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Hazard Degrees Assessment of Flash Floods, Applying Multi-Criteria Analysis, Gulf of Aqaba Basins, Sinai, Egypt

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ABSTRACT
Flash flood disasters have a significant impact and cause immense damages to lives and infrastructure. This study will assess the risk of flash floods in Gulf of Aqaba Basins (GAB), Sinai Peninsula. Watershed Modeling System (WMS) package was used to automatically delineate the drainage network and determine the hydro-morphological parameters of 33 GAB sub basins via the 90 m Digital Elevation Model files. These data were statistically analyzed applying Multi Criteria Analysis (MCA) technique to create flash flood hazard scale with and without outliers. Based on the resulted hazard scale MCA technique, it was found that 4% of the studied basins with high hazard degree (class five) while moderately high hazardous basins (class four) represent 32%. Class three contained 29% of the studied basins (moderate hazardous). While the moderately low hazardous basins (class two) contained 18% and the rest belongs to low hazardous degree. It is highly recommended to put into consideration this scale before investing in any flash flood protection projects in the study area.

Keywords: Hydrology, Flashflood, hazard assessment, WMS, MCA technique, Sinai, Egypt.

1-INTRODUCTION

Flash floods are among the catastrophic natural hazards in the world causing the largest amount of deaths and property damage (CEOS 2003). Floods can have an impact on many aspects of human life due to their destructive effect, and can create significant expenses through mitigation efforts. There have been many studies on flood hazard and risk mapping using remote sensing data and GIS tools (O. Adel et al. 2015). Radar remote sensing data have been extensively used for flood monitoring across the globe (Hess et. al. 1995, Le Toan et al. 1997), and many of these studies have applied probabilistic methods (Horritt and Bates 2002, Pradhan and Shafie 2009, Pradhan 2010, Bhuyian et al. 2009, Gad et al, 2016). Hydrological and stochastic rainfall methods for flood susceptibility mapping have been employed in other areas (Haeng, et. al. 2001, Gad, 2001, Cunderlik and Burn 2002 and Gad, 2009). Flood susceptibility mapping using GIS and neural network methods have been applied in various case studies (Sanyal and Lu 2005, Zerger 2002). Drainage characteristics of hydrographic basins and sub-basins in many areas of the world have been studied using conventional geomorphologic approaches (Horton 1945, Strahler 1964, Gad et al. 2002, Rudriaiah, et al. 2008, Al Saud 2009, Gad, 2009 and Nageswararao et al. 2010). Gardiner, 1990 and Gad and Abdel-Latif 2003, indicated that in some studies, the morphometric characteristics of basins have been used to predict and describe flood peaks and estimation of erosion rate, underling the importance of such studies.
Moreover, the application of geomorphic principles to flood potential or flood risk has led to a noteworthy amount of researches, attempting to identify the relationships between basin morphometry and flooding impact (Patton 1988 and Abulohom and Gad 2011). Identification of drainage networks within basins or sub-basins can be achieved using traditional methods such as field observation and topographic mapping, or alternatively with advanced methods using remote sensing and Digital Elevation Models (Macka 2001, Maidment 2002, Galal, and Gad 2010). Many authors have pointed out that it is difficult to examine all drainage networks from field observations due to their extent throughout rough terrain over vast areas.
In addition, hydrological and stochastic rainfall methods for flood susceptibility mapping have been employed in other areas (Haeng et. al. 2001). In arid and semiarid environments, large floods present the only hydrologic process that generates large volumes of water for surface storage and groundwater recharge. With this in mind, flash floods

in arid and semiarid regions can be viewed as a potential water source for future use and sustainable development. A major challenge in these areas is therefore the wise use of floodwater to allow the sustainable management of water resources. A barrier is that observation data is generally scarce and model results are too coarse to allow accurate predictions. The importance of the challenge is only likely to increase since the frequency and impact of flash floods are expected to grow as a result of climate change. Adopting a modeling approach related to flash flood risk level can circumvent these problems. This approach takes into consideration the hydro-morphological parameters of the catchments and the flash flood event itself.

2-SITE DESCRIPTION

The Gulf of Aqaba region is a destination for many tourisms activities. As the tourism is considered a major source of Egypt's national income, this location is critical for maintaining a healthy economy. Thirty three basins on the western coast of Aqaba Gulf were selected from GAB based on the available rainfall records. They occupy about 165 km of the shore line of the Gulf of Aqaba between Taba and El-Nabq Cities, with total surface area of about 7950 km^2 as shown in Figure 1. Climatic conditions of the study area are characterized by a temperate climate. The mean monthly maximum air temperature value reaches 30 ºC in August, while the average minimum value reaches 9 ºC in January with mean annual value of 19 ºC. The average recorded value of pitch evaporation reaches 4000 mm/year. The recorded maximum relative humidity varies from 57% to 63% (in March and December respectively). The study area is characterized by short rainy season (Nov.-Feb.). December is the rainiest month (60 mm).

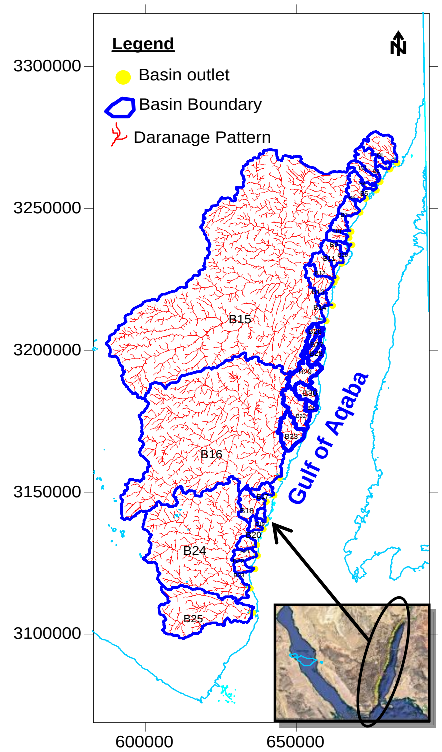

Fig.1: Drainage network of GAB

3-GEOMORPHOLOGICAL AND GEOLOGICAL SETTING

Sculpturing of geological terrains is the product of exogenic and endogenic geomorphic processes, which may act either individually or integrated with each other (Simoni et al., 2003, Taha et al., 2004). Formation of different types of drainage patterns, stream terraces, alluvial fans and development of foothill slopes and scarps are usually controlled by hinterland uplifting and/or sea level declining (Maroukian et al., 2008). The development of drainage systems in Gulf of Aqaba area and related landforms illustrates integrations of fluvial and tectonic activities during their geomorphic evolution (El Refaei 1992). This is documented by uplifting the bordering areas of Gulf of Aqaba - Dead Sea rift since its rifting history (Zain Eldeen et al., 2002; Mart et al., 2005). Therefore the basement rocks on both sides of Gulf of Aqaba are presumably exposed concomitantly with tectonic evolution of the gulf. On the other hand, the Pleistocene rainy periods (Deuser et al. 1976; Givertizman et al., 1992) have sculptured the basement landscapes and its sedimentary cover by formation of drainage systems and alluvial fans. Formations of fault scarps, deep canyons, hanging valleys, stream and wave-cut terraces and raised beaches indicate that the fluvial and tectonic activities were working simultaneously in development of landscapes in the Gulf of Aqaba area. It is geomorphologically subdivided into two major geomorphic units; 1) the rugged basement badlands and 2) the Nabq alluvial plain. The structural investigation of the area indicates that these geomorphic units are affected by formation of Gulf of Aqaba fault systems. Four stages of morphotectonic evolution of Kied area are investigated. The first stage witnessed the structural foundation of the area that are related to rifting of the Gulf of Aqaba, while the second stage is related to formation of drainage system and beginning of deposition of old deltaic sediments during Pleistocene. Drainage systems, alluvial plains and development of escarpments are outstanding landforms formed during this stage. The third stage is associated with rising sea levels submerging the pediments of fault-scarps and the eastern limits of Nabq alluvial plain. The fourth stage is marked by quaternary uplifting for the hinterlands and Nabq alluvial plain. The faults are reactivated, consequently hanging terraces, hanging valleys, canyons and waterfalls are characteristic geomorphic landforms. The older delta in Nabq alluvial plain is exposed northward and tilted southward on E-W trending normal faults. The sediments of younger deltas are therefore deposited to southern areas of the Nabq plain. Hinterland uplifting and sea level declining resulted in formation of different types of stream and wave-cut terraces while bajada plains and spurs are formed on the foot-slopes of fault scarps.

In addition, the highlands extend towards the south until it goes over into the southern area consisting of granite and volcanic rock deposits, and layers of Marine fossils. Limestone and sandstone sediments are replaced by granite and basalt escarpments that slope into the Gulf of Aqaba. Both rocks are produced by volcanic activity on the bottom of the ocean from the Precambrian Age.

4-DATA USAGE

The long term rainfall data used in this paper were collected from the Water Resources Research Institute, National Water Research Center (NWRC), Ministry of Water Resources and Irrigation (MWRI), based on the installed rain gauge stations and monitoring monthly periodic record. The total annual rainfall from three stations Nwebaa, Dahab and Sharm El-Sheikh are listed in Table (1). These rainfall records were used in estimating the recurrence period and rainfall event distribution in GAB according to Weibull (1932) ranking method and Raghunath, (1990). The statistical analysis of the rainfall records during the period 1990 to 2014 (24 seasons), including the recurrence period (T) and the probability of exceedance (Pr), was estimated based on the following relations (Bennett and Doyle 1997);

$Pr = M / (N + 1)$ …………………..……………………….. (1)

$T = (1/ Pr)$ …………………..…………………..…….. (2)

Where M is the descending order rank (dimensionless) and N is the total number of records (dimensionless).The results of the three stations are shown in Figure 2 on Log-log scale.

It is worth to mention that a linear best fit method was used to predict the recurrence period for the three stations (Nwebaa, Dahab, and Sharm El-Sheikh) with R^2 (0.96, 0.87, and 0.99) respectively, the results show that when there

Table (1) :Total annual rainfall (mm) in the period (1990-2014) WRRI

year	Nwebaa	Dahab	Sharm El-Sheikh	year	Nwebaa	Dahab	Sharm El-Sheikh
1990			2.1				
1991			6.2	2003	5.1	4.5	3
1992	0		3.8	2004	4.8	0	0.1
1993	5.9		7.8	2005	1.9	0	0
1994	56.5		6.5	2006	5	7	0
1995	7		1.9	2007	19.4	15.2	0.4
1996	24		56.3	2008	1.7	1	0.3
1997	12.9		2.2	2009	0	0	0
1998	1.6		0	2010	24.9	12.3	83.9
1999	2.1	0	0.3	2011	1.8	9.1	12.3
2000	2.6	0	0	2012	4.7	12.9	0.8
2001	0.2	0.1	1.4	2013	5.5	1.5	1.3
2002	27.3	13.2	9.4	2014	27	30	33.8

is a need to design a hydraulic structure in the study area for a recurrence period of 100 years the maximum rainfall will be about (150, 450, and 750 mm) for the three stations (Nwebaa, Dahab, and Sharm El-Sheikh) respectively.

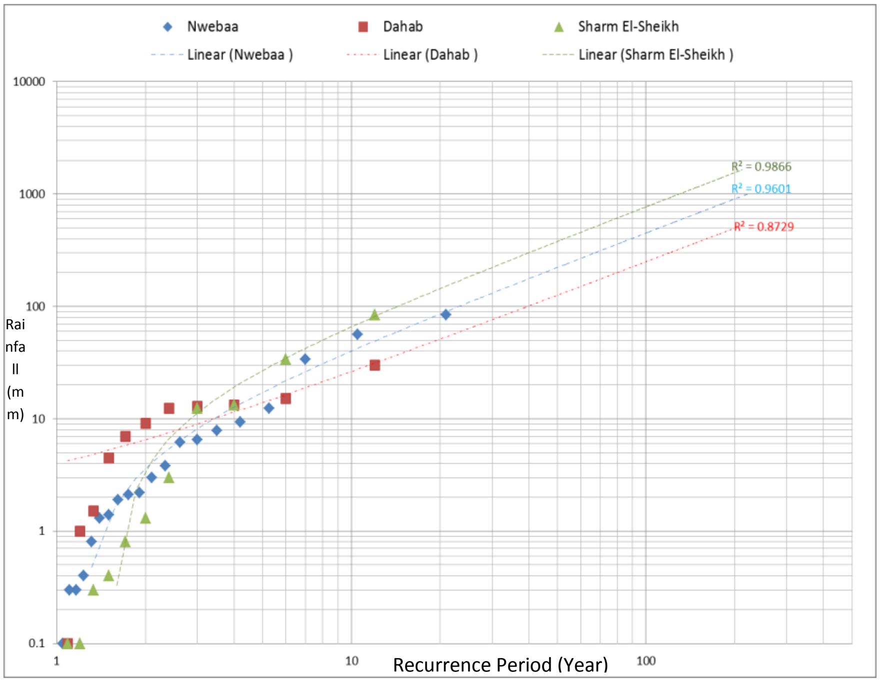

Fig. (2) :Recurrence Period vs rainfall in study area stations

5-METHODOLOGY

The methodological approach used in this paper is based on the mathematical modeling techniques applying Watershed Modeling System (WMS, version 7.1) and STATISTICA version 7 computer programs. The criteria adopted in this study for risk analysis was based on hydro-morphological parameters that may result in more loss in surface water and damage to the crossing locations. These selected parameters are the basin drainage area (A), basin average slope (BS), average overland flow (AOLF), basin length (L), basin shape factor (Shape), basin sinuosity factor (Sin), basin average elevation above mean sea level (AVEL), basin maximum stream length (MSL), basin maximum stream slop (MSS), basin Perimeter (P) and basin centroid stream distance (CSD).

To estimate these selected eleven dependent parameters required for the flash flood risk assessment, delineation of the watershed boundaries and their characteristics was carried out through the use of a Digital Elevation Model (DEM) file Figure (3) and the Topographic Parameterization program technique (TOPAZ) (Martz and Garbrecht 1993).

In order to obtain these selected basin characteristics, Watershed Modeling System (WMS) package had been used. WMS is a comprehensive environment for hydrologic analysis. It was developed by the Environmental Modeling Research Laboratory of Brigham Young University in cooperation with the U.S.A. Army Corps of Engineers Waterways Experiment Station. It was used to delineate the catchment and basin streams (Nelson et al 2000). The input data to WMS model were obtained from SRTM3 (Shuttle Radar Topography Mission).

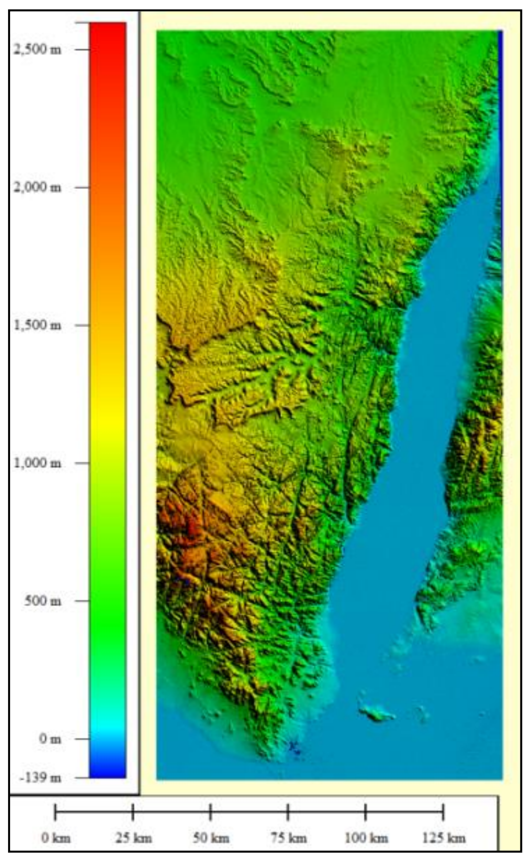

Fig. (3) Digital Elevation Model (DEM) of the study area

SRTM3 data gave the elevations in reference to the mean sea level in the center of a grid of 90m x 90m spacing. Moreover, SRTM3 data are used to trace and convert the drainage network and basin boundaries to lines and polygons by WMS drainage coverage (Nelson et al, 2000). Figure 4 shows a flow chart for the methodology of this study. These hydro-morphological parameters of the different selected basins in the GAB were statistically analyzed by using Pearson's correlation coefficient in order to differentiate and confirm the interpretation of them. The Pearson's correlation coefficient is the most applicable one of the most multivariate correlation (John, C. Davis, 1986). By using these eleven hydro-morphological variables, basic statistics and correlation matrix of these different variables are obtained. Moreover, the cluster analysis was carried out on the non-transformed input data matrix of 33 selected basins with eleven hydro-morphological parameters applying STATISTICA software V.7.1. Hierarchical agglomerative cluster analysis begins by calculating a matrix of distances among all pairs of samples, this is known as a Q-mode analysis; an R-mode analysis is also run, which calculates distances (similarities) among all pairs of variables. The results are given as R-mode and Q-mode dendrograms with amalgamation rule of single linkage with (1-Pearson r) method.

On the other side, Multi Criteria Analysis (MCA) was used for statistical analysis after standardization of the selected eleven hydro-morphological parameters.

MCA was appeared in the 1960s as a decision-making tool. It was used to make a comparative assessment of alternatives or heterogeneous measures. With this technique, several criteria can be taken into account simultaneously in a complex situation. The method is designed to help decision-makers to integrate the different options, reflecting different factors of the addressed problems, into a prospective or retrospective framework. The results are usually directed at providing advice or recommendations for future activities. MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish certain or several objectives. In MCA, desirable objectives are specified and corresponding attributes or indicators are identified. The actual measurement of indicators need not be in monetary terms, but are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria (Baptista et al., 2007). MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used.

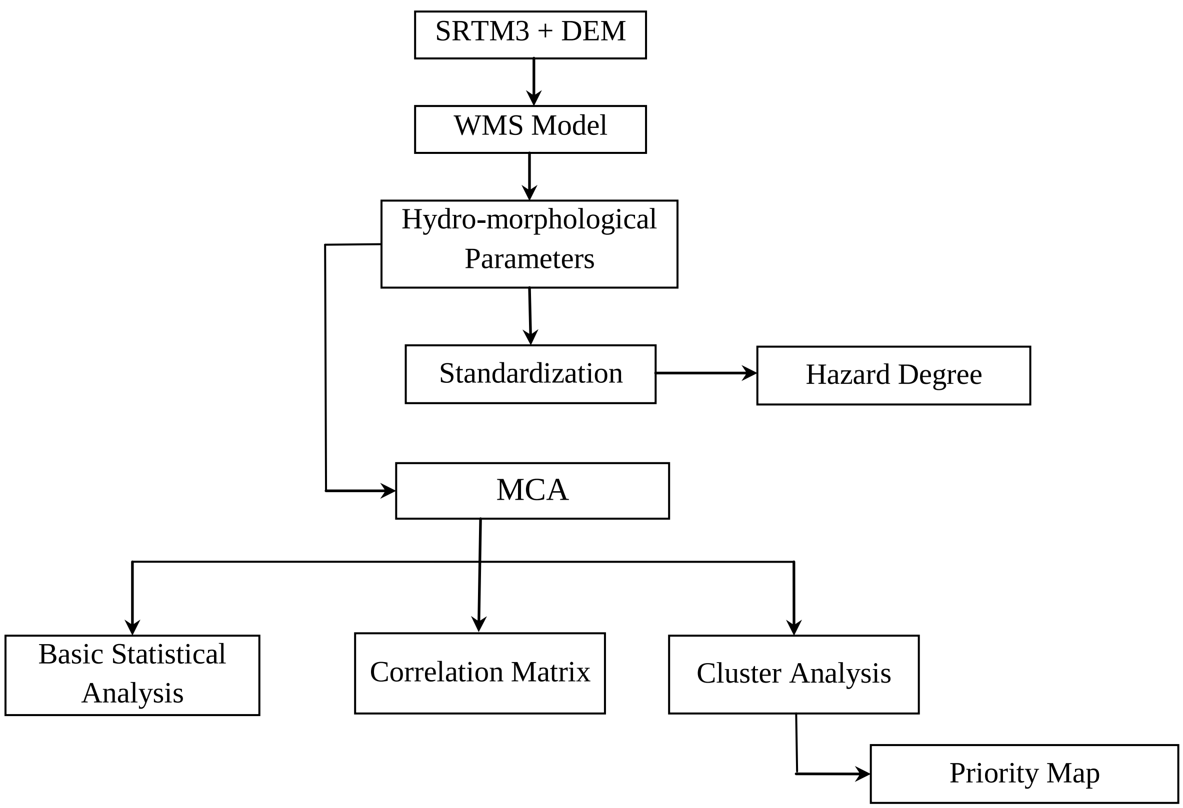

Fig. (4) Flow chart for the methodology of the study

6-STANDARDIZATION HYDRO-MORPHOLOGICAL PARAMETERS

The selected eleven hydro-morphological parameters obtained for each basin are expressed in different units. Consequently, it is difficult to compare between the different basins by normal statistical methods. Therefore, a weighted factor will be used to analyze these parameters dimensionless, which is called standardization.

An empirical relation between the relative hazard degrees of basins with respect to flash floods was applied on the chosen hydro-morphological parameter, the equal spacing or simple linear interpolation between data points procedure was chosen. Assuming that a straight linear relation exists between sample points, intermediate values can be calculated from the geometric relationship (Davis 1975):

$$Y = \frac{(Y_{max}-Y_{min})(X'-X_{min})}{(X_{max}-X_{min})} + Y_{min} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where Y is the relative hazard degree, Y_{max} and Y_{min} are the upper and lower limits of the proposed standardized scale (Y_{min}=1 and Y_{max}=5), X_{max} and X_{min} are the higher and lower estimated values of any parameter. X′ is the estimated value of any parameter between higher and lower values.

In order to obtain a weighted factor for each for the different basins, the above equation was applied to calculate the Standardized Risk Factors (SRF) of the 11 parameters that reflect the risk degree for each parameter compared to the same parameter in the other basins, (Heun, 2008 and Baptista et al., 2007), which are A_{SRF}, BS_{SRF}, MSL_{SRF}, MSS_{SRF}, L_{SRF}, P_{SRF}, $SHAPE_{SRF}$, SIN_{SRF} $AOFD_{SRF}$, CSD_{SRF} and $AVEL_{SRF}$ as shown in tables 2. The summation of all the Standardized Risk Factors was calculated then equation 3 was applied another time with these new values to obtain the total SRF of each basin.

The relative hazard degrees, of the chosen basins with respect to flash floods, are estimated to classify the different basin as shown table 2, this classification was ranked as follow:-

Total SRF	Class of the hazard degree
1	Low
2	Moderately Low
3	Moderate
4	Moderately High
5	High

Studying the following tables it was found that there are four basins (B15, B16, B24 and B25) representing Wadi Watier, Wadi Dahab, Wadi Kied and Wadi Om Adawy have areas of (3511.25, 2057.72, 1036.26and 352.63) Km^2 respectively, which is considered very large when compared with the other basins area and consequently have the maximum hazardous degrees, the results of classification of the pervious basins are Wadi Watier and Wadi Dahab high hazardous while Wadi Kied moderately high hazardous and Wadi Om Adawy moderate hazardous . The preceding basins were excluded and classification of the flash flood hazard degrees was studied once more as shown in table 3. It was found that six of them remain with the same degree of hazardous which are (B2, B5, B10, B14, B31 and B32) representing Wadi toyna, Wadi Al Makla, Wadi South of Al- Mahash Al-Asfal, Wadi Al-malha Al-Atshanaa, South of north east of Wadi Dahab and East of Wadi Dahab respectively. Secondly two of them become moderately low hazardous (B20, B21 and B22) representing Wadi Al- Ghorabi, Wadi Kabilat Al- Albu and Wadi Al-Samraa respectively. Finally one basin becomes moderately high hazardous which is B1 representing Wadi Taba.

On the other hand the basins exhibit moderately low hazardous have four behaviors; firstly only two basins remain the same hazardous which are (B7andB19) representing Wadi Om Moghra and Wadi North Al-Ghorabi. Secondly there eight basins become moderate hazardous which are (B6, B8, B9, B17, B26, B27, B28 andB30) representing Wadi Al Mahash AlAala, Wadi Kadib, Wadi Al- Mahash Al-Asfal, Wadi East Muilha, Wadi Al Badan, South of Wadi Al Badan, South South of Wadi Al Badan and North east of Wadi Dahab. Thirdly also eight basins become moderately high hazardous which are (B3, B4, B11, B12, B13, B18, B29 and B33) representing Valley Alemrakh, Wadi Alfahirh Albahari, Wadi North Al-Malha, Wadi Al-Malha, Wadi South Al-Malha, Wadi Muilha, South of

Wadi Watier and South East of Wadi Dahab. Finally just one basin become high hazardous which is B32 representing East of Wadi Dahab.

When assessing GAB according to flash hazard degrees with and without large basins the results are shown in the following graph Figure 5 where it's obvious that it was important for overlooking these four large basins in order to be able to give respectable assessment of the majority of basins in the study area with recommendations of studying them individually.

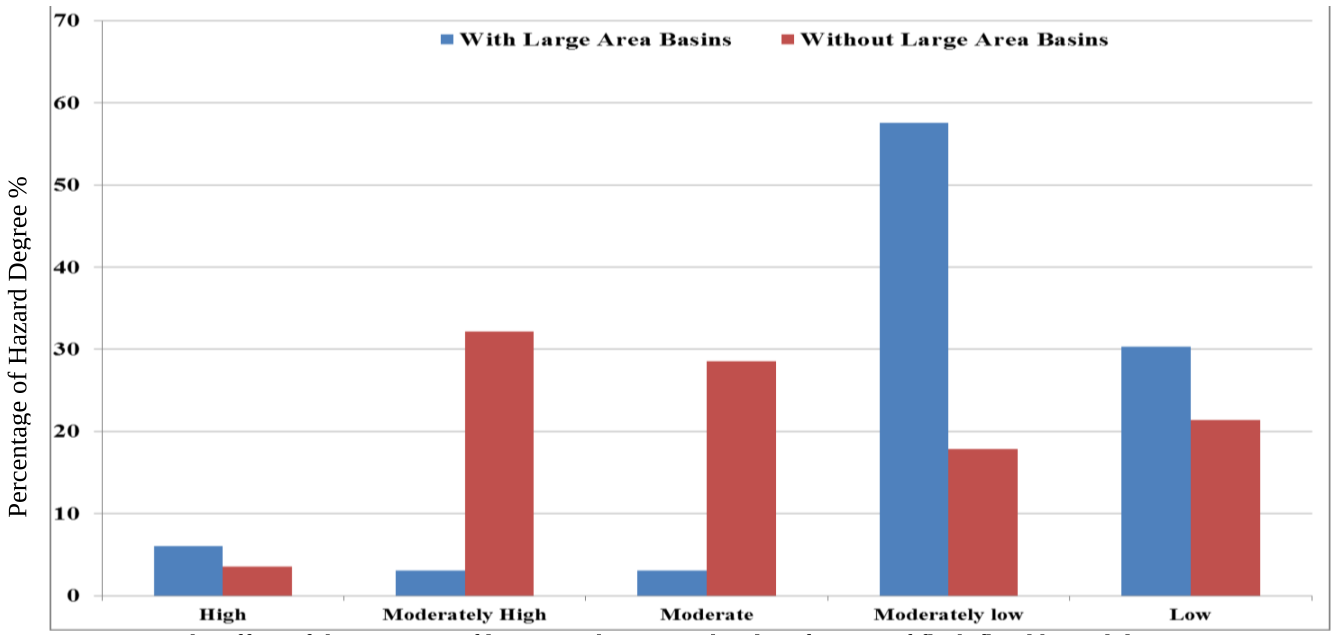

Fig. 5: The effect of the presence of large area basins on the classification of flash flood hazard degrees in GAB

Table (2): Results of the selected 11 hydro-morphological parameters of GAB and corresponding Standardized Risk Factor (SRF) with large area basins

Basin code	Basin Name	Area	A_{SRF}	Basin Slope	BS_{SRF}	Overland Flow	$AOLF_{SRF}$	Centroid Stream Distance	CSD_{SRF}	Basin Length	L_{SRF}	Max Stream Slope	MSS_{SRF}	Max Stream Length	MSL_{SRF}	Basin Perimeter	P_{SRF}	Basin Shape Factor	$SHAPE_{SRF}$	Basin Sinuosity Factor	SIN_{SRF}	Basin Average Elevation	$AVEL_{SRF}$	SUM	$TOTAL_{SRF}$	Hazard Degree Classification
B1	wadiTaba	77.91	1	0.1294	1	0.68	3	8.29	1	16.91	1	0.0412	2	13.3066	2	60.0742	1	2.2728	2	1.2705	3	558.4731	2	20	1	Low
B2	wadi toyna	12.6	1	0.1992	2	0.64	3	3.13	1	5.62	1	0.0604	3	5.7332	1	23.4039	1	2.6097	2	0.9798	2	332.345	1	18	1	Low
B3	Valley Alemrakh	48.01	1	0.1823	2	0.59	2	10.42	2	16.25	1	0.0436	2	13.5527	2	52.7995	1	3.8259	3	1.1992	3	616.0625	3	22	2	Moderately low
B4	wadi Alfahirh albahari	35.79	1	0.2222	2	0.67	3	7.24	1	14.33	1	0.0537	3	11.8554	1	43.8911	1	3.9267	3	1.2091	3	598.2859	3	23	2	Moderately low
B5	wadi Al Makla	7.05	1	0.228	3	0.57	2	2.93	1	4.36	1	0.0871	4	4.9106	1	17.1173	1	3.4219	3	0.8879	1	347.0027	1	19	1	Low
B6	Wdi Al Mahash AlAala	44.1	1	0.287	3	0.61	2	5.26	1	10.81	1	0.065	3	10.0454	1	41.0904	1	2.288	2	1.076	2	670.9368	3	22	2	Moderately low
B7	Wadi Om Moghra	30.6	1	0.3164	4	0.69	3	3.92	1	6.74	1	0.0746	4	6.9603	1	30.9222	1	1.5831	1	0.969	2	664.9136	3	22	2	Moderately low
B8	Wadi Kadib	26.05	1	0.2613	3	0.76	4	5.25	1	6.77	1	0.1069	5	7.0407	1	30.1908	1	1.903	1	0.9618	2	651.5737	3	24	2	Moderately low
B9	Wadi Al- Mahash Al-Asfal	22.43	1	0.2747	3	0.83	5	4.47	1	6.26	1	0.0972	5	7.256	1	26.0557	1	2.3474	2	0.8633	1	539.6859	2	23	2	Moderately low
B10	Wadi South of Al- Mahash Al-Asfal	11.19	1	0.2891	3	0.68	3	3.58	1	4.44	1	0.0854	4	5.1803	1	22.366	1	2.3973	2	0.8564	1	338.878	1	20	1	Low
B11	Wadi North Al-Malha	43.38	1	0.2876	3	0.66	3	8.56	2	13.46	1	0.0492	3	9.5857	1	40.0858	1	2.118	2	1.4044	4	632.8277	3	23	2	Moderately low
B12	Wadi Al-Malha	49.77	1	0.3035	4	0.6	2	7.43	1	12.06	1	0.0658	3	11.0916	1	43.6428	1	2.4716	2	1.0877	2	676.4613	3	22	2	Moderately low
B13	Wadi South Al-Malha	51.9	1	0.2384	3	0.6	2	7.66	1	16.71	1	0.0496	3	10.9615	1	50.8892	1	2.3149	2	1.5243	4	537.2748	2	22	2	Moderately low
B14	Wadi Al-malha Al- Atshanaa	14.55	1	0.2288	3	0.61	2	3.57	1	6.25	1	0.069	3	5.4789	1	24.7439	1	2.0635	2	1.1406	2	459.0809	2	19	1	Low
B15	Wadi Watier	3511.25	5	0.1304	1	0.69	3	48.1	5	110.61	5	0.0128	1	73.0213	5	463.1522	5	1.5186	1	1.5148	4	912.2324	4	40	5	High
B16	Wadi Dahab	2057.72	3	0.2018	2	0.69	3	43.24	5	87.51	4	0.0206	1	54.0246	4	340.8826	4	1.4184	1	1.6198	5	1067.577	5	38	5	High
B17	Wadi East Muilha	25.79	1	0.187	2	0.71	3	4.5	1	11.13	1	0.0468	2	9.6266	1	40.9591	1	3.5933	3	1.1558	3	441.0144	2	21	2	Moderately low
B18	Wadi Muilha	62.77	1	0.3134	4	0.66	3	9.37	2	14.54	1	0.0351	2	10.2034	1	51.0566	1	1.6587	1	1.4255	4	704.7652	3	24	2	Moderately low
B19	Wadi North Al-Ghorabi	10.13	1	0.3856	5	0.61	2	2.64	1	3.6	1	0.105	5	4.07	1	17.8119	1	1.6347	1	0.8849	1	599.2984	3	22	2	Moderately low
B20	Wadi Al- Ghorabi	13.86	1	0.3618	5	0.58	2	3.5	1	5.59	1	0.0701	3	5.4418	1	24.1214	1	2.1368	2	1.0267	2	533.1901	2	21	2	Low
B21	Wadi Kabilat Al- Albu	22.74	1	0.3692	5	0.67	3	4.37	1	6.15	1	0.0556	3	6.4128	1	24.6355	1	1.8087	1	0.9592	2	489.9628	2	21	1	Low
B22	Wadi Al-Samraa	26.54	1	0.2703	3	0.66	3	4.7	1	9.49	1	0.0362	2	8.493	1	30.1123	1	2.7183	2	1.1175	2	390.8218	1	20	1	Low
B23	Wadi Kham Al-fahm	18.53	1	0.2164	2	0.68	3	4.65	1	7.47	1	0.0333	2	6.8542	1	23.8377	1	2.535	2	1.0897	2	313.295	1	18	1	Low
B24	Wadi Kied	1036.26	2	0.3288	4	0.65	3	34.23	4	59.76	3	0.0241	1	43.5884	3	236.0131	3	1.8335	1	1.3709	4	934.5682	4	33	4	Moderately High
B25	Wadi Om Adawy	352.63	1	0.2467	3	0.75	4	22.23	3	42.02	2	0.0312	2	31.1657	3	138.5192	2	2.7544	2	1.3484	4	681.5184	3	28	3	Moderate
B26	Wadi Al Badan	24.16	1	0.2208	2	0.55	1	6.69	1	13.19	1	0.049	3	12.0885	1	42.8436	1	6.048	5	1.0908	2	557.12	2	22	2	Moderately low
B27	South of Wadi Al Badan	21.52	1	0.3134	4	0.52	1	6.44	1	11.65	1	0.0624	3	10.6508	1	34.2798	1	5.271	4	1.0938	2	666.94	3	24	2	Moderately low
B28	South South of Wadi Al Badan	19.89	1	0.37	5	0.69	3	4.72	1	8.26	1	0.0699	3	8.3331	1	29.2431	1	3.4907	3	0.9916	2	652.918	3	24	2	Moderately low
B29	South of Wadi Watier	60.04	1	0.2465	3	0.66	3	7.83	1	15.69	1	0.0486	3	12.8069	2	61.8765	1	2.7319	2	1.2249	3	688.821	3	23	2	Moderately low
B30	North east of Wadi Dahab	34.3	1	0.2641	3	0.74	4	5.99	1	10.41	1	0.0585	3	8.5689	1	32.6385	1	2.141	2	1.2143	3	567.132	2	23	2	Moderately low
B31	South of north east of Wadi Dahab	12	1	0.3349	4	0.7	3	2.7	1	3.97	1	0.0778	4	4.5198	1	19.5074	1	1.7029	1	0.8778	1	462.334	2	21	1	Low
B32	East of Wadi Dahab	78.21	1	0.2548	3	0.61	2	10.49	2	19.23	2	0.0369	2	16.5622	2	62.9502	1	3.5072	3	1.1613	3	628.743	3	23	2	Moderately low
B33	South East of Wadi Dahab	67.25	1	0.2648	3	0.61	2	7.98	1	14.75	1	0.0412	2	11.1491	1	51.143	1	1.8483	1	1.3229	3	565.841	2	21	2	Moderately low

Table (3): The results of the selected 11 hydro-morphological parameters of GAB and corresponding Standardized Risk Factor (SRF) without the large area basins

Basin code	Basin Name	Area	A_{SRF}	Basin Slope	BS_{SRF}	Overland Flow	$AOLF_{SRF}$	Centroid Stream Distance	CSD_{SRF}	Basin Length	L_{SRF}	Max Stream Slope	MSS_{SRF}	Max Stream Length	MSL_{SRF}	Basin Perimeter	P_{SRF}	Basin Shape Factor	$SHAPE_{SRF}$	Basin Sinuosity Factor	SIN_{SRF}	Basin Average Elevation	$AVEL_{SRF}$	SUM	$TOTAL_{SRF}$	Hazard Degree Classification
B1	wadiTaba	77.91	5.00	0.1294	1.00	0.68	3.06	8.29	3.90	16.91	4.41	0.0412	1.43	13.3066	3.96	60.0742	4.75	2.2728	1.62	1.2705	3.48	558.4731	3.51	36.11	3.94	Moderatley High
B2	wadi toyna	12.6	1.31	0.1992	2.09	0.64	2.55	3.13	1.25	5.62	1.52	0.0604	2.47	5.7332	1.53	23.4039	1.55	2.6097	1.92	0.9798	1.74	332.345	1.19	19.13	0.88	Low
B3	Valley Alemrakh	48.01	3.31	0.1823	1.83	0.59	1.90	10.42	5.00	16.25	4.24	0.0436	1.56	13.5527	4.04	52.7995	4.11	3.8259	3.01	1.1992	3.05	616.0625	4.09	36.14	3.95	Moderately High
B4	wadi Alfahirh albahari	35.79	2.62	0.2222	2.45	0.67	2.94	7.24	3.37	14.33	3.75	0.0537	2.11	11.8554	3.49	43.8911	3.34	3.9267	3.10	1.2091	3.11	598.2859	3.91	34.18	3.59	Moderately High
B5	wadi Al Makla	7.05	1.00	0.228	2.54	0.57	1.65	2.93	1.15	4.36	1.19	0.0871	3.92	4.9106	1.27	17.1173	1.00	3.4219	2.65	0.8879	1.19	347.0027	1.34	18.90	0.84	Low
B6	Wdi Al Mahash AlAala	44.1	3.09	0.287	3.46	0.61	2.16	5.26	2.35	10.81	2.85	0.065	2.72	10.0454	2.91	41.0904	3.09	2.288	1.63	1.076	2.32	670.9368	4.65	31.23	3.06	Moderate
B7	Wadi Om Moghra	30.6	2.33	0.3164	3.92	0.69	3.19	3.92	1.66	6.74	1.80	0.0746	3.24	6.9603	1.93	30.9222	2.20	1.5831	1.00	0.969	1.67	664.9136	4.59	27.55	2.40	Moderately low
B8	Wadi Kadib	26.05	2.07	0.2613	3.06	0.76	4.10	5.25	2.34	6.77	1.81	0.1069	5.00	7.0407	1.95	30.1908	2.14	1.903	1.29	0.9618	1.63	651.5737	4.46	29.85	2.81	Moderate
B9	Wadi Al- Mahash Al-Asfal	22.43	1.87	0.2747	3.27	0.83	5.00	4.47	1.94	6.26	1.68	0.0972	4.47	7.256	2.02	26.0557	1.78	2.3474	1.68	0.8633	1.04	539.6859	3.31	28.07	2.49	Moderately low
B10	Vadi South of Al- Mahash Al-Asfa	11.19	1.23	0.2891	3.49	0.68	3.06	3.58	1.48	4.44	1.21	0.0854	3.83	5.1803	1.36	22.366	1.46	2.3973	1.73	0.8564	1.00	338.878	1.26	21.13	1.24	Low
B11	Wadi North Al-Malha	43.38	3.05	0.2876	3.47	0.66	2.81	8.56	4.04	13.46	3.52	0.0492	1.86	9.5857	2.77	40.0858	3.00	2.118	1.48	1.4044	4.28	632.8277	4.26	34.56	3.66	Moderatley High
B12	Wadi Al-Malha	49.77	3.41	0.3035	3.72	0.6	2.03	7.43	3.46	12.06	3.17	0.0658	2.77	11.0916	3.25	43.6428	3.31	2.4716	1.80	1.0877	2.39	676.4613	4.71	34.01	3.56	Moderatley High
B13	Wadi South Al-Malha	51.9	3.53	0.2384	2.70	0.6	2.03	7.66	3.58	16.71	4.36	0.0496	1.89	10.9615	3.21	50.8892	3.95	2.3149	1.66	1.5243	5.00	537.2748	3.29	35.19	3.77	Moderatley High
B14	Wadi Al-malha Al- Atshanaa	14.55	1.42	0.2288	2.55	0.61	2.16	3.57	1.48	6.25	1.68	0.069	2.94	5.4789	1.45	24.7439	1.67	2.0635	1.43	1.1406	2.70	459.0809	2.49	21.97	1.39	Low
B17	Wadi East Muilha	25.79	2.06	0.187	1.90	0.71	3.45	4.5	1.96	11.13	2.93	0.0468	1.73	9.6266	2.78	40.9591	3.08	3.5933	2.80	1.1558	2.79	441.0144	2.31	27.78	2.44	Moderate
B18	Wadi Muilha	62.77	4.15	0.3134	3.87	0.66	2.81	9.37	4.46	14.54	3.80	0.0351	1.10	10.2034	2.96	51.0566	3.96	1.6587	1.07	1.4255	4.41	704.7652	5.00	37.58	4.20	Moderatley High
B19	Wadi North Al-Ghorabi	10.13	1.17	0.3856	5.00	0.61	2.16	2.64	1.00	3.6	1.00	0.105	4.90	4.07	1.00	17.8119	1.06	1.6347	1.05	0.8849	1.17	599.2984	3.92	23.43	1.66	Moderately low
B20	Wadi Al- Ghorabi	13.86	1.38	0.3618	4.63	0.58	1.77	3.5	1.44	5.59	1.51	0.0701	3.00	5.4418	1.44	24.1214	1.61	2.1368	1.50	1.0267	2.02	533.1901	3.25	23.55	1.68	Moderately low
B21	Wadi Kabilat Al- Albu	22.74	1.89	0.3692	4.74	0.67	2.94	4.37	1.89	6.15	1.65	0.0556	2.21	6.4128	1.75	24.6355	1.66	1.8087	1.20	0.9592	1.62	489.9628	2.81	24.35	1.82	Moderately low
B22	Wadi Al-Samraa	26.54	2.10	0.2703	3.20	0.66	2.81	4.7	2.06	9.49	2.51	0.0362	1.16	8.493	2.42	30.1123	2.13	2.7183	2.02	1.1175	2.56	390.8218	1.79	24.75	1.89	Moderately low
B23	Wadi Kham Al-fahm	18.53	1.65	0.2164	2.36	0.68	3.06	4.65	2.03	7.47	1.99	0.0333	1.00	6.8542	1.89	23.8377	1.59	2.535	1.85	1.0897	2.40	313.295	1.00	20.82	1.19	Low
B26	Wadi Al Badan	24.16	1.97	0.2208	2.43	0.55	1.39	6.69	3.08	13.19	3.45	0.049	1.85	12.0885	3.57	42.8436	3.25	6.048	5.00	1.0908	2.40	557.12	3.49	31.88	3.18	Moderate
B27	South of Wadi Al Badan	21.52	1.82	0.3134	3.87	0.52	1.00	6.44	2.95	11.65	3.06	0.0624	2.58	10.6508	3.11	34.2798	2.50	5.271	4.30	1.0938	2.42	666.94	4.61	32.23	3.24	Moderate
B28	South South of Wadi Al Badan	19.89	1.72	0.37	4.76	0.69	3.19	4.72	2.07	8.26	2.19	0.0699	2.99	8.3331	2.37	29.2431	2.06	3.4907	2.71	0.9916	1.81	652.918	4.47	30.34	2.90	Moderate
B29	South of Wadi Watier	60.04	3.99	0.2465	2.83	0.66	2.81	7.83	3.67	15.69	4.09	0.0486	1.83	12.8069	3.80	61.8765	4.91	2.7319	2.03	1.2249	3.21	688.821	4.84	38.00	4.28	Moderatley High
B30	North east of Wadi Dahab	34.3	2.54	0.2641	3.10	0.74	3.84	5.99	2.72	10.41	2.74	0.0585	2.37	8.5689	2.44	32.6385	2.35	2.141	1.50	1.2143	3.14	567.132	3.59	30.35	2.90	Moderate
B31	outh of north east of Wadi Daha	12	1.28	0.3349	4.21	0.7	3.32	2.7	1.03	3.97	1.09	0.0778	3.42	4.5198	1.14	19.5074	1.21	1.7029	1.11	0.8778	1.13	462.334	2.52	21.47	1.30	Low
B32	East of Wadi Dahab	78.21	5.02	0.3349	4.21	0.61	2.16	10.49	5.04	19.23	5.00	0.0369	1.20	16.5622	5.00	62.9502	5.00	3.5072	2.72	1.1613	2.83	628.743	4.22	42.39	5.07	High
B33	South East of Wadi Dahab	67.25	4.40	0.3349	4.21	0.61	2.16	7.98	3.75	14.75	3.85	0.0412	1.43	11.1491	3.27	51.143	3.97	1.8483	1.24	1.3229	3.79	565.841	3.58	35.64	3.86	Moderatley High

7-APPLYING OF MULTI CRITERIA ANALYSIS

i) Basic Statistics:

The basic statistics of the selected hydro-morphological parameters are as shown in Table 4, which can be described as follows:-

a) **The drainage area (A)** ranges between min. and max. values of (B5=7.05 and B15=3511.25) km^2 representing Wadi Al Makla and Wadi Watier respectively, with mean value of 240.33 km^2 and standard deviation of 704.89.
b) **The basin slope (BS)** ranges between min. and max. values of (B1=0.17 and B19=0.39) representing Wadi Taba and Wadi North Al-Ghorabi respectively, with mean value 0.26 and standard deviation 0.06. It is well noted that the high BS value characterizing B19 reflects high tendency to generate great runoff and sediment load yields (Gad and Abdel-Latif, 2003).
c) **The basin length of average overland flow (AOLF)** can be computed by averaging the overland distance traveled from the centroid of each triangle to the nearest stream. It ranges between min. and max. values of (B27=0.52 and B9=0.83) km representing South of Wadi Al Badan and Wadi Al- Mahash Al-Asfal respectively, with mean value 0.66Km and standard deviation 0.06. These values considered small when compared with the North West coast basins which can be attributed to the great difference in the geological structures between them (Gad et. al 2016).
d) **The basin centroid stream slope (CSD)** The distance from the centroid of the basin to a point in the stream, it ranges between min. and max. values of (B19=2.64 and B15=48.1) km representing Wadi North Al-Ghorabi and Wadi Watier respectively with mean value of 9.58km and standard deviation 11.11.
e) **The minimum value of basin length factor (L)** ranges between min. and max. values of (B1=93.6 and B15=110.61) km Wadi North Al-Ghorabiand and Wadi Watier respectively, with mean value 18.06 Km and standard deviation 23.77,.
f) **The basin maximum stream slope (MSS)** ranges between min. and max. values of (B15=0.01 and B8=0.11) representing Wadi Watier and Wadi Kadib respectively, with mean value 0.06 and standard deviation 0.02.
g) **The basin maximum stream length (MSL)** ranges between min. and max. values of (B19=4.07 and B15=73.02) representing Wadi North Al-Ghorabi and Wadi Watier respectively, with mean value 13.69 and standard deviation 15.09.
h) **The Perimeter (P)** ranges between min. and max. values of (B5=17.12 and B15=463.15) m representing Wadi Al Makla and Wadi Watier respectively, with mean value 67.66 m and standard deviation 96.52.
i) **The basin shape factor (Shape)** ranges between min. and max. values of (B16=1.42 and B26=6.605) representing Wadi Dahab and Wadi Al Badan respectively, with mean value of 2.6 while the standard deviation reaches 1.05.
j) **The basin sinuosity factor (Sin)** ranges between min. and max. values of (B10=0.86 and B16=1.62) representing Wadi South of Al- Mahash Al-Asfal to Wadi Dahab respectively, with mean value 1.15 and standard deviation 0.21 reflecting the effect of lithology and geological structure.
k) **The average elevation (AVEL)** ranges between min. and max. values of (B23=313.3 and B16=1067.58) m representing Wadi Kham Al-fahm and Wadi Dahab respectively, with mean value 590.36 m and standard deviation 167.85.

Table 4: The basic statistics of non-parametric hydro-morphological variables of study area

	Mean	Geometric Mean	Harmonic Mean	Median	Min.	Max.	25%	75%	Std. Dev.
A	240.33	43.86	25.34	30.60	7.05	3511.25	19.89	60.04	704.89
BS	0.26	0.26	0.25	0.26	0.13	0.39	0.22	0.31	0.06
AOLF	0.66	0.65	0.65	0.66	0.52	0.83	0.61	0.69	0.06
CSD	9.58	6.74	5.51	5.99	2.64	48.10	4.37	8.29	11.11
L	18.06	11.71	9.06	11.13	3.60	110.61	6.26	15.69	23.77
MSS	0.06	0.05	0.05	0.05	0.01	0.11	0.04	0.07	0.02
MSL	13.96	10.34	8.69	9.63	4.07	73.02	6.85	12.09	15.09
P	67.66	43.56	35.32	40.09	17.12	463.15	24.74	51.14	96.52
SHAPE	2.60	2.44	2.31	2.31	1.42	6.05	1.85	2.75	1.05
SIN	1.15	1.13	1.12	1.12	0.86	1.62	0.98	1.27	0.21
AVEL	590.36	567.67	544.91	598.29	313.3	1067.58	489.96	666.94	167.85

ii) 2- Correlation Matrix

The correlation matrix was used in order to point out the associations between different variables. This matrix shows the overall coherence of the data set and indicates the participation of the individual hydro-morphological parameters in several influence factors. Pearson correlation analysis between the different hydro-morphological parameters (Table 5) shows that the marked correlations are significant at probability less than 0.05. Meanwhile, it is clear that the following:-

a) **The basin catchment area (A)** is highly positively correlated with CSD, L, MSS, P, (0.93, 0.96, 0.95 and 0.98) respectively, moderate correlated with SIN and AVEL (0.56 and 0.66), low correlated with AOLF (0.15), and reverse correlated with BS, MSL and SHAPE (-0.38, -0.52 and -0.29) respectively, indicating that the basins with large area are usually circular while small basins are usually elongated.

b) **The Basin Slope (BS)** is direct positively correlated with MSL (0.46) and reverse correlated with A, AOLF,CSD, L, MSS, P, SHAPE and SIN (-0.38, -0.08, -0.34, -0.39 -0.38, -0.38, -0.18 and -0.43) respectively, reflecting a high value of flood concentration time.

c) **The Basin length factor (L)** is direct high positively correlated with A, CSD, MSS and P (0.96, 0.99, 1 and 1) respectively, moderately correlated with SIN and AVEL (0.69 and0.76), low correlated with AOLF (0.14) and reverse correlated with BS and SHAPE (-0.39, -0.24).

d) **The basin sinuosity factor (Sin)** is direct positively moderate correlated with A, CSD, L, MSS, BS, P and AVEL (0.56, 0.7, 0.69, 0.81, 0.69, 0.65 and 0.62) respectively, indicating the high tendency to collect runoff forming dangerous flash flood.

e) **The Basin Shape factor (Shape)** is inverse correlated with all variables which may reflect that the shape factor has no direct effect on flash flood hazard degree.

It is worth to mention that these results are compatible with the fact that most studied basins related to the late period of geomorphological setting as prescribed in the geological section.

Moreover, the high correlation coefficient of 0.99 and0.98 characterized to the relation between basin length (L), basin perimeter (P) and basin Max Stream Slope (MSS) with Centroid Stream Distance (CSD) reflects the effect of the geological structures of these streams to form peak flow and receives flash floods (Gad, 2001).

Table 5: The correlation coefficients matrix between the selected variables of the studied area

	A	BS	AOLF	CSD	L	MSL	MSS	P	SHAPE	SIN	AVEL
A	1.00	--	--	--	--	--	--	--	--	--	--
BS	-0.38	1.00	--	--	--	--	--	--	--	--	--
AOLF	0.15	-0.08	1.00	--	--	--	--	--	--	--	--
CSD	0.93	-0.34	0.15	1.00	--	--	--	--	--	--	--
L	0.96	-0.39	0.14	0.99	1.00	--	--	--	--	--	--
MSL	-0.52	0.46	0.08	-0.65	-0.65	1.00	--	--	--	--	--
MSS	0.95	-0.38	0.14	0.99	1.00	-0.65	1.00	--	--	--	--
P	0.98	-0.38	0.15	0.98	1.00	-0.61	0.99	1.00	--	--	--
SHAPE	-0.29	-0.18	-0.44	-0.25	-0.24	-0.03	-0.20	-0.27	1.00	--	--
SIN	0.56	-0.43	-0.03	0.70	0.69	-0.81	0.67	0.65	-0.16	1.00	--
AVEL	0.66	0.00	0.07	0.79	0.76	-0.41	0.76	0.74	-0.21	0.62	1.00

iii) 3- Cluster Analysis:

Cluster analysis is used in this study, as it comprises of a series of multivariate methods which are used to find true groups of data or stations. In clustering, the objects are grouped such that similar objects fall into the same class (Danielsson et al., 1999). One of the benefits of the hierarchical method of cluster analysis, which is used in this study, is the advantage of not demanding any of prior knowledge of the number of clusters, which the nonhierarchical method does. A review by Sharma 1996 suggests Ward's clustering procedure to be the best, because it yields a larger proportion of correct classified observations than do most other methods. As a distance measure, (1-Pearson r) method is used in this study.

The cluster analysis was carried out with single linkage and Euclidean distance of (1-Pearson r) method, firstly on the non-transformed input data matrix of all the 33 basins and once more for 29 basins (excluding large area basins). The results are given as Q-mode dendrograms as shown in Figures 6 and 7. Secondly on the 11 hydro-morphological parameters all the 33 basins and once more for 29 basins (excluding large area basins), the cluster analysis results and R-mode dendrograms are shown in Figures 8 and 9. The clarification of the basin name and case number that used in the cluster analysis is given in table (6).

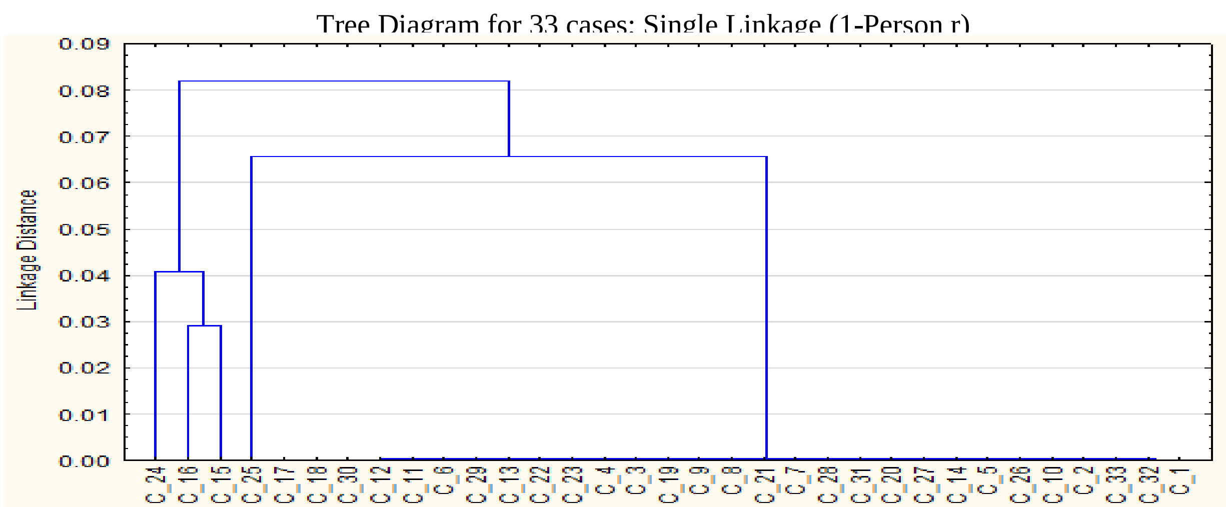

Fig.6: Vertical icicle plot of the studied 33 basins including large area basins (Q-mode).

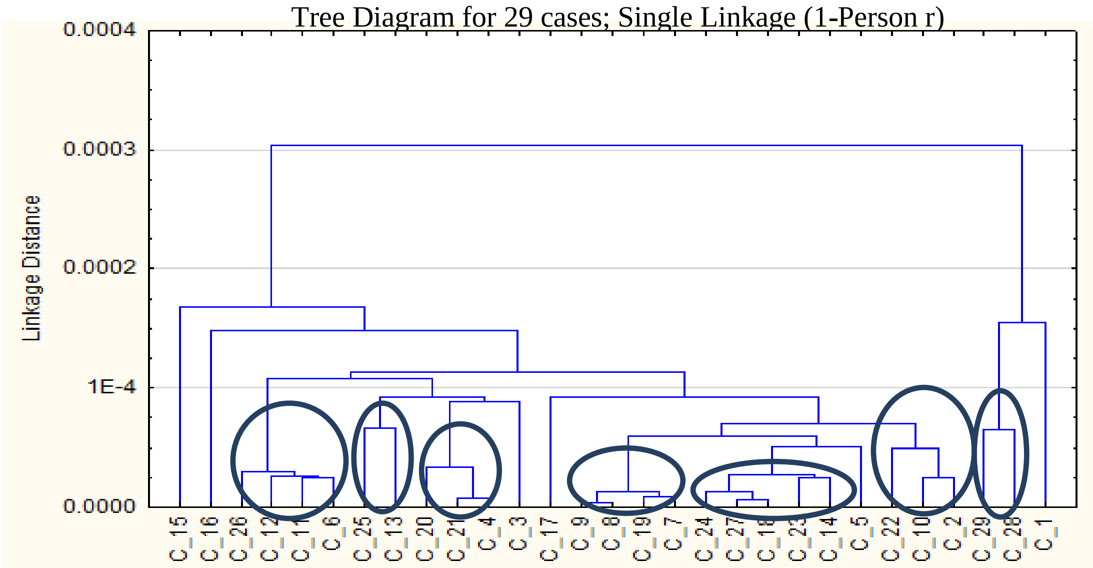

Fig.7: Vertical icicle plot of the studied 29 basins (Q-mode)

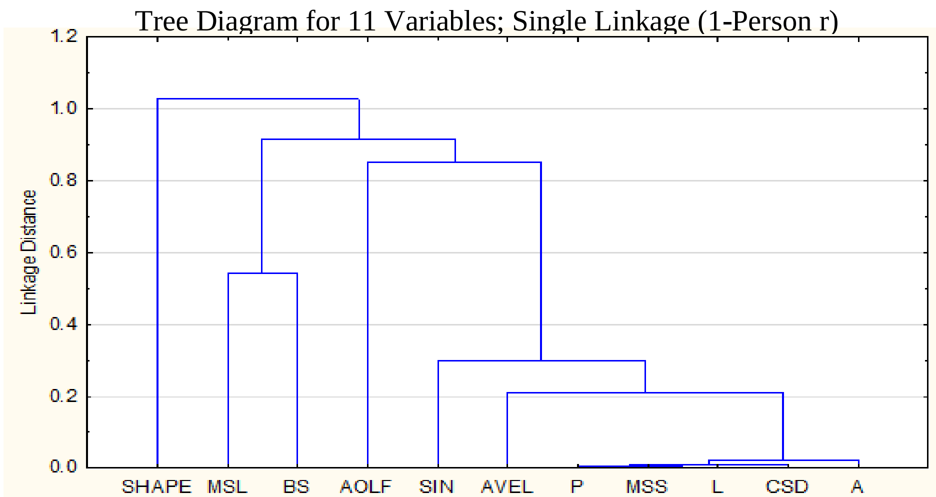

Fig.8: Vertical icicle plot of the studied 11 Hydro-morphological parameters including large area basins (R-mode)

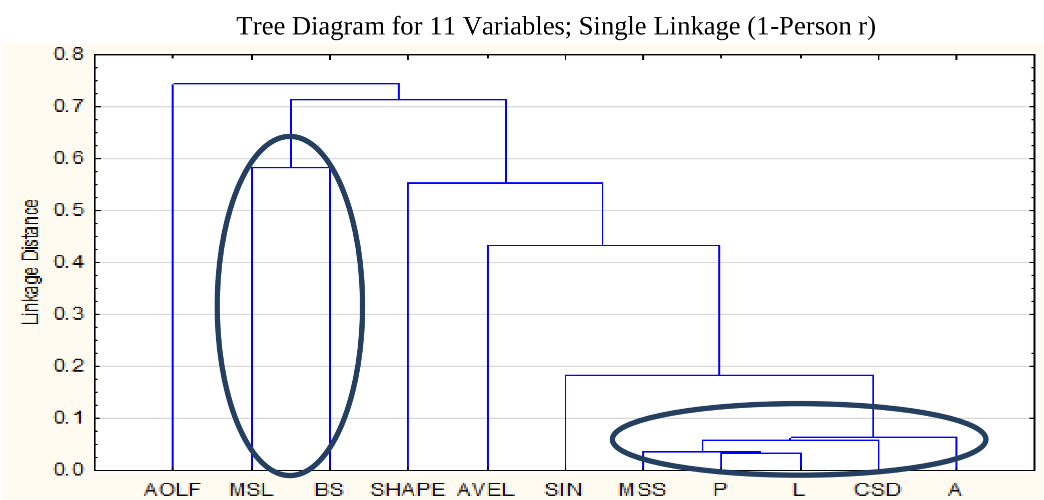

Fig.9: Vertical icicle plot of the studied 11 Hydro-morphological parameters excluding large area basins (R-mode)

It is clear from the results shown in Figure 5 that the difference in the basin area has a crucial effect on the cluster analysis. Consequently, the basin area can be considered as a governor and an influential factor among the eleven hydro-morphological parameters in GAB. Based on that, the Q-mode dendrograms in figure 5 exhibits two clusters as follows:-

a) **<u>The first cluster</u>** representing the basins with large area namely Wadi Watier (B15), Wadi Dahab (B16), Wadi Kied (B24), and Wadi Om Adawy (B25). The similarity of these basins can be attributed to their common geologic characteristics as the majority of their surface areas were overlaid with impermeable volcanic rocks which increase surface runoff and consequently the flash floods took place.

b) **<u>The second cluster</u>** include the rest 29 basins with linkage distance 0.001 which may refer to the insignificant of their areas compared to the four large area basins.

Table (6): Clarification of Basins Name, Code and Case Number as used in the cluster analysis

Basin Name	Basin Code	Case Number	
		including large basin	excluding large basin
Wadi Taba	B1	C-1	
Wadi toyna	B2	C-2	
Valley Alemrakh	B3	C-3	
Wadi Alfahirh Albahari	B4	C-4	
Wadi Al Makla	B5	C-5	
Wadi Al Mahash AlAala	B6	C-6	
Wadi Om Moghra	B7	C-7	
Wadi Kadib	B8	C-8	
Wadi Al- Mahash Al-Asfal	B9	C-9	
Wadi South of Al- Mahash Al-Asfal	B10	C-10	
Wadi North Al-Malha	B11	C-11	
Wadi Al-Malha	B12	C-12	
Wadi South Al-Malha	B13	C-13	
Wadi Al-malha Al- Atshanaa	B14	C-14	
Wadi Watier	B15	C-15	
Wadi Dahab	B16	C-16	
Wadi East Muilha	B17	C-17	
Wadi Muilha	B18	C-18	C-16
Wadi North Al-Ghorabi	B19	C-19	C-17
Wadi Al- Ghorabi	B20	C-20	C-18
Wadi Kabilat Al- Albu	B21	C-21	C-19
Wadi Al-Samraa	B22	C-22	C-20
Wadi Kham Al-fahm	B23	C-23	C-21
Wadi Kied	B24	C-24	
Wadi Om Adawy	B25	C-25	
Wadi Al Badan	B26	C-26	C-22
South of Wadi Al Badan	B27	C-27	C-23
South South of Wadi Al Badan	B28	C-28	C-24
South of Wadi Watier	B29	C-29	C-25
North east of Wadi Dahab	B30	C-30	C-26
South of north east of Wadi Dahab	B31	C-31	C-27
East of Wadi Dahab	B32	C-32	C-28
South East of Wadi Dahab	B33	C-33	C-29

By excluding the four large basin from the cluster analysis, the Q-mode dendrograms shown in Figure 6 exhibits seven clusters when interpreted at similarity level with a distance 0.0001 as the following cluster Domains:-

a) **The first cluster** representing East of Wadi Dahab (B32) and South East of Wadi Dahab (B33) basins. This cluster reflects high dangerous basins with high flash floods since these basins are characterized by high values of basin area also they are close in the basin slope and average land flow values.

b) **The second cluster** representing Wadi toyna (B2), Wadi South of Al-Mahash Al-Asfal (B10) and Wadi Al-Badan (B26) basins. This cluster represents low dangerous basins with relatively small areas about 12 km^2 specially the first two basins which seem similar hydro-morphologically, therefore they have the same plans for future development. The independence of Wadi Al-Badan regarding this cluster can be attributed to the great value of basin average elevation above mean sea level with respect to the other basins in this cluster.

c) **The third cluster** representing Wadi Al-malha Al-Atshanaa (B14), South of Wadi Al-Badan (B23), Wadi Al-Ghorabi (B20), South of north east of Wadi Dahab (B31) and South South of Wadi Al-Badan (B28) basins. This cluster is due to the similarity in the maximum stream length in all these basins which indicates moderate tendency to flash flood.

d) **The fourth cluster** representing Wadi Om Moghra (B7), Wadi Kabilat Al-Albu (B19), Wadi Kadib (B8) and Wadi Al-Mahash Al-Asfal (B9) basins. This cluster is characterized the basins having close geometrically parameters (A, L, P and MSS) which moderately low in flash flood tendency.

e) **The fifth cluster** representing Wadi Al-fahirh Al-bahari (B4), Wadi Kham Al-fahm (B23) and Wadi Al-Samraa (B22) basins. This cluster characterized the basins having close average over land flow (AOLF) values with moderate tendency to subject to flash flood.

f) **The sixth cluster** representing Wadi South Al-Malha (B13) and South of Wadi Watier (B29) basins. This cluster characterized the basins nearly common in the area and basin shape factor, having the opportunity to moderately high flash flood.

g) **Finally the seventh cluster** representing Wadi Al-Mahash Al-Aala (B6), Wadi North Al-Malha (B11), Wadi Al-Malha (B12) and North east of Wadi Dahab (B30) basins. This cluster characterized the basins have a moderate area with respect to the entire basins in the study area and consequently have a moderate flash flood tendency.

The independent cases include Wadi Taba (B1), Wadi Al-emrakh (B3), Wadi Al Makla (B5), Wadi East Muilha (B17), Wadi Muilha (B18) and Wadi North Al-Ghorabi (B19). Their independence may attribute to the effect of geologic structure in the study area or in other words they may have the same circumstances in the structure formation.

On the other side, the output of the R-mode cluster analysis between the hydro-morphological parameters is given as a dendrograms as shown in Figures 7 and 8. By comparing the cluster analysis in these two figures it is clear that there is no clear difference, either by including or excluding the four large area basins, except in the linkage distance. Based on that there are two major clusters:-

a) **The first cluster** representing A, CSD, L, P and MSS with (SIN) as independent variable. This cluster reflects the effect of the geometrical factors on the study of these basins.

b) **The second cluster** representing BS and MSL with (AOLF) as independent variable. This cluster reflects the impact of BS to generate peak flow (Abulohom and Gad, 2011).

8-CONCLUSION

Flash flood protection measures depending solely on recurrence interval have been adopted for long time without giving weight to the hydro morphological parameters of the watersheds that cause such floods. This paper presents the use of multi criteria analysis technique (Basic Statistics, correlation matrix, cluster and multi regression) to use these parameters when defining the design flash flood events. From the previous analysis it was concluded that:-

- ✓ The drainage basin area has great effect on the floods generated at its outlet while other factors have less effect than the drainage area such as the basin slope, shape factor and sinuosity factor.
- ✓ The four large areas basins in the Gulf of Aqaba namely Wadi Watier (B15), Wadi Dahab (B16), Wadi Kied (B24), and Wadi Om Adawy (B25) have the highest weighted standardized risk factor value. This means that these four basins should have high priority in the planning of the flash flood protection measures.
- ✓ In order to accurately analyze the basins with extremely different geometric parameters such as area, the large basins should be treated apart from basin with comparatively small areas.
- ✓ The basins with low, moderately low and moderate standardized risk factor (19 Basins) which are weakly hazardous basins as shown in table 3 and figure 10 are suitable for future development such as tourism projects.
- ✓ The constructions of artificial lakes in the peripheries of the tourism projects at the downstream of their basins is a suitable method for solving the problem of fresh water scarcity and recharging the groundwater shallow aquifers besides their beautiful impacts.
- ✓ The results of a linear best fit method predict the recurrence period for the three stations (Nwebaa, Dahab, and Sharm El-Sheikh) with R^2 (0.96, 0.87, and 0.99) respectively, these results show that when there is a need to design a hydraulic structure in the study area for a recurrence period of 100 years the maximum rainfall will be about (150, 450, and 750 mm) for the three stations (Nwebaa, Dahab, and Sharm El-Sheikh) respectively.
- ✓ The weighted standardized risk factor obtained can be used during the design of flash flood protection measures and/or the calculation of design of peak flows for crossing structure. This may lead to more economic design procedure that can be adopted in drainage design guidelines and manuals.
- ✓ It is recommended to carry out detailed works on the hazardous basins such as Wadi Watier, Wadi Dahab, Wadi Kied and Wadi Om Adawy to choose the most suitable places for dams and dykes required for minimizing the hazard degree of these basins.
- ✓ The constructions of earth dams at the upstream portions and digging reservoirs at the outlets of the tributaries are recommended in case of Wadi Taba and Wadi Watier according to the slightly basin slope values.
- ✓ Further studies should be made concerning the environmental hazard of the flash flood events and special intention should be made when trying to control floods to keep the environment.
- ✓ Field measurements are highly recommended to verify the results of MCA procedure used in this work.

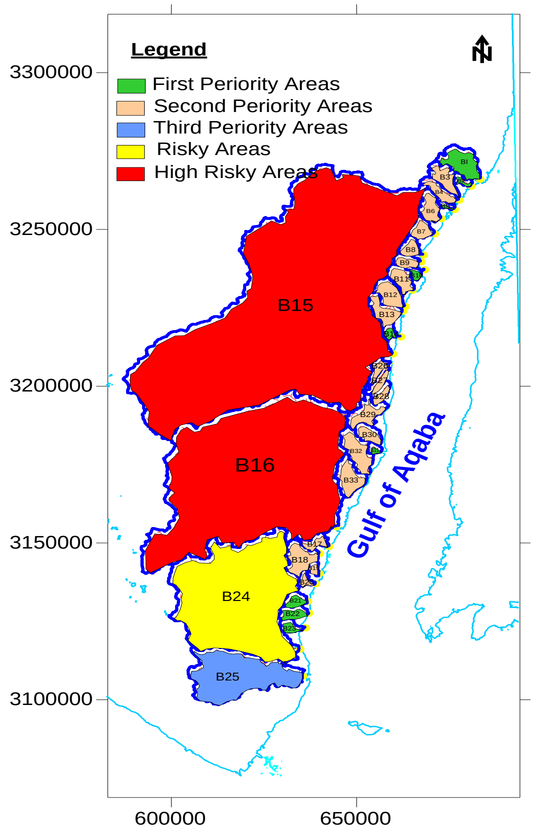

Fig. 10: Priority map at Gulf Aqaba

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