



Flash Floods Hazard Degrees Assessment Applying Multi-Attributes Utility Theory for Gulf of Suez Basins, Egypt

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Keywords

Multi-Attributes Utility Theory, flash floods, morphological parameters, hazard degree, risk map.

Abstract

Good management of flash floods requires accurate estimation for both the hazard degrees and flood risk maps. Morphological parameters greatly affect the strength of flood's hydrograph and accordingly the flash flood hazard degree. This study uses decision-making tools such as Multi Criteria Analysis (MCA) and/or Multi-Attribute Utility Theory (MAUT) to estimate the Gulf of Suez's flash flood hazard degree, Sinai Peninsula, Egypt. The MAUT was applied successfully in estimating the hazard degrees of 56 basins in the coastal zone of the Suez Gulf. Based on the resulted correlation between all hydro-morphological parameters, only six equal weight parameters were selected and used to calculate the hazard degree. The results showed that, about 40 % of the 56 basins have high or moderately high hazard degree. Values of the correlation factors between the hydro-morphological parameters and the resulted hazard degrees are ranged between 0.813 for basin's Sinuosity and 0.011 for Centroid Stream Slope. The weights of those parameters were non-linearly optimized to make the correlation of all chosen parameters with the hazard degree higher than or equal to the threshold value (0.6). Accordingly, percentage of basins with high or moderately high hazard degree have decreased to 32 %. Capability and validation of current model have been achieved using the damage information of some flood events in the last few decades. The comparison between current model's scenarios and flood events showed that, all the affected basins that had high or moderated high hazard degree are highly coincide with the real cases.

Abbreviations:

MCA	: Multi Criteria Analysis	A	: Drainage Area
MAUT	: Multi-Attribute Utility Theory	BS	: Average Slope
U_i	: Single utility function	AOLF	: Average Overland Flow
RDU	: Rank-Dependent Utility Functions	AVEL	: Average Elevation above mean sea level
SIN	: Sinuosity Factor	Shape	: Shape Factor
L	: Basin's Length	MSL	: Max. Stream Length
MSS	: Max. Stream Slope	P	: Perimeter
CSD	: Centroid Stream Distance	CSS	: Centroid Stream Slope

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1. Introduction

An accurate estimation of the flash flood hazard degrees can be used to recognize areas vulnerable to high flooding and to design works and infrastructure for flood control and to prepare new land use for future development plans [1]. Several researchers indicated that, the morphological parameters of the basins are the most significant factors affecting the strength of the flood hydrograph and should be considered in any flash flood risk assessment studies [2-4]. To estimate the flash flood hazard degrees based on hydro-morphological parameters, a decision-making tool such as Multi-Criteria Analysis Technique (MCA) has been widely used [3,5-8]. One of these MCA techniques is the Multi-Attribute Utility Theory (MAUT). The overall hazard degree for each Basin is defined in MAUT as a weighted addition of its values with respect to its relevant attributes. This relative value is called the Utility Function that could be estimated assuming linear, concave, or convex shape [9]. The key issue in selecting the type of these functions is their inability to predict revealed behaviour [10].

Additional challenge in the MAUT is the weight and the selection of the independent attributes. Seven plus or minus two attributes is proposed by several studies [11-13]. Hall [14] has concluded that good attributes should be highly correlated with the objective and uncorrelated with each other. Also, the weights of the attributes should be adjusted according to the relative importance of the attribute i^{th} relative to the others. The simplest is the 'Equal Weights Method' where the decision maker gives the same weight to all attributes. No attention was paid to the shape of the utility function or the weight of each parameter in previous studies concerning flash flood hazard degrees. They usually apply linear function with equal weights for all analysed parameters regardless their number [3,7,8]. The presence of the extreme high or low values of the parameters used may lead to biased results and may cause skewness to the resulted hazard degree. At least 20 % of the basins included in any study may have extreme outlier values in one or more parameters and should be removed before estimating the hazard degree. In addition, given equal weight to all parameter without any statistic basic or parameters importance is another Problem. Odu [15] has evaluated different weighting methods applicable to multi-criteria optimization techniques. The study had emphasized on the use of these weighting methods in determining the criteria preference of each criterion to bring about desirable properties.

Several fatalities and enormous damages to infrastructure in urban centres, such as bridges, roads electric poles, and water and oil pipelines, have been reported in several flash floods in the Sinai Peninsula [16,17]. Examples of these floods are the flood in Wadi El-Aawag in 1991, which damaged some houses in El-Wadi village and killed some livestock, the flood in Wadi Water in 2004, which destroyed 40% of the highway to Nuweiba city, and the flood in Wadi El-Arish in 2010, which crossed Al-Rawafa Dam and destroyed Mubarak-sport city in El-Arish city [19,20]. Also, flash floods are an important source of water in arid and semi-arid areas [1,21]. Major challenges in these areas are the safety and protection of the infrastructures and the sustainable management and development of the flood's water, the important water resource in this region. In present study, the ability of three different utility functions to manage the extreme outlier values are examined and investigated. In addition, to decrease the number of attributes and adjust their relative weights, a correlation-based criterion is developed and applied. The study is linked to the Gulf of Suez area, Sinai Peninsula. In terms of local topography, accessibility and water availability, this region strongly attracts human occupation as it represents desired areas and has been affected during recent years by frequent violent desert flash floods.

2. The Study Area

The study area is located on the eastern coast of the Gulf of Suez between latitudes 27°27'58" to 30°21'47" N and longitudes 30°51'20" to 35°59'6" E within the southwest Sinai as shown in Fig. (1-

a). It is an elongated northwest-trending zone with approximately 300 km long and 20-40 km wide parallel to the Gulf of Suez with total surface area of 12260 km². Land uses, including tourism, urbanization, land reclamation, medical tourist, industrial and petroleum activities, are dominated by heavy showers accompanied by sporadic torrential floods, coastal erosion, and sand encroachment hazards [19,20].

In addition, short winters from January to March and extreme aridity, long hot and rainless summers from April to October distinguish the climate conditions of the study area. In summer and winter, the average temperature is 27 and 17°C respectively. Evaporation values increase toward south Sinai Peninsula about the continental effect, while the annual evaporation rate approaches 10 mm/day for El-Tur, 12 mm/day for Ras Sudr and 17.9 mm/day for Sharm El-Sheikh. In addition, the mean annual rainfall is 10 mm/year for El-Tur, 15.4 mm/year for Ras Sudr, 21.5 mm/year for Abu Rudeis, and 63 mm/year for St. Catherine [20]. Some areas experience brief but intense rainfall during the winter months that sometimes causes extreme flash floods. The highest amounts of rainfall recorded in one day were 21 mm in Ras Sudr, 19 mm in El-Tur, 24 mm in Abu Rudeis, and 48 mm in Sharm El-Sheikh. Figure (1-b) shows the geological setting of the study area, Suez Gulf Basins. The rocks that outcrop it are belong to Pre-Cambrian, Pre-Tertiary, Tertiary and Quaternary [22-24]. Most of the coastal plain, especially El Qaa plain, is covered by the Quaternary deposits, while the Tertiary and Pre-Tertiary sediments are mainly located in the northwestern parts from Gabel Qabaliat to El Tur. The study area can be divided into a several zones. El Qaa plain, located in the southern parts, is covered by sand dunes and deposits. At the north, limestone, clay and initial rocks can be found. In addition to layers of Sabkha deposits and marine fossils, other rock compositions can be found in the eastern mountains, including Granitr, Alserbeltan, Limestone, Carbonate and phosphate rocks.

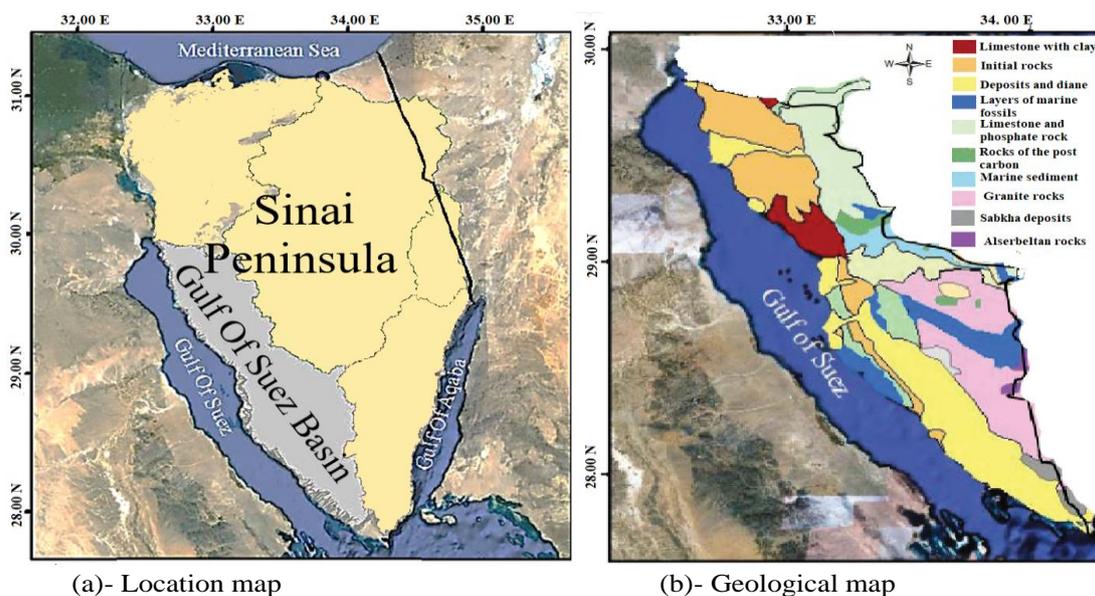


Figure 1: Study Area (modified after Elsayad 2013).

It is possible to classify the geomorphological units recognized in the study area as follows:

- The eastern mountainous region which characterized by high relief with altitudes ranging between 300 m and 2624 m.
- The Western Sedimentary region which represented by Gabel El-Qabaliat and some hillock, e.g., Gabel Naqus and Gabel Hammam Saydna Musa. It has an average elevation of 250 m with moderate slope towards El-Tur plain. It is characterized by dense consequent net of drainage lines that following the general slope towards the east.

- Saline sand (Sabkhas) that are present either in the coastal area or inland in different patches at the south of El Tur and along Gulf of Suez coast. In most cases, parallel drifting sands cover the surface. The sabkhas are of lagoonal origin in south El Tur area. These sabkhas are, hydrologically, sources of saline water feeding the adjacent sediments.
- The central plain, which formed mainly during Quaternary periods, can be described as a pen plain. It is categorized into four sectors: Bilaiyim, Sudr, Ras Malaab, and El-Tur coastal plain. However, it is not exactly flat and is dissected by Wadi courses terraces, playa deposits, alluvial fans with sand dune and sheets. According to their catchment areas, the hydrographic basins are classified into major and minor basins. The upstream portions of the major basins are located along the mountainous areas, while they are locally constituted the coastal hills in the minor basins.

3. Materials and Methods

The data collection methodology and the theoretical technique used to evaluate the Flash Floods Hazard Degrees are described and summarized in Figure (2).

- The study of morphometric basin characteristics in Gulf of Suez Basins is based on the analysis of a 90 m resolution Digital Elevation Model (DEM) file obtained from SRTM3 (Shuttle Radar Topography Mission) via the TOPAZ module [25,26].
- The Watershed Modeling System (WMS v.11.) package is used to delineate the watershed boundaries and their characteristics, and the hydro-morphometric drainage characteristics of terrain are extracted too.
- Pearson's correlation coefficients between morphological variables are estimated. Based on the results, the uncorrelated parameters are selected.
- Based on their effect on flash flood hazard, these variables are divided into two groups. The first group includes the ascending hazard degree variables (high values represent the higher hazard degree), while the second group includes the descending hazard degree variables (low values reflect the higher hazard degree).
- The Single Utility Function (U_i) for each variable is constructed by arranging the assigned values for all basin in ascending or descending order.
- Three different utility functions are tested and compared to each other to estimate the hazard degree of the selected basins. Those functions are Linear, Logarithmic, and Rank-Dependent Utility (RDU) functions.
- In addition, the Multi-Attribute Utility Theory (MAUT) is used to estimate the hazard degree using equal weights for all variables.
- Using the Generalized Reduced Gradient method (GRG Nonlinear [27]) by Excel Solver, the weights of these attributes are then optimized nonlinearly to make the correlation of all chosen attributes with the hazard degree higher or equal to the threshold value.
- Finally, to identify the different basins as shown in Table (1), the relative hazard degrees of the studied basins with respect to flash floods are calculated according to MAUT with the optimized weights.

Table 1: Classification of relative hazard degrees.

Hazard Degree	Class of the hazard degree
0.0 - 0.2	Low (L)
0.2 - 0.4	Moderately Low (ML)
0.4 - 0.6	Moderate (M)
0.6 - 0.8	Moderately High (MH)
0.8 - 1.0	High (H)

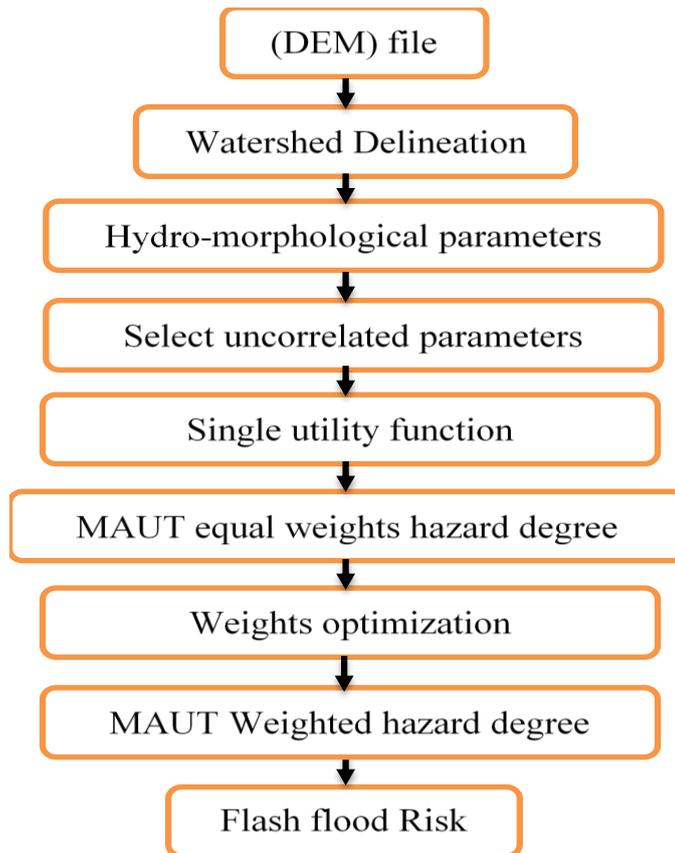


Figure 2: Flowchart of the risk map method.

3.1 Multi-Attribute Utility Theory (MAUT)

MAUT is one of the widely used decision maker methods. It represents the preferences of the decision-maker as a function, called the Utility function U [28]. MAUT is a way of measuring the desirability of the preference of objects, called Alternatives. It depends solely on the reference level and not on the absolute level. It has an interval range from zero, which reflects the least preferred performance, to one, which corresponds to the best attribute performance. In present study, MAUT could be used to estimate the flash flood risk assessment. MAUT is suitable for structured problem where utility function is known. It has the ability of making a complete ranking of the given alternatives, specifically, in our problem. Moreover, the methodology of the MAUT that used in current study depends on the Multi-Attribute Utility Function (U) in the form of $U(d_1, d_2, \dots, d_n)$. Where d_1, d_2, d_n represent independent parameters. In the sense that the decision maker's attitude towards risk with respect to d_i is not affected by values of the other fixed attributes. The Utility function U is either additive or multiplicative. Due to its simplicity, the additive function could be used as:

$$U(d_1, d_2, \dots, d_n) = \sum_{i=1}^n w_i U_i(d_i) \dots \dots \dots (1)$$

Where U_i are utility functions scaled from zero to one for the parameter i . The w_i values are scaling constant or weight of the i^{th} attribute with $0.0 < w_i < 1.0$, where:

$$\sum_{i=1}^n w_i = 1.0 \dots \dots \dots (2)$$

The multivariate utility function $\underline{U}(d_1, d_2, \dots, d_n)$, given by Eq. (1), should be rescaled from 0 to 1.0 to ensure the presence of all classes applying Eq. 3:

$$U(d_1, d_2, \dots, d_n)_{Rescaled} = \frac{U(d_1, d_2, \dots, d_n) - U_{min}}{U_{max} - U_{min}} \dots \dots \dots (3)$$

3.2 Selection of the variables

It is the process of identifying and removing irrelevant and redundant information as much as possible. This reduces the dimensionality of the data. Keeney and Raiffa [28] suggested five properties that are desirable for selecting a set of attributes (completeness, operational, decomposable, non-redundancy, and minimum size). Yurdakul and Tansel [29] argued that most of studies completely ignored constructing formal procedures for the selection of attributes. Several studies suggested seven plus or minus two criteria for a selection problem [11-13]. Hall [14] mention that good attributes should be highly correlated with the objective and uncorrelated with each other. Yurdakul and Tansel [29] applied these criteria using 0.65 as threshold value for positive correlation and -0.65 for negative correlation.

3.3 Single utility function

Moreover, the third step of MAUT is the selection of proper utility functions in which the shape of the utility function represents the risk-attitude of the decision maker. It could be linear, logarithmic, exponential, or any other suitable shape. Linear utility functions are frequently used in flash flood hazard [6,7].

$$U_i(d_i) = \frac{(d_i - d_{min})}{(d_{max} - d_{min})} \dots \dots \dots (4)$$

Where $U_i(d_i)$ is the utility function of attribute d , d_{max} and d_{min} are the higher and lower estimated values of any attribute d . Extreme outliers leads to inflated error rates and substantial distortions of parameter and statistic estimates and should be removed before estimating d_{max} and d_{min} . Furthermore, several utility functions are tested including logarithmic and Rank-dependent utility functions (RDU). The logarithmic utility function is one of commonly used utility function.

$$U_i(d_i) = \frac{\log(d_i) - \log(d_{min})}{\log(d_{max}) - \log(d_{min})} \dots \dots \dots (5)$$

Laghrabli et al. [30] argued that utility function cannot have a unique curvature. It may have two or more behaviours adopted simultaneously. Rank-Dependent Utility (RDU) that originally developed by Quiggin [31] has been proposed as alternative utility function in decision making under risk in recent years [31-33]. RDU assumes that the weight assigned to outcomes is a function of their rank in the distribution of possible outcomes. In this article, the data given for all the basins in each parameter are arranged in ascending or in descending order according to the behaviour of this parameter. The utility function $U_i(d_i)$ is then calculated as the ratio between the rank value and the total number of the basins.

$$U_i(d_i) = \frac{Rank\ order}{number\ of\ Basins} \dots \dots \dots (6)$$

3.4 The weights of the variables

Moreover, the most important step of MAUT is the scale constant or the weight of the attributes. It should be adjusted according to the relative importance of the attribute i^{th} relative to the others. Several weighting methods have been proposed in the literature by Wang et al. [34]. The simplest one is called ‘equal weights method’ where the decision maker give the same weight to all attributes. Additionally, the ‘rank-order method’ was classified by Wang et al [34] to three categories, namely, (a) subjective weighting method (depends on the preference of decision-

makers), (b) objective weighting method (obtained by mathematical methods based on the analysis of the initial data.) and (c) combination weighting method. In this study, a technique based on objective weighting method and the correlation matrix is adopted and used. As mentioned before, the attributes should be highly correlated with the objective. The method can be summarized as follow:

1. Initially, an equal weight value is given to each attribute in form

$$W_i = \frac{1}{n} \dots\dots\dots(7)$$

2. The MUF is calculated and its correlation with each attribute is calculated
3. Then, the weights are optimized in the way that the correlation between the resulted hazard degree and each attribute should be greater than a threshold value.

$$Max \sum_{i=0}^n ABS(corr_{ij}) \dots\dots\dots(8)$$

Where, $(corr_{ij}) > \text{threshold}$.

$$\sum_{i=0}^n w_i = 1, \quad w_i > 0 \dots\dots\dots(9)$$

4. Results and Discussions

The morphometric drainage characteristics of terrain surfaces of the studied 56 drainage basins were performed using WMS as shown in Fig. (3). The computed non-parametric hydro-morphological variables include the basin drainage area (A), the basin average slope (BS), the average overland flow (AOLF), the basin length (L), the basin shape factor (Shape), the basin sinuosity factor (SIN), the basin average elevation above mean sea level (AVEL), the basin maximum stream length (MSL), the basin maximum stream slop (MSS), the basin perimeter (P), the basin centroid stream distance (CSD), and the basin centroid stream slope (CSS).

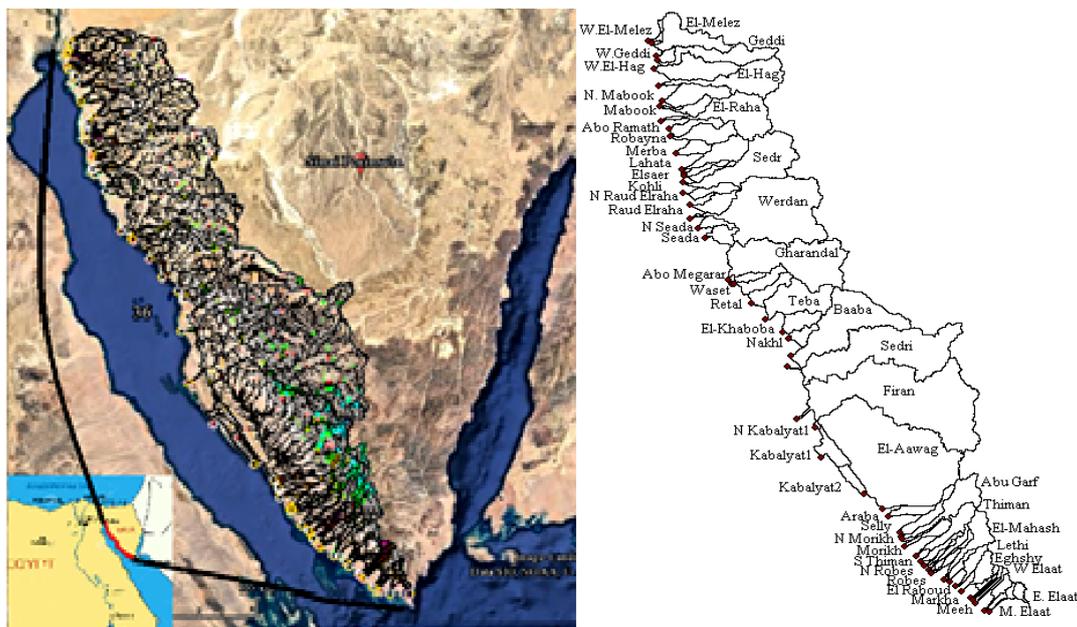


Figure 3: Drainage network of the studied basins extracted by WMS

The basic statistics of the selected non-parametric hydro-morphological variables show high variation in the basins characteristic data. The area (A) of the drainage basins ranges from 7.6 km² for N- Kabalyat1 basin, to 1915 km² for Al-Aawag basin, with mean value of 239.5 km² and standard deviation of 398.7 km². The Basin Slope (BS) ranges from 0.021 to 0.395 with mean value of 0.112 and standard deviation of 0.079. The high BS value reflects a high tendency to generate great runoff and sediment load yields. This variation in the data could be an indication of the present of outliers. The Box-and-Whisker's plot of the extracted hydro-morphological parameters is shown in Fig. 4, where the original 12 non-parametric hydro-morphological parameters as a percentage of their maximum value are shown. It also displays the three quartiles, Q25, Q50 and Q75 on a rectangular box in addition to each parameter's extremely high values that may lead to unrealistic risk factor (extreme outliers) and need to be excluded. As a result, the excluding of these extreme outliers in the linear utility function enhances the utility shape.

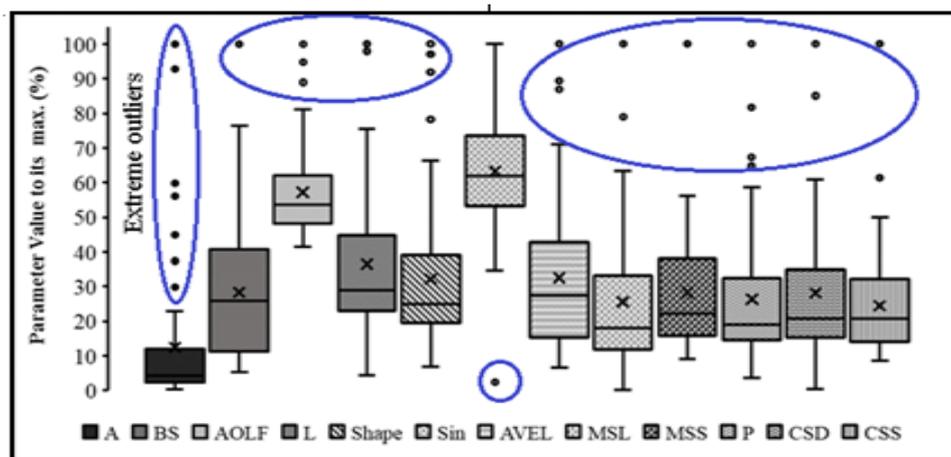


Figure 4: Box-and-Whisker's plot of the 12 hydro-morphological parameters as a percentage from its maximum values.

Using the criteria described in the current study, the estimated 12 hydro-morphological parameters are statistically analysed using Pearson's correlation coefficient considered the most applicable in multivariate correlation [35]. Correlation matrix of these different variables is obtained as shown in Table (2).

Table 2: The correlation coefficients matrix between the selected variables of the studied area.

	A	BS	AOLF	L	Shape	Sin	AVEL	MSL	MSS	P	CSD	CSS
A	1.00	0.26	-0.22	0.83	-0.34	0.62	0.50	0.86	-0.30	0.92	0.83	-0.26
BS		1.00	-0.09	0.32	0.05	0.17	0.83	0.30	0.57	0.33	0.31	0.47
AOLF			1.00	-0.27	0.54	-0.50	-0.11	-0.35	0.19	-0.30	-0.32	0.16
L				1.00	-0.17	0.75	0.65	0.98	-0.31	0.97	0.98	-0.33
Shape					1.00	-0.34	0.07	-0.26	0.26	-0.27	-0.20	0.15
Sin						1.00	0.39	0.80	-0.50	0.75	0.76	-0.54
AVEL							1.00	0.62	0.36	0.63	0.65	0.28
MSL								1.00	-0.32	0.98	0.99	-0.32
MSS									1.00	-0.31	-0.31	0.94
P										1.00	0.96	-0.29
CSD											1.00	-0.31
CSS												1.00

Based on Pearson's correlation coefficients, six Attributes are selected including the basin drainage area (A), the basin average slope (BS), the basin shape factor (Shape), the basin sinuosity factor

(Sin), the basin average overland flow (AOFL), and the basin centroid stream distance (CSD). The remaining 6 attributes could be eliminated. The basin catchment area (A) is highly positively correlated with L, MSL, P and CSD (with correlation coeff. of 0.83, 0.86, 0.92 and 0.83; respectively). So, the area A was selected as an independent attribute, while, L, MSL, P and CSD were eliminated. In addition, the Basin Slope (BS) is highly positively correlated with AVEL (0.83). Consequently, BS was selected and AVEL was eliminated. Both the AOLFL and the Shape Factor were not correlated with any other criteria, so that they were considered as independent and were selected. The Sin Factor was highly correlated with L, MSL, P and CSD (with correlation coeff. of 0.75, 0.8, 0.75, and 0.76; respectively) which have already been eliminated and the Sin Factor was selected. The MSS was only correlated with the CSS. So, CSS was selected, and MSS was eliminated. These attributes were divided according to their effect on flash flood risk to two groups. The first group includes the A, BS, Sin, and the CSS. This group reflects the ascending hazard degree (high values reflect the higher hazard degree) (Fig. 5 (a-d)). While the second group includes the Shape Factor and the AOFL with descending hazard degree (low values reflect the higher hazard degree) (Fig. 5 (e and f)).

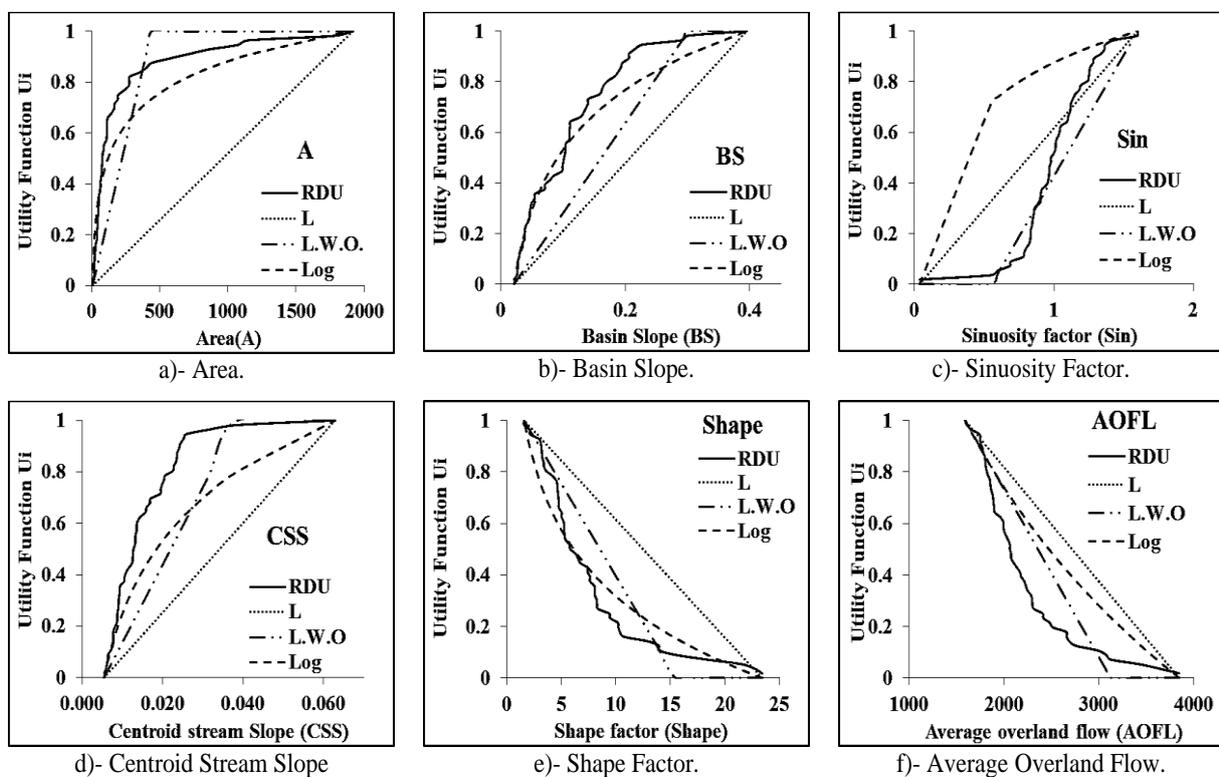
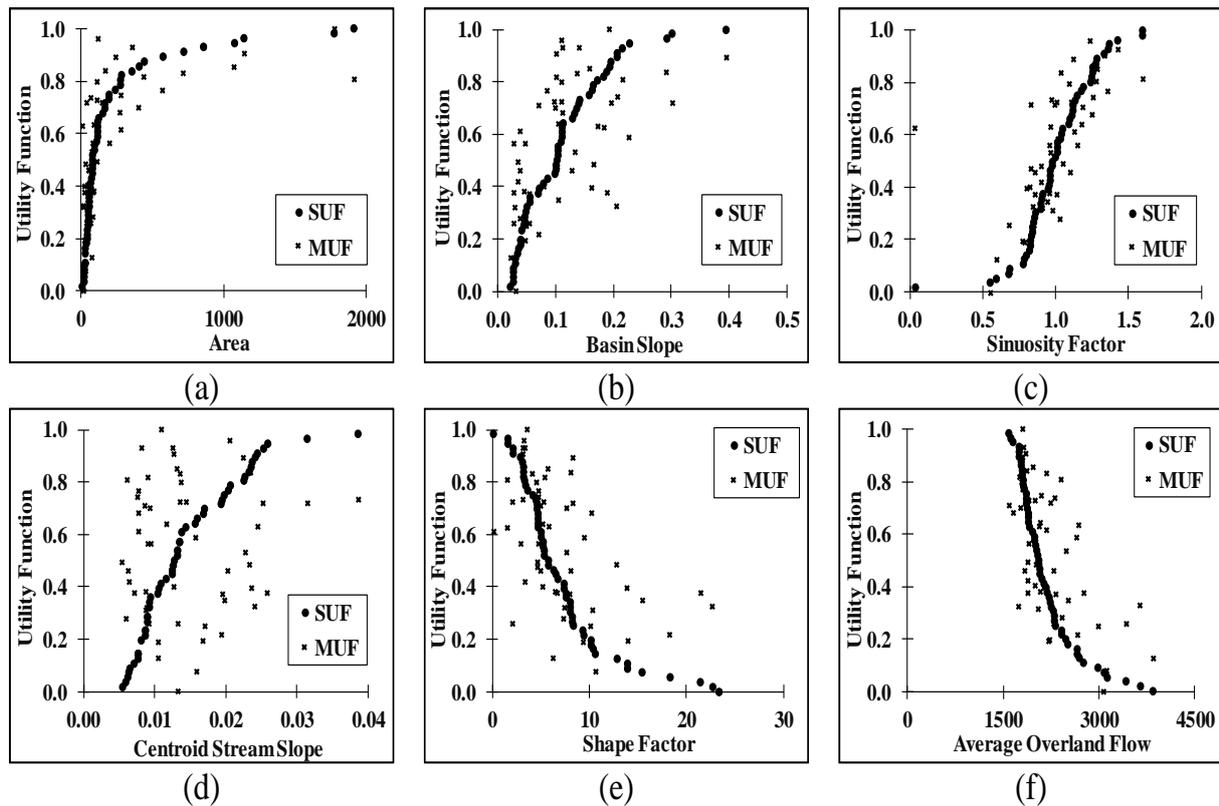


Figure 5: Comparison between Linear, Logarithmic and RDU Utility functions for all selected attributes (RDU = Rank-Dependent Utility Function; L = Linear Function; L.W.O = Linear Without Outliers; Log = Logarithmic Function).

Excluding the Sin, all the attributes have a decreasing marginal utility (risk-averse). While the Sin utility has sometimes an increasing and sometimes a decreasing one, i.e., neither risk-averse (everywhere) nor risk-seeking (everywhere), as shown in Fig. 5. Using the Linear without Outliers or the Logarithmic Shape function is seemed to be suitable for all parameters except the Sin. Moreover, the RDU shows the real distribution of all the data which may be suitable for the utility functions.

In addition, applying an equal weight value (1st scenario) for all attributes, the model showed relatively high correlation with all parameters except CSS which has a very low correlation value

(0.011) with the hazard degree (Fig.6). Accordingly, this parameter is excluded in the second scenario and its weight is redistributed to the other parameters.



- a)- Area (Correlation = 0.781).
- b)- Basin Slope (Correlation = 0.616).
- c)- Sinuosity Factor (Correlation = 0.813).
- d)- Centroid Stream Slope (Correlation = 0.011).
- e)- Shape Factor (Correlation = 0.575).
- f)- Average Overland Flow (Correlation = 0.638).

Figure 6: Comparison between the Single-Utility Function (SUF) and the Multi-Utility Function (MUF) for each parameter for the 1st scenario.

Accordingly, in the 2nd scenario, only five attributes are used, and the weights of these attributes are nonlinearly optimized using GRG Nonlinear to make the correlation of all chosen attributes with the hazard degree higher or equal the threshold value (Fig. 7 & Fig. 8a). This implied that these attributes are highly correlated with the hazard degree and low correlated with each other. Table 3 shows the Assigned weight values for each attribute.

Applying the above-mentioned procedure, the relative hazard degree of the chosen 56 hydrographic basins concerning flash floods was estimated (Table 4). The results exhibit eleven highly hazardous basins (H class) with 20% from all studied basins. Their names are El-Raha, Werdan, Gharandal, Teba, Al-Khaboba, BaaBa, Sedri, Firan, Al-Aawag, Abu Garf and El-Mahash. Moreover, the moderately highly hazardous basins (MH class) include E-Elaat basin, Eghshy basin, Thiman basin, Kabalyat1basin, N- Kabalyat1 basin, Nakhl basin, Retal basin, Waset basin, Sedr basin, Lahata basin, Robayna basin, Elhag basin, N Elhag basin, E. Geddi basin and Elmelez basin with total ratio of 27%. The moderately hazardous basins (M class with total ratio of 19%) include N Mabook basin, Merbaa basin, Raud Elraha basin, N Seada basin, Seada basin, Abo Megarar basin, Kabalyat2 basin, Selly basin, Lethi basin, Markha basin, and SW-Elaat basin. Moreover, the moderately low hazardous basins (ML class) reached 25% from the total basins (25 basins). They include E Elmelez basin, E Geddi Mabook basin, Abo Ramath basin, Kohli N basin, Raud Elraha basin, S-Thiman basin, Robes basin, S-Robes basin, El-Raboud basin, Meeh basin, W-Elaat basin, Middle Elaas basin. Accordingly, the rest of the studied basins (five basins) cover the low hazardous basins (L

class). Fig. (8.b) reveals the number of basins in each group while Figure 9 shows the risk map for the two scenarios.

On the other side, when use the second scenario, some following remarks may be noticed:

1. Mathematically, the results of the second scenario are correlated to the expected hazard degree as shown in the previous flood records (See validation paragraph)
2. The eleven highly hazardous basins (H class) in the 1st scenario decreased to ten basins while El-Raha, BaaBa and Sedri basins were replaced by El-melez and E-Elaat basins due to applying of 2nd scenario. This may be attributed to the drainage characteristics of terrain surfaces of these basins (Table 4) reflect great tendency of these catchments to receive flash floods with peak runoff because of weathered and fractured nature of the volcanic bedrock.
3. The fifteen moderately highly hazardous basins (MH class) increased in number from fifteen to eighteen basins but El-melez and E-Elaat basins were replaced according to second scenario results by El-Raha, Seada, Baaba, Sedri and selly basins.
4. The total number of moderately hazardous basins (11 basins with total ratio of 19%) didn't change. The only change in this M class is the replacement of Seada and Selly basins by Abo Ramath and Middle Elaet basins.
5. The total number of moderately hazardous basins (11 basins with total ratio of 19%) didn't change. The only change in this M class is the replacement of Seada and Selly basins by Abo Ramath and Middle Elaet basins.
6. The fourteen moderately low hazardous basins (ML class) decreased after applying 2nd Scenario from 14 to 12 basins. Abo Ramath, S-Robes and Middle Elaet basins were disappeared and Elsaer basin was appeared.
7. The number of five low hazardous basins (L class) didn't change but S-Robes basin replaced instead of Elsaer basin.

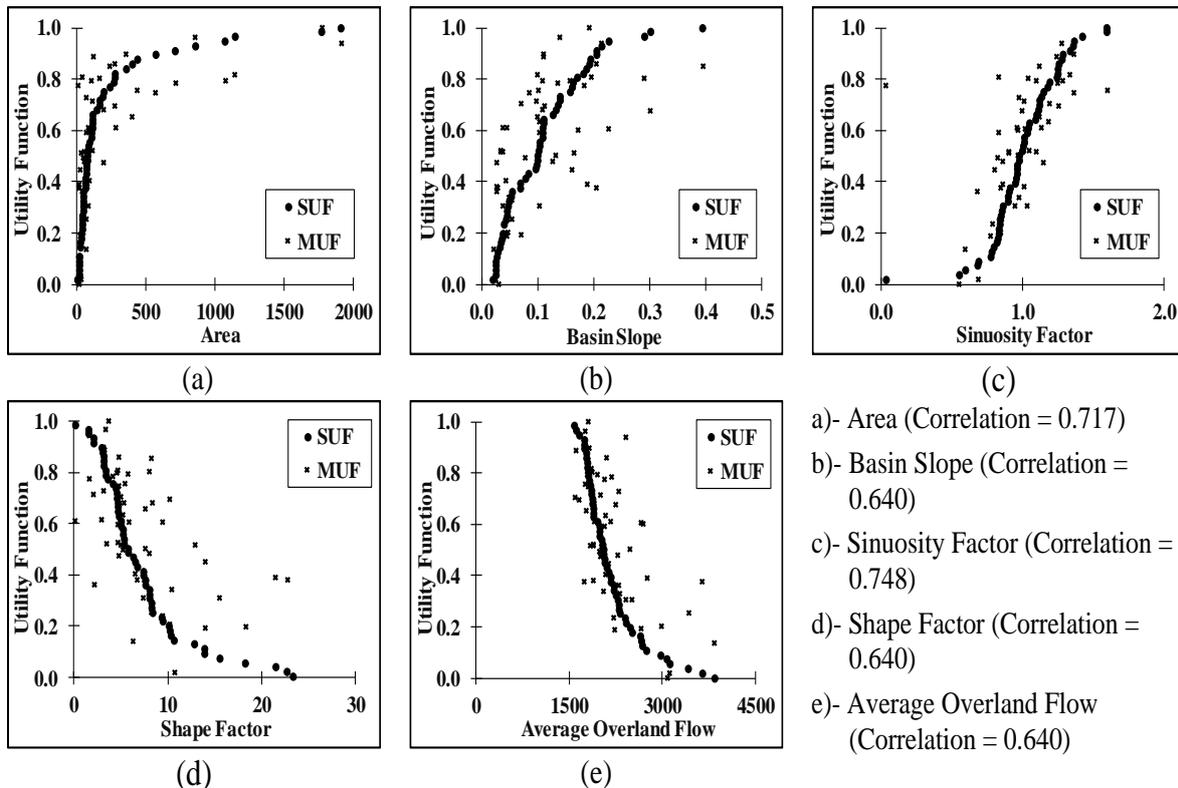


Figure 7: Comparison between SUF and MUF functions for each parameter for the second scenario.

Table 3: Assigned weight for all attributes of the study area.

Scenario	A	BS	Shape	Sin	AOFL	CSS
Scenario 1 (equal weight)	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
Correlation with Hazard	0.781	0.616	0.575	0.813	0.638	0.011
Scenario 2 (objective method)	0.094	0.37	0.269	0.066	0.202	---
Correlation with Hazard	0.711	0.640	0.640	0.748	0.640	---

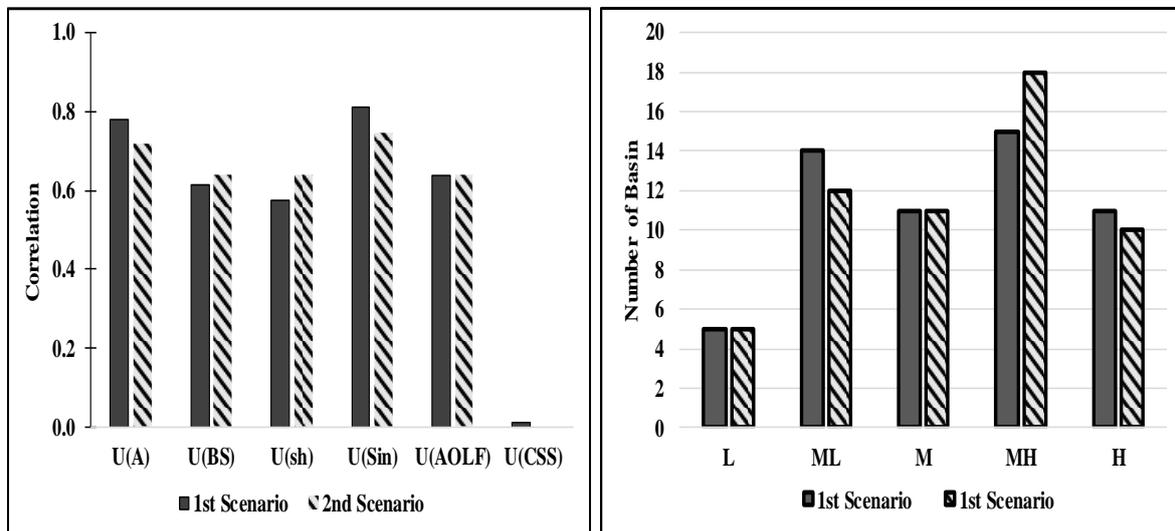


Figure 8: Correlation between attributes and hazard degree (left map) and number of basins classified in each group (right map).

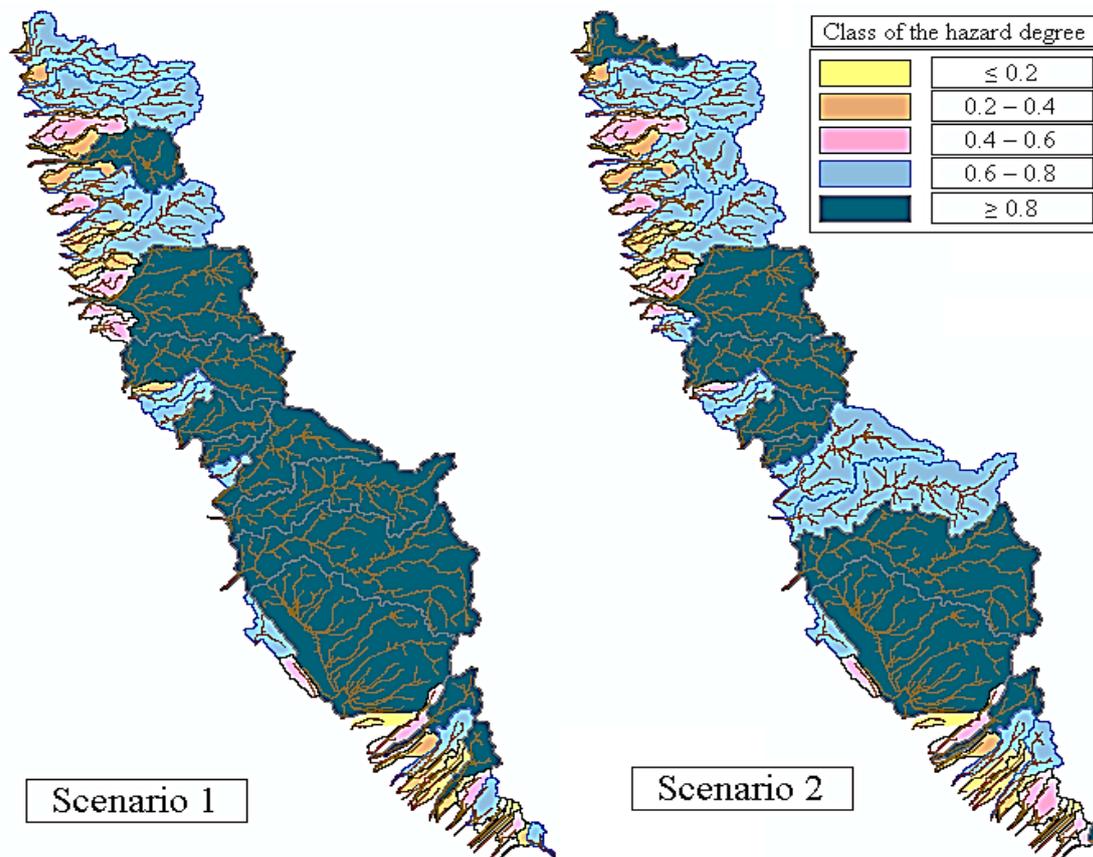


Figure 9: Location map of the promising Deltas for tourism projects at Suez Gulf Wadi systems (Yellow colour).

Table 4: The flash flood risk classes based on MAUT extracted from WMS and STA.

ID	A	U(A)	BS	U(BS)	Shape	U(sh)	Sin	U(Sin)	AOLF	U(AOLF)	CSS	U(CSS)	Hazard 1		Hazard 2		
													U	U _{re}	U	U _{re}	
E Elmelez	17.9	0.036	0.029	0.107	7.43	0.393	0.913	0.375	1743.28	0.929	0.009	0.268	0.35	0.32	0.36	0.38	ML
Elmelez	276.9	0.804	0.206	0.911	4.75	0.661	1.258	0.857	2103.41	0.429	0.008	0.125	0.63	0.74	0.73	0.86	H
E Geddi	39.7	0.214	0.027	0.054	2.16	0.911	0.682	0.071	2298.61	0.286	0.009	0.321	0.31	0.26	0.35	0.36	ML
Geddi	272.2	0.786	0.112	0.643	10.24	0.179	1.254	0.839	1657.75	0.946	0.008	0.143	0.59	0.68	0.61	0.69	MH
N Elhag	279.4	0.821	0.038	0.196	0.17	0.982	1.135	0.732	2170.25	0.393	0.008	0.143	0.54	0.61	0.54	0.61	MH
Elhag	402.6	0.857	0.099	0.464	7.64	0.375	1.120	0.696	1776.09	0.875	0.009	0.339	0.60	0.70	0.58	0.65	MH
N Mabook	195.1	0.750	0.027	0.089	4.78	0.625	1.151	0.750	1996.78	0.571	0.009	0.286	0.51	0.56	0.44	0.47	M
Mabook	77.9	0.482	0.027	0.071	6.76	0.429	1.010	0.536	1879.68	0.696	0.007	0.107	0.39	0.37	0.36	0.38	ML
El-Raha	439.6	0.875	0.101	0.500	5.40	0.518	1.598	1.000	1755.03	0.893	0.009	0.286	0.68	0.82	0.65	0.75	MH
Abo Ramath	88.9	0.536	0.044	0.250	6.53	0.446	0.963	0.429	2077.02	0.446	0.009	0.232	0.39	0.38	0.38	0.40	M
Robayna	166.1	0.696	0.070	0.375	5.04	0.589	1.192	0.786	1591.98	0.982	0.009	0.214	0.61	0.71	0.61	0.70	MH
Merbaa	75.9	0.464	0.035	0.161	3.42	0.786	0.902	0.339	1890.93	0.661	0.006	0.089	0.42	0.42	0.47	0.52	M
Lahata	193.1	0.732	0.110	0.571	5.33	0.536	1.113	0.679	1903.44	0.625	0.014	0.571	0.62	0.73	0.59	0.68	MH
Elsaer	45.6	0.250	0.040	0.232	9.39	0.232	0.787	0.125	2216.02	0.357	0.011	0.393	0.26	0.19	0.25	0.24	ML
Kohli	52.7	0.339	0.049	0.321	10.38	0.161	0.978	0.500	2044.46	0.518	0.009	0.232	0.35	0.31	0.33	0.34	ML
Sedr	570.3	0.893	0.085	0.429	4.77	0.643	1.362	0.929	1801.19	0.839	0.008	0.143	0.65	0.77	0.65	0.75	MH
W-Elaat	81.1	0.518	0.038	0.179	7.40	0.411	1.033	0.589	2417.17	0.214	0.006	0.036	0.32	0.28	0.31	0.31	ML
E-Elaat	113.9	0.643	0.034	0.143	4.71	0.679	1.050	0.625	1887.06	0.679	0.005	0.018	0.46	0.49	0.47	0.52	M
Werdan	1144.4	0.964	0.100	0.482	3.23	0.839	1.337	0.911	1857.74	0.732	0.013	0.500	0.74	0.91	0.70	0.82	H
N Seada	54.0	0.357	0.038	0.196	5.04	0.607	1.100	0.661	1833.21	0.768	0.006	0.071	0.44	0.46	0.47	0.52	M
Seada	80.7	0.500	0.046	0.268	2.95	0.893	0.958	0.411	1898.56	0.643	0.009	0.357	0.51	0.56	0.54	0.61	MH
Gharandal	858.9	0.929	0.140	0.714	3.39	0.804	1.428	0.964	1751.89	0.911	0.008	0.196	0.75	0.93	0.81	0.96	H
SW-Elaat	44.1	0.232	0.078	0.411	5.26	0.554	0.822	0.161	1993.16	0.589	0.013	0.482	0.40	0.40	0.45	0.49	M
Waset	111.5	0.589	0.104	0.554	5.22	0.571	1.180	0.768	2076.76	0.464	0.012	0.429	0.56	0.64	0.56	0.63	MH
Retal	107.8	0.571	0.110	0.589	4.54	0.732	1.094	0.643	1781.94	0.857	0.014	0.607	0.67	0.80	0.68	0.79	MH
Teba	356.3	0.839	0.111	0.625	3.19	0.857	1.367	0.946	1819.09	0.786	0.013	0.464	0.75	0.93	0.76	0.89	H
Al-Khaboba	119.8	0.661	0.110	0.607	3.25	0.821	1.242	0.804	1610.35	0.964	0.021	0.786	0.77	0.96	0.75	0.89	H
Meelh	65.9	0.411	0.141	0.732	3.13	0.875	0.977	0.482	2300.33	0.268	0.039	0.982	0.63	0.73	0.63	0.73	MH

Table 4 (Cont.): The flash flood risk classes based on MAUT extracted from WMS and STA

ID	A	U(A)	BS	U(BS)	Shape	U(sh)	Sin	U(Sin)	AOLF	U(AOLF)	CSS	U(CSS)	Hazard 1		Hazard 2	
													U	U _{re}	U	U _{re}
Nakhl	716.2	0.911	0.137	0.696	4.16	0.750	1.249	0.821	2182.2	0.375	0.014	0.571	0.69	0.83	0.67	0.78
BaaBa	1074.7	0.946	0.158	0.750	5.77	0.500	1.287	0.893	1960.89	0.607	0.013	0.518	0.70	0.85	0.68	0.79
Sedri	1776.8	0.982	0.193	0.857	3.64	0.768	1.596	0.982	1808.94	0.804	0.011	0.411	0.80	1.00	0.84	1.00
Firan	7.6	0.018	0.183	0.821	1.61	0.964	0.036	0.018	2062.81	0.500	0.063	1.000	0.55	0.63	0.67	0.77
Kabalyat1	113.2	0.607	0.098	0.446	2.12	0.929	1.011	0.554	2000.81	0.554	0.014	0.625	0.62	0.73	0.62	0.71
Kabalyat2	65.4	0.375	0.103	0.518	4.64	0.714	0.830	0.179	2063.66	0.482	0.012	0.446	0.45	0.47	0.53	0.59
Al-Aawag	1914.9	1.000	0.215	0.929	1.61	0.946	1.280	0.875	2409.17	0.232	0.006	0.054	0.67	0.81	0.80	0.94
Araba	71.2	0.429	0.021	0.018	6.32	0.464	0.596	0.054	3845.9	0.000	0.010	0.375	0.22	0.13	0.18	0.14
Selly	113.8	0.625	0.227	0.946	9.49	0.214	1.017	0.571	2656.96	0.161	0.016	0.643	0.53	0.59	0.54	0.60
Abu Garf	239.4	0.768	0.395	1.000	8.29	0.268	1.121	0.714	1804.14	0.821	0.023	0.804	0.73	0.89	0.73	0.85
N-Morikh	19.2	0.071	0.030	0.125	23.41	0.000	0.553	0.036	3078.36	0.071	0.013	0.536	0.14	0.00	0.07	0.00
Morikh	65.6	0.393	0.054	0.339	8.25	0.286	0.851	0.268	3422.05	0.036	0.013	0.536	0.31	0.26	0.26	0.25
Thiman	147.0	0.679	0.302	0.982	8.37	0.250	0.999	0.518	2249.98	0.321	0.025	0.929	0.61	0.72	0.59	0.68
S-Thiman	50.6	0.304	0.048	0.304	10.18	0.196	0.842	0.232	2984.15	0.089	0.017	0.696	0.30	0.25	0.23	0.20
N-Robes	23.6	0.107	0.046	0.286	13.97	0.089	0.777	0.107	2232.03	0.339	0.017	0.679	0.27	0.19	0.22	0.19
Robes	48.2	0.286	0.104	0.536	15.51	0.071	0.947	0.393	2515.49	0.179	0.020	0.750	0.37	0.35	0.31	0.31
S-Robes	38.6	0.196	0.070	0.393	18.31	0.054	0.832	0.196	2662.9	0.143	0.019	0.714	0.28	0.22	0.22	0.19
SS-Robes	29.6	0.161	0.026	0.036	10.69	0.143	0.690	0.089	3124.64	0.054	0.016	0.661	0.19	0.08	0.08	0.02
El-Mahash	168.0	0.714	0.291	0.964	8.08	0.304	1.041	0.607	1864.98	0.714	0.024	0.857	0.69	0.84	0.69	0.80
El-Raboud	46.2	0.268	0.055	0.357	8.04	0.339	0.905	0.357	2316.91	0.250	0.020	0.732	0.38	0.37	0.32	0.33
Lethi	74.7	0.446	0.133	0.679	7.64	0.357	0.966	0.446	2483.85	0.196	0.023	0.821	0.49	0.53	0.46	0.50
Eghshy	91.6	0.554	0.172	0.804	5.83	0.482	0.967	0.464	2687.12	0.125	0.024	0.911	0.56	0.63	0.53	0.60
Markha	29.0	0.143	0.165	0.786	12.87	0.125	0.901	0.321	2021.77	0.536	0.023	0.839	0.46	0.48	0.47	0.51
N Raud Elraha	18.0	0.054	0.206	0.893	22.73	0.018	0.846	0.250	3644.63	0.018	0.024	0.893	0.35	0.32	0.36	0.38
Raud Elraha	20.9	0.089	0.188	0.839	21.49	0.036	0.863	0.304	2756.95	0.107	0.026	0.946	0.39	0.37	0.37	0.39
Middle Elaat	37.5	0.179	0.196	0.875	4.66	0.696	0.833	0.214	1853.83	0.750	0.031	0.964	0.61	0.72	0.69	0.81
N- Kabalyat1	52.4	0.321	0.128	0.661	8.06	0.321	0.857	0.286	2285.76	0.304	0.020	0.768	0.44	0.46	0.44	0.48
Abo Megarar	23.6	0.107	0.162	0.768	13.96	0.107	0.801	0.143	2138.00	0.411	0.024	0.875	0.40	0.40	0.42	0.45

5. Validation

Validation of the results of the flash hazard risk analysis seem to be difficult. Damage information of some pervious flood events occurred in the last few decades could be collected. The obtained risk map could be compared with those major hazard flash floods and found that they are highly coincided. Data in Table 6 extracted from the published articles [37,38], the dissertation [19] and the newspapers' archive. The results showed that all the affected Wadies were considered high or moderately high risk in the two scenarios.

Table 6: Validation of the two scenarios with the recorded previous floods (Source [38]).

Date	Location	Flood effects	1 st Scenario	2 nd Scenario
6/1/1988	Wadi Sudr	The flood caused the death of 5 passengers inside a car.	MH	MH
13/10/1991	Wadi Firan	Damage of the main road following Wadi Firan and some houses in El-Tarfa village.	H	H
20-22/3/1991	<ul style="list-style-type: none"> • Wadi Al- Aawag & • El-Mahash 	Some houses in Wadi Al- Aawag were destroyed, and some animals died.	H	H
17/01/2010	<ul style="list-style-type: none"> • Wadi Firan 	<ul style="list-style-type: none"> • A flash flood occurred in most of sub wadies like wadi Elshekh and wadi Elakhdar. The present of wadi Elakhdar dam stored 6 m height of water behind it. This protected the roads following Wadi Firan. 	H	H
	<ul style="list-style-type: none"> • Wadi Sudr 	<ul style="list-style-type: none"> • Several areas around Ras Sudr City were isolated and Some houses are destroyed 	MH	MH
28/10/2016	<ul style="list-style-type: none"> • Werdan, • Gharandal, • Teba, • Baaba, • Sedri, • Firan, and • Al-Aawag 	The construction of dams and other flood control works protected the roads and houses and stored 250 thousand cubic meters behind Teba and Shiba dams and 600 thousand cubic meters behind wadi Elakhdar and Salaf dams	H H H H H H H	H H H MH MH H H

6. Conclusions and Recommendations

Protection measurements of flash flood which depend solely on the recurrence interval have been adopted for long time giving weightless to their watershed's hydro-morphological parameters. Present research introduces the ability of using the Multi-Attribute Utility Theory (MAUT) technique with watershed parameters in designing flash flood events. Among the 12 morphological parameters extracted from the Gulf of Suez Basins, only six uncorrelated parameters were selected and used to calculate the hazard degree. These parameters were divided into two groups; the first group introduces parameters that reflect the ascending hazard degree, and it includes A, BS, Sin, and the CSS. The second group introduces parameters that reflect the descending hazard degree, and it includes both the Shape Factor and the AOFL. Results showed that, the Rank-Dependent Utility (RDU) is the best to reflect all data's real distribution. In addition, given equal weight to the

six parameters, values of the correlation between the hydro-morphological parameters and the resulting hazard degrees ranged from 0.813 for basin's Sinuosity to 0.011 for Centroid Stream Slope. Using non-linear weights optimization of those parameters, to make the correlation of all chosen parameters with the hazard degree higher than or equal to the threshold value, percentage of basins with high or moderately high hazard degree has decreased from 40 % to 32 %. In the two suggested scenarios, Wadies of Firan, Al-Aawag, Teba, Gharandal, Werdan, El-Mahash, Abu Garf and Al-Khaboba have been classified as highly hazard degree basins.

The study results were validated using data of the few available flash flood events in the past few decades in the studied area. It was found that all the affected Wadies were high or moderately high risk in the two scenarios. Although the study concentrated on the morphological parameters, other data such as climate, weather, and soil texture data are of comparable and even have higher importance and are recommended to be considered in any future studies. From the environmental point of view, it is difficult to completely control flash floods and special attentions should be given. Finally, further studies concerning the flash flood environmental hazards are still needed.

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تقييم مخاطر السيول والفيضانات اللحظية باستخدام نظرية الأداة متعددة السمات للأودية الواقعة شرق خليج السويس، مصر

الملخص العربي:

أدت التغيرات المناخية في السنوات الأخيرة الي زيادة الفيضانات اللحظية الكبيرة كما وتكرارا. تتطلب الإدارة الجيدة للفيضانات اللحظية تقديرا دقيقا لدرجة الخطورة وتوزيع الفيضانات على الاودية المختلفة ودقة خرائط المخاطر المتوقعة لتلك الفيضانات. كما تؤثر المعاملات المورفولوجيا للأودية واحواض تصريف الفيضانات بدرجة كبيرة على منحنيات التصريف وقوة الفيضان وبالتالي على درجة خطورته. تقدم الدراسة الحالية موضوع البحث باستخدام بعض أدوات ونظريات التقييم وصنع القرار مثل طريقة التحليل متعدد المعايير Multi Criteria Analysis (MCA) ونظرية الأداة متعددة السمات Multi-Attribute Utility Theory (MAUT) لتقدير درجة المخاطر للفيضانات المحتملة في منطقة خليج السويس، مصر. تم تطبيق نظرية MAUT بنجاح لتقدير درجات الخطورة لعدد ٥٦ وادي في المنطقة الساحلية الشرقية لخليج السويس. بناءً على الارتباط الناتج بين جميع المعاملات المورفولوجية المائية للأحواض والأودية محل الدراسة، تم فقط اختيار ست متغيرات متساوية الوزن واستخدامها لحساب درجة الخطورة. أظهرت النتائج أن حوالي ٤٠٪ من الـ ٥٦ حوضًا بها درجة خطورة عالية أو متوسطة. تراوحت قيم عوامل الارتباط بين المعاملات المورفولوجية المائية ودرجات الخطورة المستنتجة بين (٠,٨١٣) لقيم الـ Sinuosity للأودية وقيمة (٠,٠١١) لانحدار المجري المركزي Centroid Stream Slope. تم تحسين وتعظيم أوزان المعاملات المختارة بشكل غير خطي لجعل الارتباط بينها وبين درجة الخطورة لا تقل عن قيمة ٠,٦٠ كقيمة حدية (Threshold) لجميع المعاملات. وبناءا عليه، انخفضت نسبة الاودية ذات درجة الخطورة العالية أو المتوسطة إلى ٣٢٪. وأخيرا تم التحقق من صحة النموذج المستخدم في الدراسة وقدرته على قياس درجات الخطورة للفيضانات اللحظية باستخدام البيانات والارصاد الخاصة ببعض الفيضانات التي وقعت في العقود القليلة الماضية. كما أظهرت المقارنة بين السيناريوهات التي خلصت اليها الدراسة النظرية باستخدام النموذج المقترح والبيانات الواقعية والفعلية لتلك الفيضانات أن جميع الاودية المتأثرة ذات درجة الخطورة العالية أو المعتدلة تتوافق بشكل كبير مع الحالات الحقيقية مما يؤكد إمكانية تطبيق النموذج المقترح بدقة عالية.