS

The Settings of the Study Area

The study area is located in the Southeastern part of wadi Natrun depression in the West Nile Delta, Egypt. It is represented by wadi Alhaytah watershed that extends from latitudes 30° 19' 20" to 30° 32' 22" N and longitudes 29° 52' 0" to 30° 10' 38" E (Fig 1). It extends over an area of about 447.6 km² (44760 ha), which is considered as a promising area for new land reclamation projects and agriculture extension in the West Nile Delta. The wadi drains the high upstream land on Jabal Hadid from the Southward and flows into Al Jaar Lake in wadi Natrun depression, where Afunah village is mostly located (Fig 1).

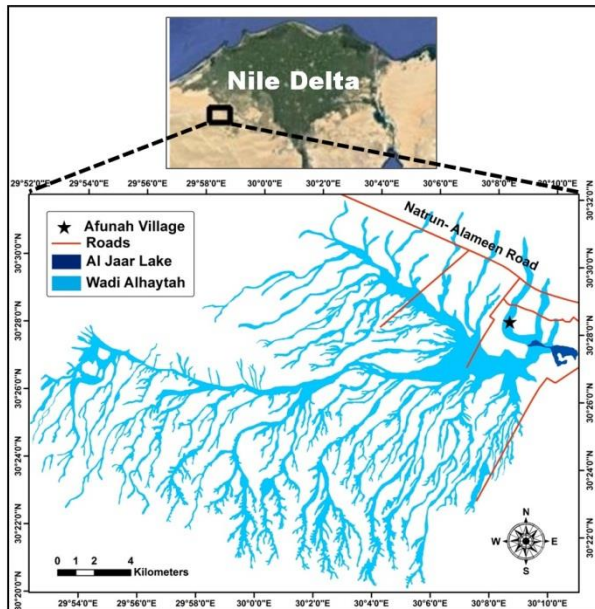


Fig. 1. Location map of wadi Alhaytah watershed in the West Nile Delta, Egypt, and the wadi streams (extracted from the topographic map).

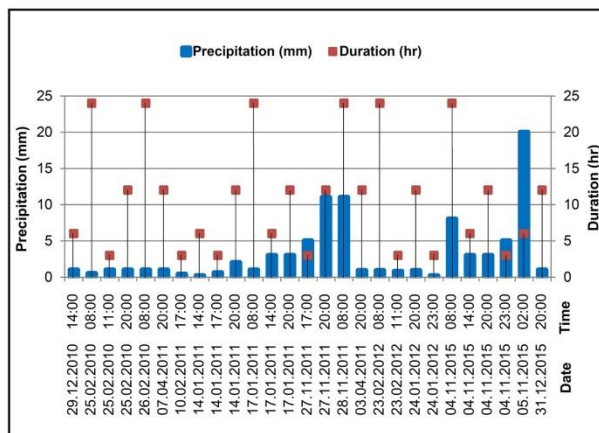


Fig. 2. The daily measured precipitation and duration in the region of the study area during the period from 2010 to 2015.

The study area is characterized by arid climate conditions with very hot summer and cold winter.

Meteorological data were obtained from the Wadi Natrun Meteorological Station for the period from 2005 to 2015.

Analysis of the obtained climatic data indicates that the average annual summer and winter temperature in the study area are 27.6 °C and 13.8 °C, respectively. The driest months are July and August with 0 mm of rainfall. Most of the precipitation falls in November and December. The mean annual rainfall is 8 mm that mostly occurs in the form of splashes of short rainfall duration. The study area didn't witness measurable precipitation for the period from January, 2005 to November, 2010. However, one heavy rainfall storm (20 mm) occurred in the area over a six hour-duration in November 5, 2015 (Fig 2). This storm exceeded the average annual value (8 mm) in the region that was associated with thunderstorms, much amount of surface water runoff, loss of top-soil as well as the damage of farmlands and loss of human and animal beings (Fig 3).



Fig. 3. Flood hazards of November 5, 2015 storm in wadi Alhaytah watershed (Sources: Private photos and local newspapers)

Geomorphologically, the study area occupies the Northwest part of wadi Natrun depression, which includes Al Jaar Lake (Fig 1), and Jabal Hadid Tableland that represents the highland in the most South and Southwestern region of the area. The area extends between wadi Natrun depression and Jabal Hadid Tableland is represented by huge eroded fragmental materials of gravel and sand. These materials have been derived from Jabal Hadid and cover the Western and Southern slopes of wadi Natrun depression (El-Sayed 1999 and El-Fayoumy 1964).

Geologically, most of the study area is essentially composed of gravels and sands with thin clay and carbonate intercalations which belongs to Miocene times (Fig 4) (EGSMA 1981, Hammad 1975, and Said 1962).

Hydrologically, the study area belongs to the Miocene and Pliocene aquifers, where the ground water mainly exists under free water table conditions (unconfined aquifers) at a level of more than 60 m from the ground surface (El-Sayed 1999).

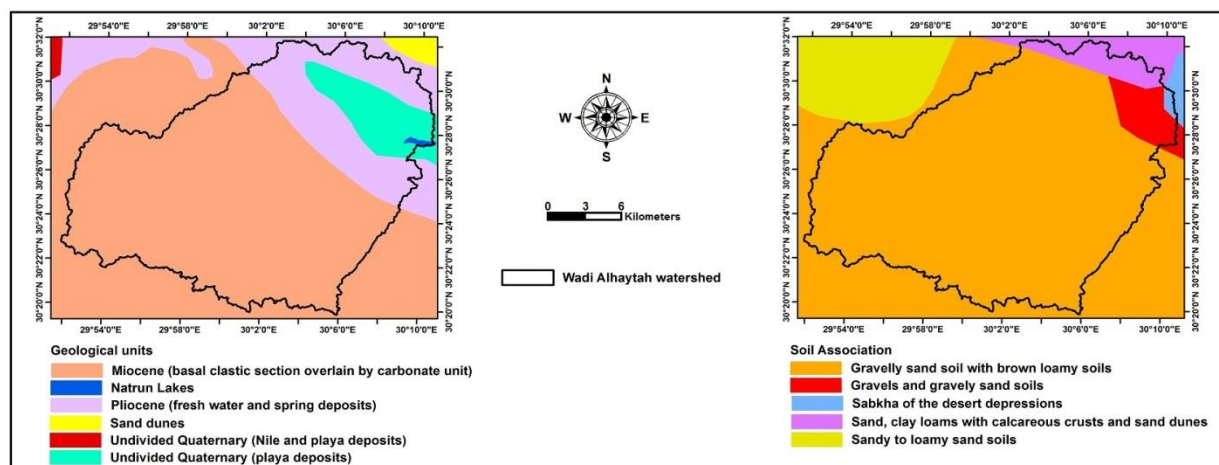


Fig. 4. Geological settings and soil association of the study area (After EGSM 1981 and Hammad 1975).

The Digital Elevation Model (DEM)

DEM is an essential data source for several applications that require terrain surface analysis. DEM with medium spatial resolution 30 m of the Advanced Land Observing Satellite (ALOS) World 3D (AW3D) was used for the purpose of this study. ALOS was launched in 2014 by the Japan Aerospace Exploration Agency (JAXA). The global digital surface model (DSM) dataset with a horizontal resolution of 30-meter was released with free of charge on May 2015 (<https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm>).

A recent study performed by Alganci *et al.* (2018) concluded that the ALOS-DSM produces very good results and it has the highest accuracy compared to other medium spatial resolution and freely available DSMs such as the Shuttle Radar Topography Mission (SRTM 30 m) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER 30 m).

Terrain surface analysis of the study area was performed using ArcGIS10.1 spatial analyst tools (ESRI 2012) based on ALOS DSM. This process included delineation of watersheds, generation of slope, estimation of flow accumulation, and creation of stream networks. The boundary of wadi Alhaytah watershed was identified. Flow accumulation help to understand topographic controls on water within watersheds, it refers to the total amount of water that flows into each terrain cell (Do *et al.*, 2011 and Moore *et al.*, 1991).

Satellite data and image classification

Two Sentinel-2 satellite images were used in the study. The first image was captured on 16/8/2015 (before the November 5 flash flood) and the second image was captured on 14/11/2015 after the flood, where they were freely downloaded from the United States Geological Survey website (<https://glovis.usgs.gov>).

The two images were pre-processed in ERDAS 9.2 (ERDAS 2008) to obtain a layer stack of the three spectral bands 3,4, and 8 with 10 m spatial resolution, and then they were geometrically corrected using three topographic maps (scale 1:50,000) covering the study area and ground truth points collected during field inspections. The two images were finally co-registered with root mean square error of 0.073. A subset of each image was extracted by the boundary of wadi Alhaytah watershed (Fig 5) and then image calibration was applied on the image subset. The maximum likelihood supervised classification technique

was applied on the two images to produce two initial LULC maps. Four LULC categories were identified and extracted from each image which are cropland, uncultivated land, wadi, and water flooding. In this process some patches (group of pixels) on the images were misclassified as wadi since they have the same appearance (reflectance) of the pixels of the main wadi. To overcome this problem buffer zone was created for wadi Alhaytah streams (Fig 7 A) in ArcGIS and then used as a mask to exclude and correct the misclassified pixels. The assigned buffer for the August-16 LULC map was 194 m which represents the maximum width of the wadi on the image (measured visually on the image). The assigned buffer for the November-14 LULC map was 570 m. On the other hand, several fish farms were classified as water flooding areas on the two images, which spatially distributed around Al Jaar Lake. Fish farms were easily identified and distinguished by their special shape and appearance on the images. They were separated from the water flooding areas through a digitizing process. Finally, two enhanced LULC maps were produced representing five LULC classes. Accuracy assessment was applied on the two maps to assess their validity using a stratified random sampling of 250 ground truth points.

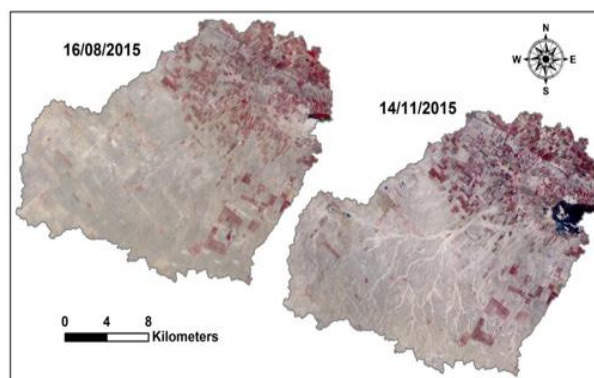


Fig 5. Sentinel-2 temporal images (RGB 8, 4, 3) of wadi Alhaytah watershed.

Flood control strategy

Due to the economic importance of wadi Alhaytah watershed, as it has the highest priority for agricultural extension and development in the West Nile Delta, a flood control strategy was proposed to prevent or mitigate unexpected future flood hazards in the study area. Traditionally, wadi flood risk reduction is concentrated on

the construction of embankments and retention by reservoirs (Merz *et al* 2010 a). Such measures, i.e. flood control strategies, aim at reducing the flood hazard and decreasing the probability of flooding. For the flood risk management in wadi Alhaytah watershed, a technical GIS methodology was developed and used in the present study to identify appropriate locations for dam construction based on a set range of factors, including the wadi stream network, soil association, geology of the study area (EL-Raye *et al* 2009), slope percent, and flow accumulation. Model builder in ArcGIS was used to perform this task

(Fig 6), which included the following two steps: Step-1: Extraction of stream-of-uncultivated land from the full stream network in the catchment area. Step-2: On each stream-of-uncultivated land one location of a storing dam was identified based on the maximum flow accumulation, the slope percent (< 1%), and permeable deep soil. These conditions should ensure that the location of a storing dam is at the nearest point of farmlands in the direction of flow and in lands with slope less than 1% and good permeability.

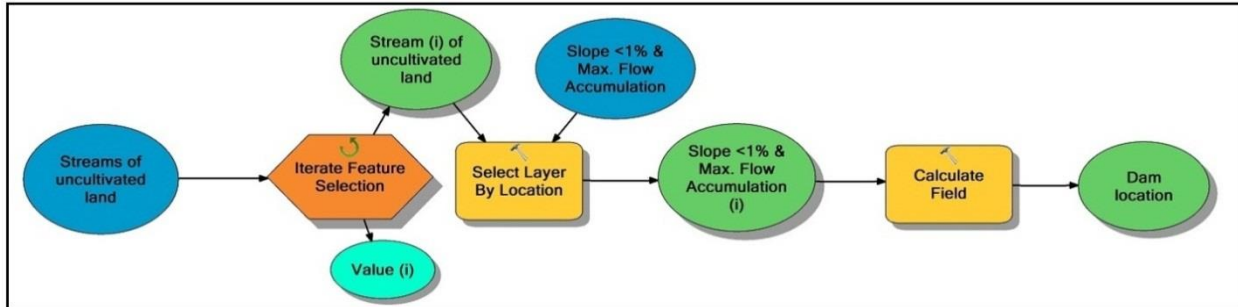


Fig 6. Identifications of storage dam locations using model builder in ArcGIS.

RESULTS AND DISCUSSION

Terrain surface analysis:

Digital surface analysis of ALOS-DEM in the study area resulted in 102 watersheds. Wadi Alhaytah watershed is the largest catchment area with the longest water stream network, since it occupies about 61% of the total study area (Fig 7 A). It should be mentioned that the water stream network resulting from the terrain surface analysis was very consistent with that derived from topographic maps (Fig 1), which increases confidence in the use of the terrain surface analysis data as input data in subsequent analyses. The maximum elevation in Wadi Alhaytah watershed and its surroundings reached 180 m above sea level, which

occupied the most South and Southwestern parts of the study area representing the upstream land of Jabal Hadid geomorphological unit. The minimum elevation was 39 m below sea level representing the downstream land in the most middle-eastern part of the study area (Fig 7 B). This low land is part of wadi Natrun depression. Results also indicated that most of Wadi Alhaytah watershed area (66.7%) is characterized by slope percent between 1 and 5% and about 32 % of its area has slope percent less than 1% (Fig 7 C). Generally, flow accumulation increases to the Eastward direction in the catchment area and reaches its maximum value (313,000 cells) at Al Jaar Lake as a water storage point (Fig 7 D).

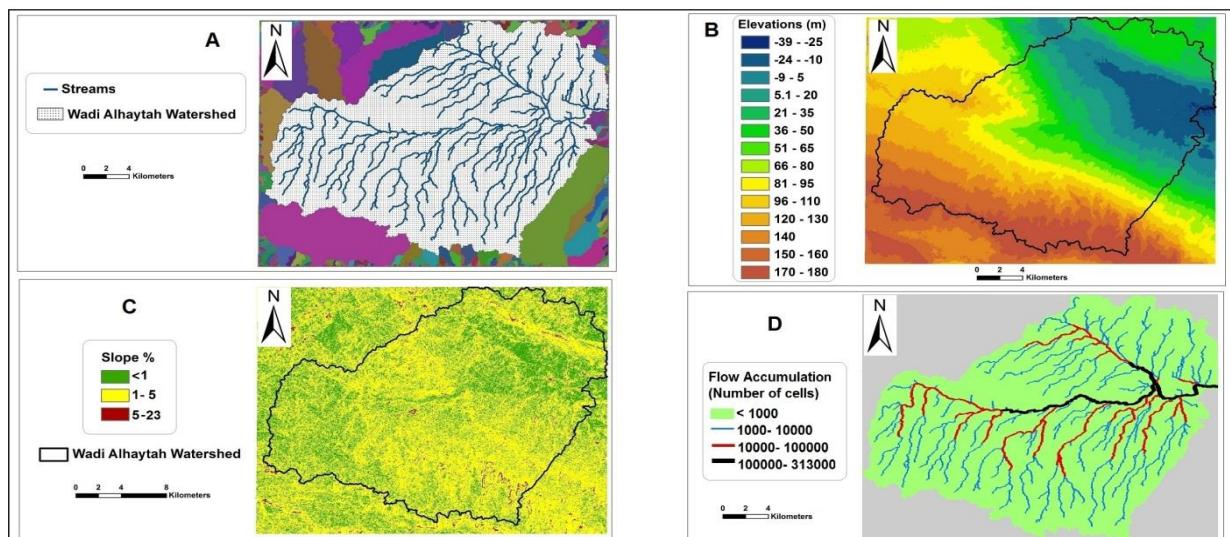


Fig. 7. Watersheds and stream network (A), Elevations (B), Slope (C), and Flow accumulation (D) maps of the study area.

Flood hazard assessment:

Assessment of November 5 flood damage in Wadi Alhaytah watershed was mainly based on the interpretation and classification of the selected satellite images, which acquired before and after the November 5 flash flood. Results of image classification (Figs 8, 9 and 10) indicated

that noticeable changes were observed in all LULC categories in the study area before and after the flash flood, where the cropland area occupied about 181 km² (18100 ha) and 143 km² (14300 ha) in August 16 and November 14, respectively (Fig 8).

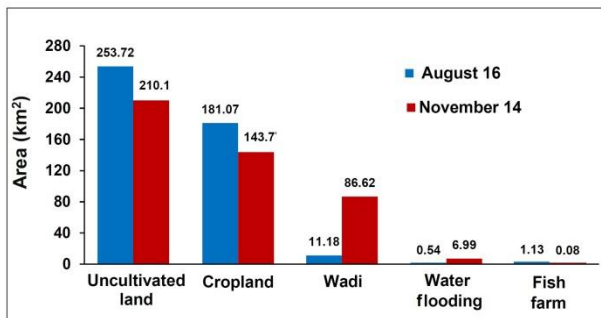


Fig. 8. Area (km²) of each LULC type in Wadi Alhaytah watershed for the two dates.

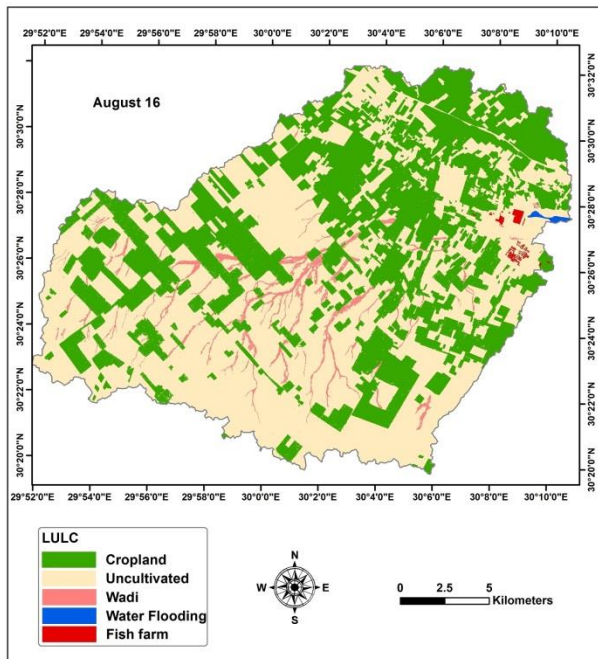


Fig. 9. Map of LULC categories in Wadi Alhaytah watershed (August 16, 2015)

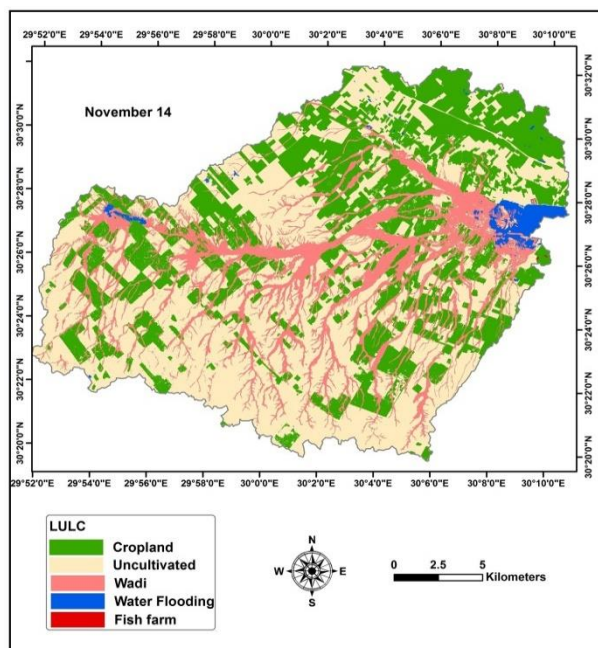


Fig. 10. Map of LULC categories in Wadi Alhaytah watershed (November 14, 2015)

In August 16, the area covered by wadi (water stream runoff) was about 11 km² (1100 ha) against about 87 km² (8700 ha) in November 14. Wadi development mainly concentrated in the middle of the study area and extended from West to East (Figs 9 and 10).

The water flooding areas increased from 0.54 km² (54 ha) representing Al Jaar Lake in August 16 to 6.99 km² (699 ha) in November 14. A remarkable damage in the fish farm land use was noticed in the catchment area, where its area decreased from 1.13 km² (113 ha) to 0.08 km² (8 ha) in August 16 and November 14, respectively. The classification accuracy of August 16 and November 14 LULC maps had overall Kappa coefficients greater than 0.8 (Table 1), which confirmed that the interpretation and classification results met the analysis requirements (McHugh 2012).

Table 1. Kappa Statistics of LULC classifications.

LULC class	Kappa (K [^])	
	16/8/2015	14/11/2015
Cropland	0.90	0.91
Fish farms	1.00	0.00
Uncultivated land	0.84	0.78
Wadi	0.83	0.87
Water flooding	0.00	1.00
Overall Kappa Statistics	0.87	0.85

Monitoring of LULC changes between the two dates indicated that the flash flood of November 5 has an obvious effect on the changes of LULC categories in the study area (Figs 11 and 12) and consequently this process would have a negative impact on the agricultural production and food security in the study area. A damage effect of water erosion on the cropland and fish farms was observed and estimated, where 31.56 km² (3156 ha) and 0.54 km² (54 ha) of the cropland and fish farms were removed or damaged and converted to wadi, respectively. On the other hand, 0.67 km² (67 ha) and 0.5 km² (50 ha) of the cropland and fish farms were submerged and converted to water flooding areas, respectively. The resulted LULC change map illustrates that the middle part of the study area from West to East is the highest risk zone for flash flood and water erosion with more hazards to the Eastward (Fig 12). The remarkable hydro-geomorphological conditions of this zone as discussed later support the obtained result.

Flood risk management:

The hydro-geomorphological conditions of the study area reveal that most of Wadi Alhaytah watershed is eligible for surface runoff and soil erosion, especially under severe rain fall, as more than two-thirds of the watershed area has a slope of 1% to 5% and most of the area is bare land with a gravelly to sandy surface soil layer. All these conditions increase the amount and energy of the surface runoff and thus increase the rate of soil erosion and destruction of property and infrastructures. Therefore, flood risk management is very important in Wadi Alhaytah catchment area.

Flood risk management requires flood control strategies which include assessment and mitigation of flood risk. To perform this task, the settings and conditions of the catchment area were justified through the integration of the wadi streams (Fig 7 A), the slope (Fig 7 C), the flow accumulation (Fig 7 D), and the extent of August-16 cropland (Fig 9). The geological settings and soil association in the study area were taking into consideration (Fig 4). An integrated map showing these conditions was produced using the overlay procedure in ArcGIS (Fig 13).

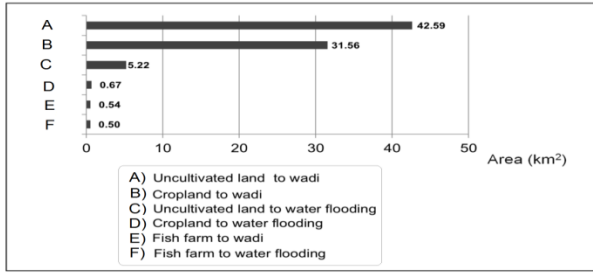


Fig. 11. LULC change area (km²) in Wadi Alhaytah watershed, between August 16 and November 14.

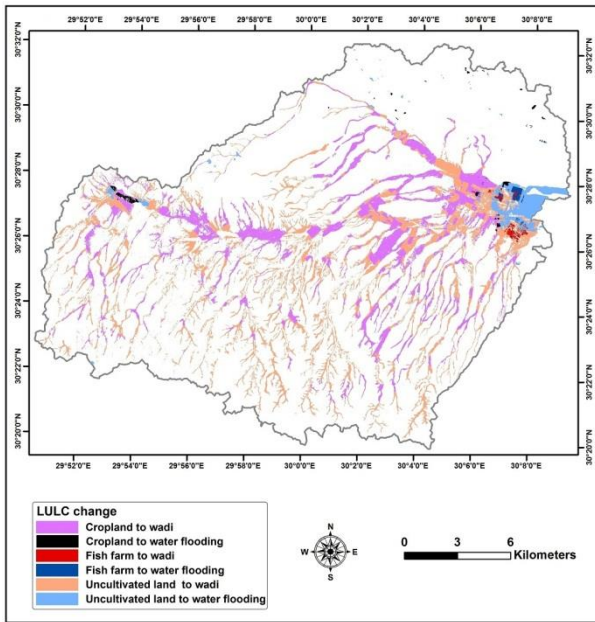


Fig 12. LULC change map in Wadi Alhaytah watershed, between August 16 and November 14.

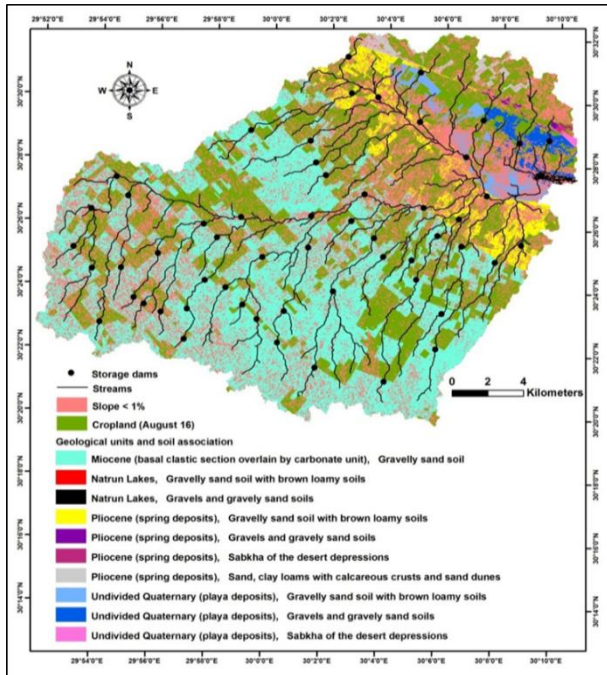


Fig. 13. Map of the proposed locations for dam construction in Wadi Alhaytah watershed.

By using Model Builder in ArcGIS, fifty six suitable locations for dam construction (obstacle barriers) were identified along the flow path of the water stream

network in Wadi Alhaytah watershed. These storage dams were proposed to mitigate unexpected floods, prevent loss of human and animal lives, decrease soil erosion, enhance soil moisture in such drylands, and increase the yield of the existing aquifers. The proposed locations are characterized by the nearly leveled to flat slopes (< 1%) and permeable soils (gravels and gravelly sand) which decrease the energy of floodwater and yield acceptable infiltration rate. These conditions, with the establishment of dams will increase the travel time, encourage water to percolate into the underlying layers, and give the best chance for water infiltration. It is preferred to apply this system at a near distance from farms in the direction of water runoff to enhance the soil moisture content of the root zone. The water table in the study area is adequately deep to keep groundwater seeps below the bottom of the recharging watershed.

CONCLUSION

In the present work, water erosion by flash flood was assessed in wadi Alhaytah watershed in the West Nile Delta of Egypt using GIS and remote sensing data. Two Sentinel-2 satellite images were selected for the purpose of the study, which acquired in 2015 before and after the November 5 flash flood. More than two-thirds of the watershed area has a slope of 1% to 5% (with high range of elevations) and most of the catchment area is bare land with a gravelly to sandy surface soil layer. These conditions increase surface runoff and soil erosion. Analysis of the LULC types of the two images by using image classification and change detection indicated that the flash flood of November 5 has an obvious effect on the changes of LULC in wadi Alhaytah watershed. The effect of flash flood and water erosion on the cropland and fish farms were estimated, where 32.23 km² (3223 ha) and 1.04 km² (104 ha) of the cropland and fish farms, respectively, were removed or damaged. These effects would have a negative impact on the national agricultural production and food security. Therefore, a strategy of flood risk management was assigned to the study area using a developed GIS methodology. In this strategy, fifty six suitable locations of storage dams were proposed along the flow path of the water stream network. This strategy was proposed to mitigate unexpected floods, prevent loss of human and animal lives, decrease soil erosion, enhance soil moisture, and increase the yield of the existing aquifers, especially groundwater is the only water resource available for irrigation and agricultural development in the region. Thus, another challenge in this region is therefore the efficient use of flood water to allow the sustainable management of natural resources and environmental protection.

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تقييم مخاطر فقد التربة بواسطة الفيضانات المفاجئة باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية دراسة حالة: المستجمع المائي لوادي الحيطه، وادي النطرون، مصر أسامة راضي محمد عبد القوي قسم الاراضى والمياه- كلية الزراعة (الشاطبي) – جامعة الاسكندرية

يعتبر فقد التربة بواسطة الأمطار الشديدة من أخطر التهديدات للتنمية المستدامة والبيئة، ففي الاعوام الأخيرة حدثت أمطار شديدة ومفاجئة بشكل متكرر في مصر نتج عنها فيضانات قوية تسببت في خسائر في الأرواح والممتلكات وتدمير للنظم البيئية الزراعية والبنية التحتية. أحد المناطق التي تعرضت حديثاً لمخاطر الفيضانات في مصر هو المستجمع المائي لوادي الحيطه. لذلك تهدف الدراسة الحالية الى تقييم مخاطر الفيضان الذي حدث في الخامس من نوفمبر عام 2015 في منطقة وادي الحيطه بوادي النطرون، وذلك باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد. أيضا وضع استراتيجيات لتقليل مخاطر الفيضانات الناتجة عن التساقط الغير متوقع والمفاجيء للأمطار الشديدة داخل وادي الحيطه. لتحقيق أهداف الدراسة استخدمت صورتين للقمم الاصطناعى *Sentinel-2*، والملتقطتين قبل وبعد حدوث الفيضان في 16 أغسطس 2015 و 14 نوفمبر 2015. تم تطبيق تقنية التصنيف الموجه *Supervised Classification* على صورتين لإنتاج خرائط غطاء التربة واستخدام الأرض (*LULC*) قبل وبعد الفيضان. تم تقييم مخاطر السيول وفقد التربة من خلال رصد التغيرات الحادثة في غطاء التربة واستخدام الأرض قبل وبعد حدوث الفيضان. تم اقتراح استراتيجيات للتحكم في مياه الفيضانات المفاجئة داخل وادي الحيطه بالاعتماد على تقنية نظم المعلومات الجغرافية. كشفت نتائج الدراسة أن المستجمع المائي لوادي الحيطه يتميز بالتباين الملحوظ في المناسيب والميول به. أيضا أوضحت النتائج ان الفيضان المفاجيء الذي حدث بمنطقة الدراسة يوم 5 نوفمبر 2015 أدى الى إزالة وتدمير 32.23 كيلومتر مربع (3223 هكتار) من أراضي المزارع بالإضافة الى تدمير 1.04 كيلومتر مربع (104 هكتار) من المزارع السمكية. لذلك تم اقتراح 56 موقعاً مناسباً لإنشاء سدود تخزين المياه داخل المستجمع المائي لتخفيف مخاطر الفيضانات الغير متوقعة ولمنع حدوث خسائر في الأرواح والممتلكات، وتقليل فقد التربة، وزيادة رطوبة التربة، وتغذية الخزان الجوفى بالمنطقة، خاصة ان المياه الجوفية تعتبر هي المصدر الوحيد للرى والتنمية بمنطقة الدراسة.