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Using GIS based Morphometry Estimation of Flood Hazard Impacts on Desert Roads in South Sinai, Egypt

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Abstract:
Flooding is one of the most common environmental hazards, which weather-related and that can affect many aspects of human life and the natural environment. The major cause of flash flood in Sinai Peninsula is the occurrence of extremely heavy rainfalls over a short period, they are sudden and highly unpredictable and rapid snow melt and low water absorptive capacity of soil, etc. leading to an increased overland flow despite the total fall rainfall amount relatively small in these area. This paper presents the based methodology on (GIS) to estimate flash flood risk levels in sub-basins within the Wadi Fran and Wadi El-Aawag and then estimate its impact on the road network through integrating geomorphological and geological data in a geographic information system (GIS) environment. In addition to, use remote sensing data. Where was calculated flash flood hazard degree on the highway Suez-Sharm El-Shaikh, which is passing in Al- Tour city, as well was calculated the risk degree of the flash flood on Fran–Katherine road using the morphometric analyses model, and also was produced a flood risk map based on the results of the morphometric analysis, These results are essential to define the more sections of roads, which will Exposed of flood hazard, Thus it is possible to help this study in taking appropriate measures to mitigate the probable hazards from floods in the area with prioritization.

Keywords: GIS, Morphometry, Flood assessment, Risk, Road, Egypt, Geomorphology.

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1 INTRODUCTION

FLoods is one of the most destructive natural hazards in the world, causing significant loss of life and property [1]. So that frequent flash floods seriously affect the highway and human activities along the many areas in Gulf of Suez [2]. Floods can have a significant impact on various aspects of life due to the damage caused by the great destruction. It comes because of heavy rainfall which cause an increase in the volume of water in the watershed. In addition, the land using changes in basin areas as a result of human activities and various engineering applications which helped in increasing the size and frequency flooding events. Therefore, there is an urgent need to find ways and models of effective interpretation and understanding about the factors that cause these problems, thus working to mitigate and reduce the devastating effects of the floods, which dramatically increased in recent years [3]. However, there are other many factors, mainly affected on the floods, especially in the desert areas. Where some of these factors calculated which included, drainage networks, drainage orders, water loss, environmental and human processes, rainfall characteristics and drainage characteristics [4]. Drainage attribute in many basins and sub-basins in different areas of the world have been studied using conventional approaches [5], [6], [7].

Morphometric studies include the evaluation of streams through measuring the stream network properties. Morphometric parameters could be evaluated by analyzing the various drainage parameters such as basin area, perimeter, and drainage density, length of drainage channels, texture ratio, bifurcation ratio, ruggedness number, basin relief, stream frequency, overland flow and time of concentration [8]. It is difficult to examine each details of drainage parameters in the field using traditional methods, which was analysis of drainage networks that are manually conducted via tracing the stream network from the topographic maps and field observations, which takes a long time and painstaking [5], [9]. Thus it is better to use advanced methods to describe the geomorphology of drainage networks using remote sensing and a DEM within a GIS environment [10], [11]. Many authors explained in their studies the flood hazard and risk mapping using remote sensing data and GIS tools, which used too for monitoring the flood all around the world [12]. Geomorphology evaluation of hydrographic basins provides necessary information to define basins with the potential flood hazard in arid regions, especially where long-term field observations are scarce and limited [13]. The risk analysis takes into account some sensitive and important factors including (transportation networks, land cover information, etc...), on which based on which Degree of risk were classified into categories (low risk, medium risk, and high risk) [14].The risk map will show us the areas that are likely to be exposed to the risk of flooding, which will have serious consequences on those areas because of its large impact on human life, as well as its impact on all economic and social aspects and causing in occurrence of environmental changes in the region, also the risk map will display information about how much value at risk in order to create all the possibilities to work on the face of such disasters and minimize them. Flooding "flash flooding" is of the main sources important groundwater .Although it is considered one of the disastrous and destructive phenomena, the size of infiltration from the amount of rainfall, intensity and their location is one of the main reasons for increasing the underground water, as well as there are reasons linked to the characteristics of geomorphology and geological special surface drainage basins. [4]. The aim of this paper is assessing the Geo-environmental hazards including, flash flooding on highway Suez - Sharm El-Shaikh and the extended road in Wadi Feiran. This paper describes how the Geographic Information System techniques and remotely sensing have been used to both in extract stream network parameters, and also to produce a flood hazard risk map based on the results of the morphometric analysis. These results are essential to define the higher risk of locations which affects the infrastructure in general and the road's network are particular in the study area, and that can help the initiate appropriate measures to mitigate the probable hazards in the area with prioritization.

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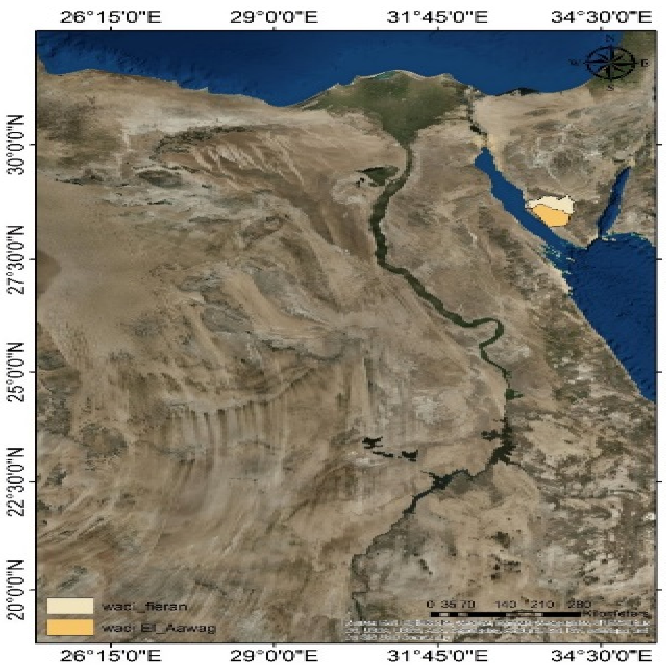
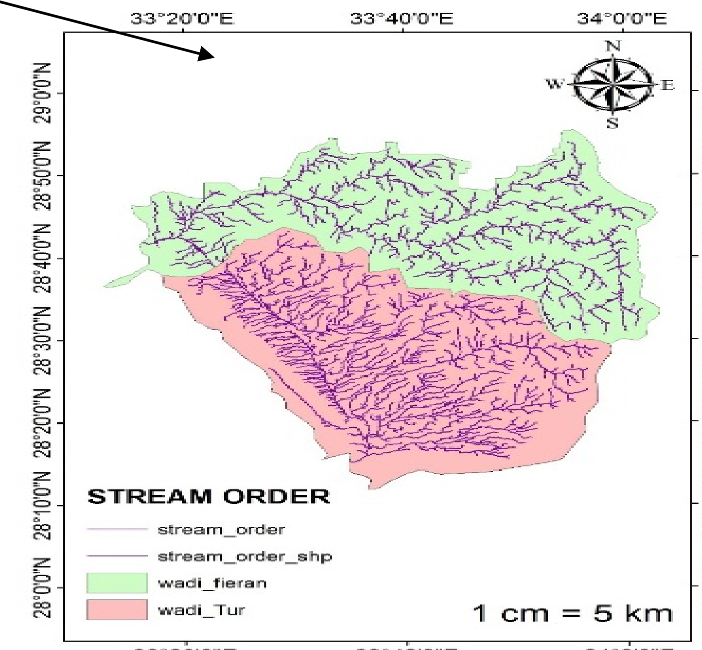
Figure (1): Location map of the study area in the





south of Sinai

2. Study Area

The study area includes two of the largest hydrographic Drainage basins in the region (Wadi Feiran and Wadi El-Aawag). The study area is located at the southwestern - part of Sinai Peninsula between latitude (28 15` and 28 50`) N and longitude (33 12` and 34 15`) E. (Fig.1). Bounded, in the west by the Gulf of Suez, and in the east by Wadi Kid and Wadi Dahab, while bordered by the Wadi Sedry from the north, and the red sea from the south. The study area is occupied by the high complex mountains, such as Catherina mountain (2,641 m amsl), and Serbal (2,070 m amsl).

2.1 Wadi Feiran Characteristics

The Wadi Feiran basin is one from the largest drainage systems basins in Sinai southern. The Wadi Feiran basin covers an area of approximately (1,785) km2 and perimeter (2290) km. The direction of drainage Networks in the wadi Feiran be westward, where the Gulf of Suez, and through this path, it shows us a variety of terrains. Extends inside wadi feiran network of roads in different directions with a total lengths of the network, including the main road more than155 km.

Geologically, [15]. Feiran basin is covered by basement rocks. It is consisted of igneous and metamorphic rocks, forming high patches. It is deeply dissected with numerous narrow and long wadis bounded by steep cliffs. Form high mountains with extended flat-topped plateaus and steep slopes. The different rock units are highly affected by several faults and joints with different trends and densities. Feiran metamorphic belt is a part of Feiran-Solaf metamorphic belt, extends NW-SE and forms a conspicuous rugged terrain that is intruded by different granitic bodies. In the study, it was obtained on geological maps, of scale 1:250000 from (geological survey of Egypt 1994), It was converted into a digital map through used tool georeferensing (Fig. 2) (Fig. 3). For that, the exposed basement rocks can be classified in chronological order into three major rock units, include, the metamorphic rocks, syntectonic Granitoid, and the out-crops of the late and post-tectonic.The main lithological units are quartzofeldspathic paragneiss and biotitehornblende paragneiss with generally minor but locally

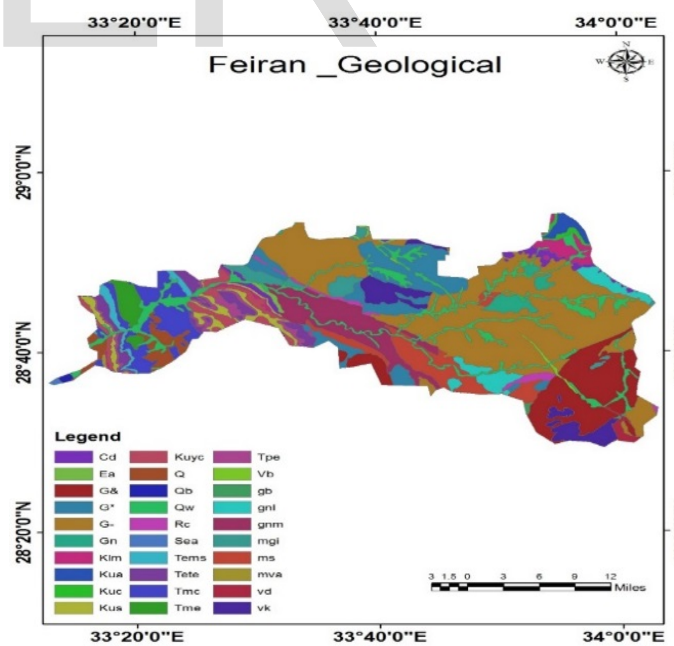


Figure (2): Geological map of the Wadi Feiran

2.2 Wadi AL_AWAGE Characteristics

El-Aawag basin is one of the big drainage basins in South Sinai, covering an area of about (1915) km2 and a perimeter more than

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1350) km and the main city in the wadi is the AL_TUR City. The highway length of about (110) km and extend in the main channel to the Wadi, it is considered, one of the main roads in the region and which exposed to the risk of floods. The direction of drainage Networks in the El-Aawag basin be from north east to south west accordance to the geologic structures in region. (fig.3)

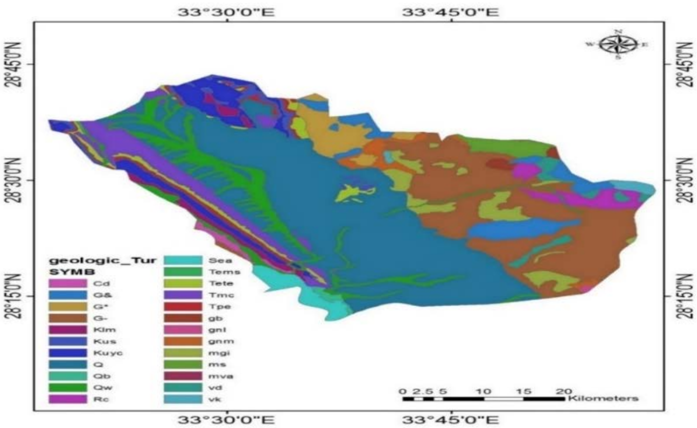


Figure (3): Geological map of the Wadi El- Aawag

Study Area Climate: The area in general be long hot and rainless summer and warm in the winter. South Sinai climate is influenced by the Mediterranean and the tropical effect of the Gulf of Suez and the Gulf of Aqaba. While the high variability considered an advantage in the process of rainfall in south Sinai from both time and space [17]. The minimum of temperature is 10c and maximum is 30c in the Abu Rudeis station. While the average annual rainfall is between 0.61mm and 3.4 mm. The highest recorded rainfall in the studied area is 38 mm. Table summarizes the climatic data for the last six years (2009–2014) for the studied area.

3. Methodology

this study was different data included: Digital Elevation Model (DEM) with 30 m resolution of the study area has been obtained from the ASTER (Advanced Space borne Thermal Emission and Reflection)[18], which used to calculate morphometric parameters in each basins (feiran and al-awage).The DEM is a digital representation of cartographic information in a raster form created from terrain elevation data, as well as used Geological and topographic maps with the working scale of 1:250,000 and 1:50,000, respectively.

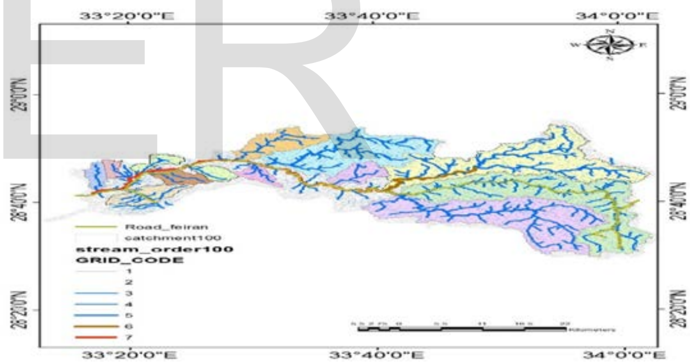
Using the Arc Hydro tools in ArcGIS 10.1. For extracting the drainage network from DEM exist in the literature [19]; [20]. The first step “Fill Sinks” which is used to remove small imperfections in a DEM grid were removed in order to eliminate discontinuities in the drainage network, and is one of the complex. Steps in the drainage calculate process. Flow direction was calculated from the (filled DEM) for each pixel, the direction water will flow out of them pixel to one of the eight surrounding pixels according to the eight-direction pour point model.

Flow accumulation was calculated from the flow direction grid. Each pixel has been appointed a value equal to the number of pixels drained through a given pixel in the flow accumulation, through the calculation of the "flow accumulation" grid, to delineate the drainage network of the study area, then calculate the Stream Definition function takes a flow accumulation grid as input and creates a Stream Grid for a user defined threshold, The cell values will have a value of ‘1'. The Catchment grid delineation this tool works on build up a grid in which each cell carries a value indicating to which catchment the Cell belongs, The Adjoin Catchment Processing function are generates the aggregated upstream catchments from the Catchment feature class. Then, we calculate stream order from arc Toolbox. The Stream Order assigned a numeric order to segments of a raster representing branches of a linear network, and the stream ordering system used was based on Strahler method. All Drainage basin parameters were useful to predict the relative flood hazard degree, and were calculated based on mathematical equations.

4. Results

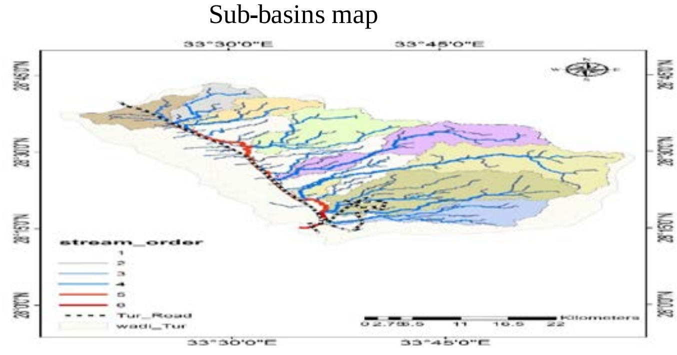
Morphometric Analysis: the drainage systems of Wadi Feiran Was divided into of 13 sub basins and wadi El Aawag into 8 sub basins according to the homogeneity of the hydrological characteristics which poses danger to the Highway network have been mapped and analyzed in (Fig. 4) (Fig. 5).

Figure (4): the drainage networks of the Firan



Sub-basins map

Figure (5): the drainage networks of the El Aawag Sub-basins map



Morphometric parameters analysis of very important processes for the finding out the drainage characteristics and to understand the

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overall evaluation of the basins. All parameters have been performed with the help of GIS. The morphometric parameters result for all sub-basins showed in (Table 1, 2).

Table. 1 Morphometric parameters for the 13 sub-basins of Wadi Feiran

subbasin	p	U	Lb	Nu	Lu	Rb	Lo	A	D	F
B1	35.46	3	10.34	117	51.35	5	0.20	20.77	2.47	5.63
B2	31.9	4	8.03	63	33.32	3.5	0.20	13.2	2.52	4.77
B3	34.4	5	10.39	107	54.61	3.3	0.19	20.84	2.62	5.13
B4	61.9	4	15.07	312	150.81	3.2	0.23	69.59	2.17	4.48
B5	123.9	5	25.8	1288	452.72	3.9	0.23	204.26	2.22	6.31
B6	201	6	41.16	2028	753.56	3.2	0.21	314.58	2.40	6.45
B7	209	5	50.42	2180	829.31	2.8	0.21	340.6	2.43	6.40
B8	157.3	5	39.19	1520	692.86	2.1	0.22	310	2.24	4.90
B9	44	4	10	191	77.3	4.1	0.25	38.26	2.02	4.99
B10	39.23	4	9.75	134	52.55	5.2	0.20	21.13	2.49	6.34
B11	31	4	7.63	133	46.78	3.8	0.23	21.26	2.20	6.26
B12	42.64	4	9.8	134	70.4	4.6	0.20	28.2	2.50	4.75
B13	62.5	5	13.68	213	133.88	3.7	0.18	47.64	2.81	4.47

Table. 2 Morphometric parameters for the 8 sub-basins of Wadi El Aawag

subbasin	p	U	Lb	Nu	Lu	Rb	Lo	A	D	F
B1	82.30	4	27.74	66	141.72	2.95	0.46	129.50	1.09	0.51
B2	103.46	5	33.70	151	310.14	3	0.49	305.76	1.01	0.49
B3	142.95	4	51.24	102	219.60	4.2	0.61	267.61	0.82	0.38
B4	113.46	4	38.86	79	170.43	3.85	0.56	191.23	0.89	0.41
B5	75.84	4	25.33	86	168.50	2.85	0.53	179.69	0.94	0.48
B6	60.06	4	20.44	34	70.50	2.2	0.55	77.64	0.91	0.44
B7	56.06	4	17.40	39	63.65	2.95	0.58	74.04	0.86	0.53
B8	53.99	4	15.84	45	92.52	2.4	0.42	78.62	1.18	0.57

Flood Hazard Index

The degree of flash floods hazard for all the basins and sub-basin are expressed in different units for this it would be is difficult to compare across criteria. For this each morphometric parameter were st normalized using feature scaling. And this became necessary to decrease the scores to the same unit, this is called normalized [24]. The normalized scores are ranged from (0 to 1) to minimize the value of total flood risk.

for Determining the risk degree of the different sub-basins, Morphometric parameters were classified into two groups: Group (1) includes: number of orders, basin area, drainage density, drainage frequency, slope, total drainage number and total drainage length, these parameters have a positive impact on the degree of risk, where the higher the value of these parameters, the higher degree of risk as [13]:

$$N_x = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (1)$$

Where:
Nx = normalized morphometric parameter for the area
x = raw morphometric parameter data of the area
Min(x) = the smallest number of morphometric parameter of All areas
Max(x) = the largest number of morphometric parameter of All areas.

While Group (2) includes: Length of Overland Flow and Bifurcation Ratio, These parameters have a negative impact on the degree of risk, where the higher the value parameters, the lower degree of risk. Been using the following formulas [13]

$$N_x = 1 - \frac{x - \min(x)}{\max(x) - \min(x)} \quad (2)$$

After getting parameters values and In order for come up with a final assessment of flood hazards, to show an understandable final map, was selected 12 only of these parameters that were relevant to the flash flood risk. Using ArcGIS and statistical method (3) were helped to calculate the value of all the dangerous sub-basin and that contributed to the design and determine the highly hazardous sub-basins in both wadi feiran and wadi el awaag and were used to deter mine the highly vulnerable private sectors of roads linking in the cities of Southwest Sinai. The result was divided into three categories (low, medium and high risk) using equal intervals. The raw score for each feature was normalized using (equations 1, 2) taking into account the different signs of parameters as well. The final value Of flood hazard index was estimated as:

$$\text{Flood Hazard} = [N(A) + N(S) + N(U) + N(\sum N_u) + N(R_c) + N(R) + N(R_h) + N(\sum Lu) + N(L_o) + N(R_b) + N(D) + N(F)] \quad (3)$$

(N is the normalized value)

By the results shown in Table 3, 4 find that the sub basins (5, 6, 7, and 8) have the highest values and represent the main dangerous sub-basins in wadi feiran. Whereas, basins (1, 2, 3, 4, 9, 10, 11, 12 and 13) have low values, while in el wadi Aawag find that the sub basins (2, 5) have the highest values and represent the main dangerous. Bifurcation ratio (Rb) characteristically range between 3.0 and 5.0 for watersheds when the influence of geological structures on the drainage network is negligible [25]. The mean bifurcation ratios in the sub-basins of the wadi feiran range from (2.1 to 5.2), this result suggests that the geological structures have little influence on sub-basins (1, 2, 3, 4, 5, 6, 9, 11, 12, 13) and some influences on some sub-basins (7, 8, 10). Drainage density (D) shows the landscape dissection, runoff potential, and infiltration capacity of the land, climatic conditions and vegetation cover of the basin [26]; [11]. Drainage density reflects the geological composition of the area, where the higher value of Drainage density shows the high resistance of soil and this increases the runoff process in region, while a low drainage density Increases soil infiltration process and therefore forms a groundwater there. While the stream frequency (F) analysis of the drainage network shows high values existing in sub-basins 1, 3, 5, 6, 7, 10 and 11 (table 3). Generally, high stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief conditions and low infiltration capacity. The same analysis applies on the sub-basins in wadi el awaag.

Flood Hazard Maps

Flood risk maps were produced based on the morphometric analysis results presented in (table 4), where in wadi feiran she was sub-basins 7, 8, 6 and 5 respectively are highly hazardous sub-basins, while sub basin 9, 11, 13 and 4 respectively are the Moderate hazardous , and the remaining sub basins are the lowest hazardous. Whilst in wadi el awaag she was sub-basins (2, 5) respectively, highly hazardous, while sub-basin 8, 3 and 6 respectively, were the Moderate hazardous. (Fig. 6, 7).

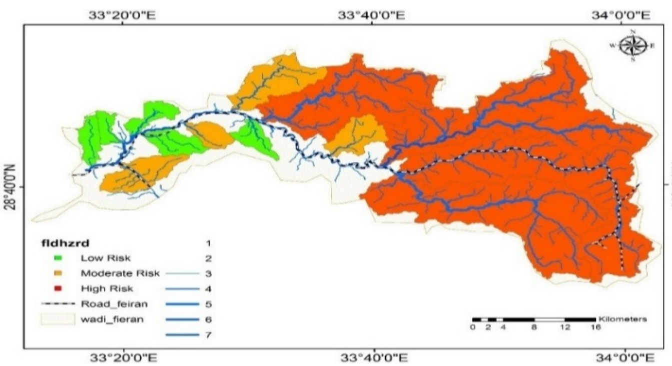
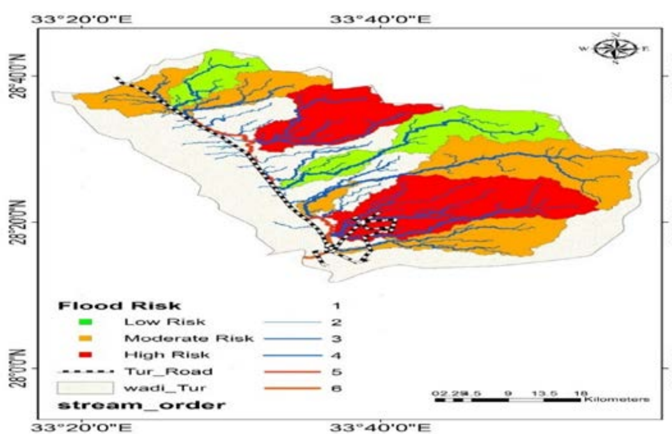


Figure (6): Flood hazard map showing degree of hazard sub-basins in Feiran basin

Figure (7): Flood hazard map showing degree of hazard sub-basins in el_awaag basin



The curvature degree: plays an important role in the hazard influenced zone. In this study the curvature degree was determined according following formulas [27].

$$Cd=R\text{-}S/S$$

Where

Cd = Curvature Degree

R = Road length in real

S = straight length

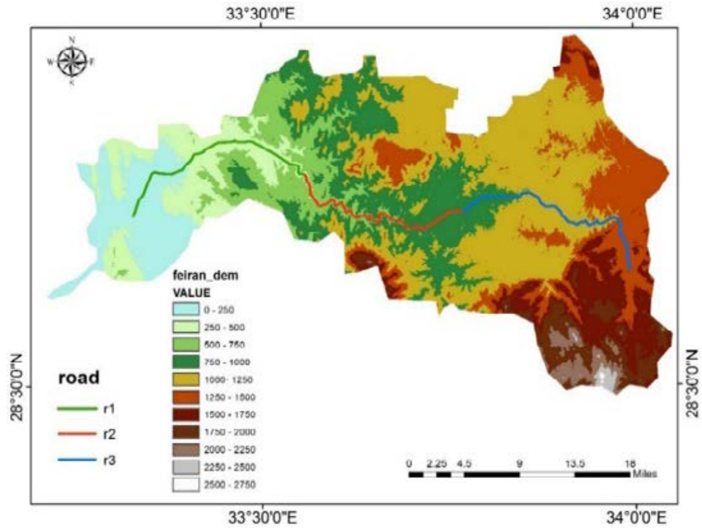


Figure (8): Geomorphological features of Feiran basin Showing diferent Elevation zones.

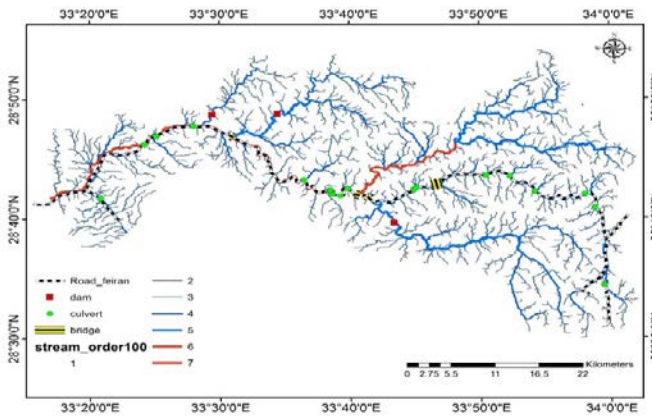
Where road is partition into three parts in lengths equal approximately and Then was calculated the curvature degree in every part (fig.10). Where the results were 28%, 41% and 35% respectively. Through the results that have been obtained, note that the high curvature degree has a main influence on the erosion of the roadsides due to the change in water flow directions. As it is clearly shown in the second part of the road which has a very high degree of curvature, as well as added to the slope degree.

That the cutoff effects of the floods become more obvious on the curved parts of the road comparatively to the straighter part. Through previous studies and images can be seen most road parts were cutoff due to the flash floods along the curvature section.

5. Conclusions and Suggestion

In conclusion, after determining areas are prone of dangerous and calculated danger degree, so it became necessary to provide some suggestions and solutions that will reduce the severity of those risks, as well as to contribute in proper planning for cities and management of various projects. This study suggests some possible solutions, including the creation of some dams that would flood alleviation as well as take advantage of the water stored, but the process of creating dams and determine of the possible sites depends on geological structures and detailed field work for study area. The proposed dams in the wadi feiran and wadi el Aawaag on the main channel. As well as the proposal of number of culvert crossings at the crosses

Figure (9): show Suggestion to mitigate flash flood hazard in Wadi Feiran



Between the main tributary channels and the roads. And also for the mitigation of flash floods along the highway requires building bridges crossing between the main channels of these wadis and the main road restricted the bridges are to crossing the highways with the largest basin channels which have large values of runoff, steep slopes and a few Thicknesses of deposits such as Wadi Solave The study area, also requires building bridge crossing between the main channel of Wadi El-Aawag and the highway Suez- Sharm El-Sheikh. (Fig.9, fig.10).

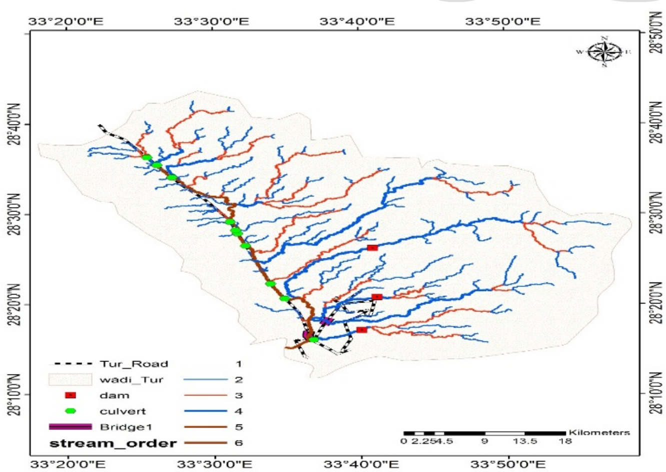


Figure (9): show Suggestion to mitigate flash flood hazard in el_awaag basin

In this study the danger degree of the flood has been determined based on some main parameters, including the morphometric which mainly affect the flooding, as well as the other influential factors should be taken into mind, also more validation data are needed, therefore the method used in the study are valid of planning and assessment purposes.

6. REFERENCE

[1] **CEOS. (2003):** The use of earth observing satel lites for hazard support: assessments and Scenarios. Final Report of the CEOS Disaster Management Support Group (DMSG), November.

[2] **Hassan OA (2000)**: Salient Geoenvironmental parameters of Ras Malaab–Abu Zenima Area, Gulf of Suez, Egypt, with an emphasis on flash flood potential and mitigative measures; Egypt. J Remote Sens Space Sci 3:37–58

[3] **Pradhan, B., & Lee, S. (2010b):** Landslide susceptibility assessment and factor effect analysis: back-propagation artificial neural networks and their comparison with frequency ratio and bivariate logistic regression modelling. Environmental Modelling & Software, 25(6), 747-759.

[4] **Youssef, A. M., Pradhan, B., & Gaber, A. F. D., & Buchroithner, M. F. (2009):** Geomorphological hazard analysis along the Egyptian red sea coast between Safaga and Quseir. Natural Hazards and Earth System Science, 9(3), 751-766.

[5] **Horton, R. E. (1945):** Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological society of America bulletin, 56(3), 275-370.

[6] **Strahler, A. N. (1957):** Quantitative analysis of watershed geomorphology. Eos, Transactions American Geophysical Union, 38(6), 913-920.

[7] **Al Saud, M. (2009):** Morphometric analysis of Wadi Aurnah drainage system, western Arabian Peninsula. Open Hydro J, 3, 1-10.

[8] **Ozdemir, H., & Bird, D. (2009):** Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods. Environmental geology, 56(7), 1405-1415.

[9] **Schumm, S. A. (1956):** Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67(5), 597-646.

[10] **Omran, A., Schroder, D., EL Rayes, A., & Geriesh, M. (2011):** Flood Hazard Assessment in Wadi Dahab, Egypt Based on Basin Morphometry Using GIS Techniques. GI_Forum Program Committee.

[11] **Máčka, Z. (2001):** Determination of texture of topography from large scale contour maps.

[12] **Hess, L. L., Melack, J. M., Filoso, S., & Wang, Y. (1995):** Delineation of inundated area and vegetation along the Amazon floodplain with the SIR-C synthetic aperture radar. Geoscience and Remote Sensing, IEEE Transactions on, 33(4), 896-904.

[13] **Shi, Q. (2014):** Flood Hazard Assessment along the Western Regions of Saudi Arabia using GIS-based Morphometry and Remote Sensing Techniques (Doctoral dissertation).

[14] **Pradhan, B. (2010):** Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. Journal of Spatial Hydrology, 9(2).

[15] **Seleem, T. A., El-Wahab, R. H. A., & Zaghloul, M. S. (2013):** Risk assessment mapping of Acacia tortilis subspecies raddiana growing in South Sinai, Egypt, using integrated field survey, remote sensing and GIS. Int. J. Curr. Microbiol. App. Sci, 2(5), 378-395.

[16] **Fowler, A., & Hassan, I. (2008):** Extensional tectonic origin of gneissosity and related structures of the Feiran–Solaf metamorphic belt, Sinai, Egypt.Precambrian Research, 164(3), 119-136.

[17] **El-Wahab, R. A., Zayed, A. E. M. M., Moustafa, A. E. R. A., Klopatek, J. M., & Helmy, M. A. (2006):** Landforms, vegetation, and soil quality in south Sinai, Egypt. The Egyptian Society for Environmental Sciences, 1(2), 127-138.

[18] **http://gdem.ersdac.jspacesystems.or.jp/search.jsp.**

[19] **Simões, S. J. C. (2013):** Interaction between GIS and hy drologic model: A preliminary approach using ArcHydro Framework Data Model. Revista Ambiente & Água, 8(3), 83-92.

[20] **El-Nahry, A. H., & Saleh, A. M. (2004):** Influence of sea sonal flashfloods on terrain and soils of El-Qaa plain, south sinai, Egypt. EGYPTIAN JOURNAL OF SOIL SCIENCE, 44(4), 489.

[21] **Glennon, J. A. (2001):** Application of morphometric relationships to active flow networks within the Mammoth Cave watershed (Doctoral dissertation, Western Kentucky University).

[22] **Culler, R. C., HADLEY, R., & SCHUMM, S. (1961):** Hydrology of the Upper Cheyenne River Basin. US Gcol. Survey Water-Supply Paper

[23] **Biswas, S., Sudhakar, S., & Desai, V. R. (1999):** Prioritisation of subwatersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. Journal of the Indian society of remote sensing, 27(3), 155-166.

[24] **Elmoustafa, A. M., & Mohamed, M. M. (2013):** Flash Flood Risk Assessment Using Morphological Parameters in Sinai Peninsula.

[25] **Verstappen, H. T. (1983):** Aplied Geomorphology. Geo morphological Surveys for Environmental Development.

[26] **Patton, P. C., & Baker, V. R. (1976):** Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. Water Resources Research, 12(5), 941-952.

[27] **Ez Eldeen FK (1989):** Topography problems in the Eastern desert Egypt, and their impacts on the roads, Quantitative and analytical study. Bull Geog Soc Egypt 21:79–108 (in Arabic).