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Weighted normalized risk factor for floods risk assessment

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KEYWORDS

Multi criteria analysis;
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Abstract Multi Criteria Analysis (MCA) describes any structured approach used to determine overall preferences among alternative options, where options accomplish certain or several objectives. The flood protection of properties is a highly important issue due to the damage, danger and other hazards associated to it to human life, properties, and environment. To determine the priority of execution of protection works for any project, many aspects should be considered in order to decide the areas to start the data collection and analysis with. Multi criteria analysis techniques were tested and evaluated for the purpose of flood risk assessment, hydro-morphological parameters were used in this analysis. Finally a suitable technique was chosen and tested to be adopted as a mark of flood risk level and results were presented.

1. Introduction

Flood protection is an important item in almost all development projects (i.e. roads, railways, airports) and the underlying consideration of safety is an integrated aspect of the detailed design of all flood protection systems. Hazards associated with flooding can be divided into primary hazards that occur due to contact with water, secondary effects that occur because of the flooding, such as disruption of services, health impacts, famine and disease, and tertiary effects such as changes in the position of river channels. Throughout the last century flooding has been one of the most costly disasters in terms of both property damage and human casualties.

Major floods in China, for example, killed about 2 million people in 1887, nearly 4 million in 1931, and about 1 million in 1938. The 1993 flood on the upper Mississippi River and Midwest killed only 47 people, the total economic loss estimates were between 15 and 20 billion dollars, Nelson [1]. Catastrophic flash flooding has recently become very common in the Red Sea areas, particularly where storms hit large settlements, Masoud [2].

Therefore, a great intention was made to implement a design criteria for flood protection in design manuals and codes of practice. Almost all of these manuals adopted the design recurrence interval as a measure for the safety level that will be considered during the design of flood protection system. A flood event that may harm highly important element should have a design recurrence interval higher than less important

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element. This method of evaluating the flood risk level almost ignored the hydro-morphological parameters of the catchments and the flood event it self.

Multi Criteria Analysis (MCA) appeared in the 1960s as a decision-making tool. It is 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, Baptista et al. [3].

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, Heun [4].

Explicit recognition is given to the fact that a variety of both monetary and nonmonetary objectives may influence the decisions taken. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indicators are used. MCA includes a range of related techniques, some of which follow this entry, Heun [4].

2. Methodology

Determination of stream networks' behavior and their interrelation with each other is of great importance in many water resources studies, Al Saud [5]. Any area under development that is subjected to flood hazards had to be protected against flood events, these events are estimated based on a certain recurrence interval. However, some points may be subject to more danger than other points. This is why a risk assessment, from the flood event point of view, has to be carried out prior the design or proposing a flood protection scheme. So that the high-risk locations will receive more attention than points with lower risk or even their protection works may be designed with a higher recurrence interval.

The criteria adopted in this work for risk analysis was based on hydro-morphological factors that may result in more damage to the crossing locations. These factors are the peak discharge, drainage area, drainage density, flow paths roughness, average slope of the catchment and the runoff volume. The most important factors of those are discussed below.

2.1. Factors affecting risk analysis of floods

The peak discharge, often called peak flow, is the maximum rate of runoff passing a given point during or after a rainfall event. The peak flow varies for each different storm, and it becomes the designer's responsibility to size a given structure for the magnitude of storm that is determined to present an acceptable risk in a given situation. Peak flow rates can be affected by many factors in a watershed, including rainfall characteristics, basin size, and the physiographic features.

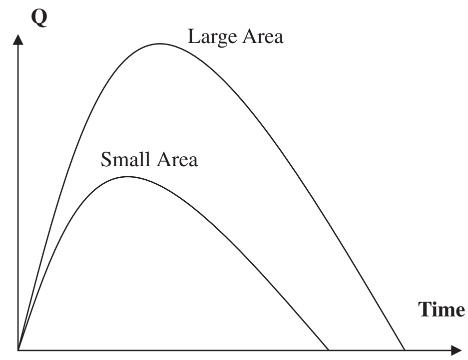

Figure 1 Effect of drainage area on flood discharge.

Drainage area is the most important watershed characteristic that affects runoff. The larger the contributing drainage area, the larger will be the flood runoff (Fig. 1). Regardless of the method utilized to evaluate flood flows, peak flow is directly related to the drainage area.

Slope is very important in how quickly a drainage channel will convey water, and therefore, it influences the sensitivity of a watershed to precipitation events of various time durations. Watersheds with steep slopes will rapidly convey incoming rainfall, and if the rainfall is convective (characterized by high intensity and relatively short duration), the watershed will respond very quickly with the peak flow occurring shortly after the onset of precipitation. Steep slopes tend to result in rapid runoff responses to local rainfall excess and consequently higher peak discharges (Fig. 2).

On the other hand, for a watershed with a flat slope, the response to the same storm will not be as rapid, and depending on a number of other factors, the frequency of the resulting discharge may be dissimilar to the storm frequency, U.S. Department of Transportation – FHA [6].

The runoff volume is also affected by slope. If the slope is very flat, the rainfall will not be removed as rapidly. The process of infiltration will have more time to affect the rainfall excess, thereby increasing the abstractions and resulting in a reduction of the total volume of rainfall that appears directly as runoff.

The time of concentration, which is denoted as T_C, is defined as the time required for a particle of water to flow from the

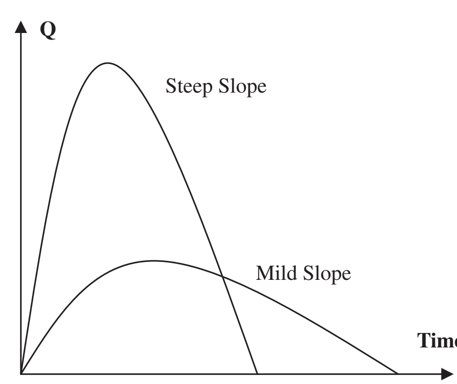

Figure 2 Effect of flow path slope on flood hydrograph.

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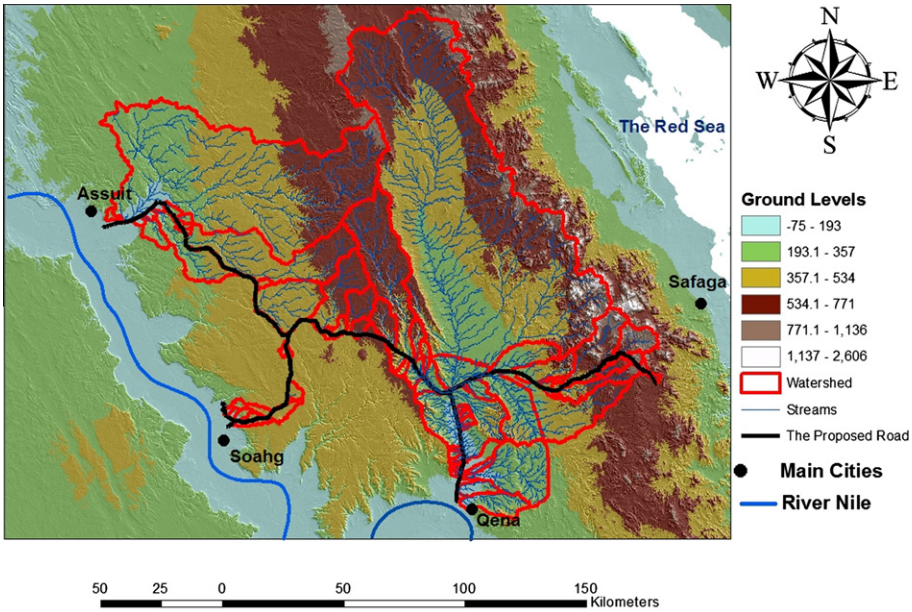

Figure 3 Sample of hydro-morphological analysis results.

hydraulically most distant point in the watershed to the outlet or design point. Factors that affect the time of concentration are the length of flow, the slope of the flow path, and the roughness of the flow path. For flow at the upper reaches of a watershed, rainfall characteristics, most notably the intensity, may also influence the velocity of the runoff. During the analysis the Kirpich formula (Soil Conservation Services (SCS), 1940), Eq. (1), which is widespread in several countries, was used.

$$T_C = 0.01944(L)^{0.77}/(S)^{0.385} \quad (1)$$

where T_C is the Time of concentration (min), L is the Longest flow path length (m) and S is the catchment area average slope (m/m).

Some factors such as the time to peak and the average runoff depth were not considered in the proposed criteria of risk analysis as they are already implemented in the factors that were mentioned previously. Other factors were not considered, as they have minor effect on the damage at the catchment outlet point such as the catchment perimeter.

For any flood protection project the hydro-morphological analysis has to be carried out first. This means that flow pattern has to be traced, catchments have to be delineated then morphological parameters such as slope and T_C calculated for the points of interest or for points that need protection. Fig. 3 represents an example for this analysis results for a proposed route of a highway located in Egypt East Desert connecting main cities on the river Nile by others on the Red Sea coast.

3. Standardization of parameters

The hydro-morphological parameters obtained for each watershed are expressed in different units. It is therefore difficult to compare across criteria. For many of the arithmetic MCA techniques, it is necessary to reduce the scores to the same unit. This is called standardization. The difference between the actual parameter and that of the lowest value is divided by the difference between the parameters of the highest value and that of the lowest value. This led to standardized factors that reflect the degree of risk for each parameter compared to the same parameter in the other sheds.

$$\text{Area Standardized Risk Factor (ASRF)} = \frac{Area - Area\ Min}{Area\ Max - Area\ Min} \quad (2)$$

$$\text{Slope Standardized Risk Factor (SSRF)} = \frac{Slope - Slope\ Min}{Slope\ Max - Slope\ Min} \quad (3)$$

$$T_C \text{ Standardized Risk Factor (TCSRF)} = \frac{T_C - T_C\ Min}{T_C\ Max - T_C\ Min} \quad (4)$$

$$\text{Runoff Volume Standardized Risk Factor (RVSRF)} = \frac{Vol - Vol\ Min}{Vol\ Max - Vol\ Min} \quad (5)$$

where Max refers to the maximum value of the mentioned parameters and Min refers to the minimum value of the mentioned parameters.

The weighted sum was then applied to standardized parameters. The principle is that the standardized parameters for each criterion are added up, leading to a single factor. And to express the importance of certain parameter compared to others, the individual standardized factors were multiplied by a weight coefficient (W), that was assumed constant for all factors and equal to 1/(no. of parameters), before being added up. The sum is called the Weighted Standardized Risk Factor (WSRF). The weight coefficient (W) was assumed constant

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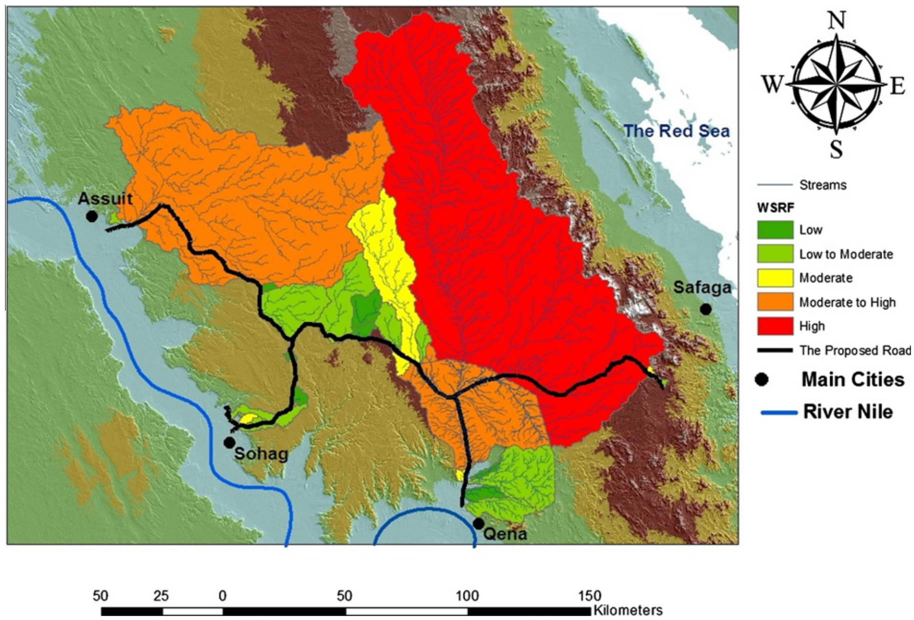

Figure 4 Sample of hydro-morphological analysis results.

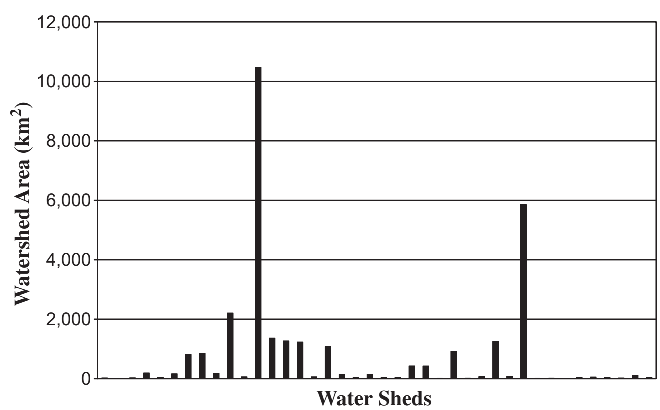

Figure 5 Drainage areas for the sample case study.

to simplify the results and could be changed based on the importance of each factor so that the more important the factor is the higher the W value will be assigned to it.

$$\mathrm{WSRF} = W \times (\mathrm{ASRF} + \mathrm{SSRF} + \mathrm{TCSRF} + \mathrm{RVSRF}) \quad (6)$$

4. Results and discussion

Fig. 4 represents the results of the analysis technique for the watersheds shown previously in Fig. 3. The WSRF was classified into five categories on a quantile basis.

From the results it was found that all catchments with large drainage area have a high WSRF and as a result it caused deviation to the resulted WSRF for all the other sheds. Therefore, almost all of watersheds have a low to moderate flood risk factor.

The drainage areas, as a main parameter directly affecting the value of flood peak flow, were plotted, Fig. 5, to test it for extreme high values that may affect the results. Fig. 5 indicates clearly two main drainage areas that are extremely high (10,469 km^2 and 5857 km^2), that appear as two extreme

Table 1 Box blot test results.

	Volume (m^3)	Slope (m/m)	T_C (min)	Area (km^2)
Median	102,120	0.00782	360	74
LQ	51,060	0.00398	228	37
UQ	1,175,760	0.01784	868	852
Interquartile range	1,124,700	0.01386	640	815
Mild high outlier	2,862,810	0.03863	1828	2075
Extreme high outlier	4,549,860	0.05942	2789	3297

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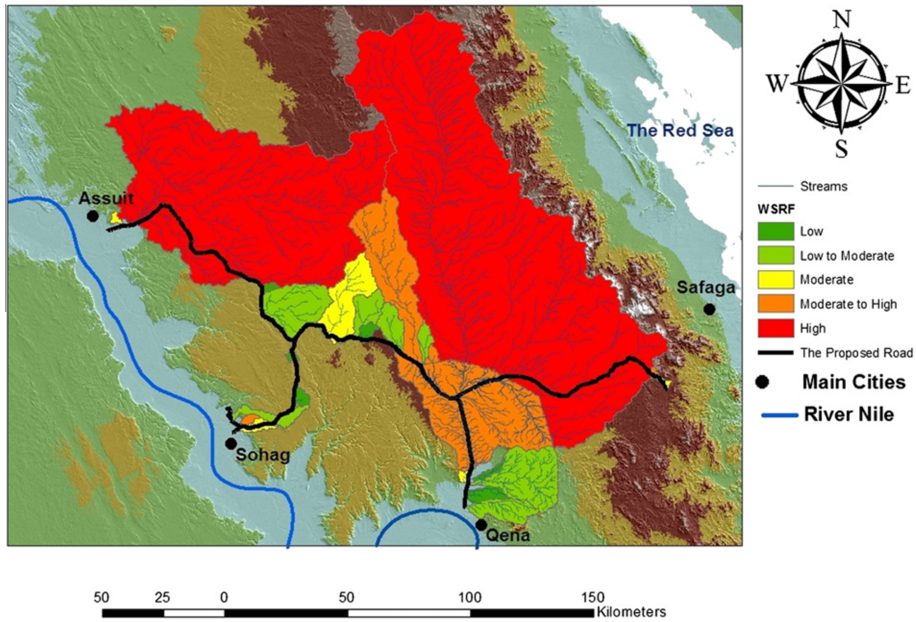

Figure 6 Reevaluation of WSRF results.

lines on the graph, while all the other values fall below 2300 km^2.

The box plot technique was applied to test all the data for values that are extremely high or an outlier. An outlier is an observation that is numerically distant from the rest of the data which may lead to biased results. Box plot technique is useful to display differences between populations without making any assumptions of the underlying statistical distribution. It is non-parametric. Spacings between the different parts of the box help indicate the degree of dispersion (spread) and deviation in the data, and identify outliers.

The mild and extreme higher outliers were calculated for each data set and all watersheds that have their parameters values above the extreme higher outlier were considered as the highest risk watersheds.

$$\text{Mild higher outlier} = UQ + 1.5\ IQR \quad (7)$$

$$\text{Extreme higher outlier} = UQ + 3\ IQR \quad (8)$$

$$IQR = UQ - LQ \quad (9)$$

where UQ is the upper quartile, LQ is the lower quartile and IQR is the inter-quartile range.

Then the extreme higher outlier was considered as the highest parameter value. This technique was adopted for all parameters (area, time of concentration, slope, and volume); results are presented in Table 1.

The WSRF for each of them recalculated and their risk level was recalculated based on the new results, Fig. 6. It can be noticed that the medium size catchment risk level was changed to a higher level.

5. Conclusion

Flood protection measurements depending solely on recurrence interval have been adopted for long time without giving weight to the morphological parameters of the watersheds that cause such floods. The paper presented the use of multi criteria analysis technique to use these parameters when defining the design flood events.

It was noticed during the analysis that the drainage basin area has a great effect on the floods generated at its outlet while other factors have less effect than the drainage area such as the slope and roughness. During the analysis a higher limit for all the parameters values were adopted based on the sample that was considered during the analysis to calculate the standardized factors. The box plot test represented a very useful, easy to use and quick tool when trying to exclude extremely high parameter that may lead to unrealistic risk factor. However, using regression techniques, maximum values can be calculated for such purpose that may depend on the meteorological characteristics of the region.

The risk Weighted Standardized Risk Factor obtained can be used during the design of flood protection measurements and/or the calculation of design peak flows for crossing structures. This may lead to more economic design procedure that can be adopted in drainage design guidelines and manuals. However, further studies should be made concerning the environmental hazards of flood events and special attention should be made when trying to control floods to keep the environment undisturbed (i.e. minimize the change of land slopes and levels associated to flood protection works' construction, keep the original paths of floods and limit the diversions as much as possible) and limit the environmental changes upstream and downstream the flood protection measures.

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