Mansoura Engineering Journal,(MEJ), Vol. 36, No. 3, September 2011. C. 13

FLASH FLOODS RISK ASSESSMENT IN SANA'A BASIN, YEMEN

تقويم خطورة العواصف الرعدية بحوض صنعاء ، جمهورية اليمن

ABULOHOM M. NAIF* and MOHAMED I. M. GAD**
*Earth Sciences & Environment Department, Faculty of Science, Sana'a University, Yemen
** Desert Research Center, Cairo, Egypt e-mail: drmohamedgad@yahoo.com

الخلاصة:

تم في هذا البحث تحديد اثنين وعشرين حوض تجميع فرعي بحوض صنعاء بجمهورية اليمن من نموذج الارتفاع الرقمي للمنطقة (90مx90م) وكذلك تحديد خمسة عشر معامل مورفومتري لكل منهم باستخدام برنامج الحاسب الآلي WMS 7.1 . كما تم استخدام الطرق الإحصائية كطريقتي التحليل متعدد العوامل وتحليل المجاميع لتقدير مؤشر للخطورة النسبية لاستقبال هذه الأحواض الفرعية للعواصف الرعديه إعتماداً على ثمانية معاملات مورفومترية مؤثره في تكوين السيول بجانب البيانات المناخية.

واوضحت النتائج ان ستة أحواض فرعية جنوب حوض صنعاء سجلت أعلى مؤشر للخطورة النسبية لأستقبال العواصف الرعدية وتكوين سيول مدمرة بينما يشير أقل مؤشر للخطورة النسبية لاستقبال العواصف الرعديه لحوضين فرعيين فقط يقعا شمال شرق حوض صنعاء . وعليه يوصى بضرورة عمل القياسات الحقلية اللازمة لمعايرة هذه النتائج وأخذها في الاعتبار في مشروعات التنمية المستقبلية لحوض صنعاء.

ABSTRACT

Water resources are increasingly a constraint on economic and social development in Yemen. Coping with the water scarcity in the Sana'a Basin (SB) requires good management for the flash floods. This requires an accurate estimation for the hazard degrees and floods risk. Multi Criteria Analysis (MCA) describes any structured approach used to determine overall preferences among alternative options, where the options accomplish certain or several objectives. The maximizing of water use in arid zones, like SB, is a highly important issue due to the damage, danger and other hazards associated to it to human life, properties, and environment. MCA techniques were tested and evaluated for the purpose of flash flood risk assessment, hydro-morphological parameters for sample catchments in SB, also used for analysis results of this paper.

Drainage network and watershed boundaries of SB shape files was created using TOPAZ (Topographic Parameterization) technique from the 90 m Digital Elevation Model (DEMs). These data are used in Watershed Modeling System (WMS) package to automatically delineate sub-basin boundaries and define stream networks. Twenty two sub-basins in SB were delineated for the study of the hazard degree of flash floods. Cluster analysis, depending on 15 estimated hydro-morphological parameters, classifies tne sub-basins of SB into five groups. Eight chosen hydro-morphological parameters, have their direct effect on flash flooding, were used for estimating hazard scale depending on the MCA procedures. The proposed risk scale assumed category five for the high Weighted Standardized Risk Factor (WSRF) of six southern sub-basins, while the category four (moderate to high WSRF) represents the middle sector of SB (4 sub-basins). The class three represents 4 sub-basins (moderate WSRF). The low to the moderate hazardous sub-basins (the category two) include 3 sub-basins while the low WSRF in relates to 2 sub-basins (9%). Field measurements are highly recommended to verify the results of MCA procedure used in this research.

KEY WORDS: Hydrology, Flash Floods, Multi Criteria Analysis, Sana'a Basin, Yemen

Accepted July 7, 2011.

INTRODUCTION

Water use maximization from flash floods is an important item in almost all development projects and an integrated aspect of the detailed design of all rain fed systems is the underlying consideration of safety. Hazards associated with flash flooding may be controlled under presence of appropriate management system. Therefore, a great intention was made to have a design criteria for flash 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 flash flood protection system. This means that a flood event that may harm highly important element should have a design recurrence interval higher than that with less importance level (Stephen A. Nelson, 2004). This method of evaluating the flash flood risk level almost ignored the hydro-morphological parameters of the catchments and the flash flood event itself.

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. MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish a 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.

Location of the study area

The Sana'a Basin (SB) is an inter-mountain plain located in the central Yemen Highlands, and surrounding the capital of country on its central part. The geographic coordinates of the basin with UTM are longitude 390000 and 460000 due east and latitude 1665000 and 1750000 due north. The plain has an elevation of about 2200 masl but it is surrounded to the west, south and east by mountains rising to about 3000 masl (Fig. 1). The Basin has an area of some 3200 km^2 and forms the upper part of the catchment of Wadi Al Kharid, a sub-catchment of the Wadi Al Jawf. The climate is semi-arid with an average annual rainfall of 235 mm at Sana'a city. Physiographic setting of SB.

The Yemen Highlands is one of the three main physiographic units of the country; the other two are the Lowlands and the Midlands. The Highlands are distinguished from the Midlands by the 1,500 m contour and are further sub-divided into the northern, central, eastern and western units. The Highlands are dissected by numerous narrow wadis most of which trend either westward or eastward. Within the Central Highlands a number of intermountain plains exist at altitudes of 2100 to 2800 m. These plains (of which Sana'a Plain is one) are commonly covered by Quaternary sediments and surrounded by mountain ranges composed mostly of volcanic rocks. SB consists of two main physiographic subdivisions; namely: the main plain and the surrounding mountain ranges which also enclose a number of smaller "elevated" plains and are dissected by several wadis. The total Basin area equal 3200 km^2, the Plain occupies about 10 % (SAWAS, 1996).

Geological setting of SB

The stratigraphic sequence of SB ranges from Precambrian to Recent with some periods of missing, Table 1. The Phanerozoic rocks of the SB mainly consist of sedimentary and volcanic rocks. The subsurface data reveals the presence of the Precambrian rocks as in Arhab and Al-Hatarish wells (DS1 in Arhab and DS2 in Al Hatarish areas) which represent the deepest wells drilled in Sana'a basin (Kruseman and Vasal, 1996). The different lithostratigraphic units in the SB from older to younger are the Kohlan Sandstone Formation of Triassic – Jurassic age, the Amran Group of Jurassic age, the Tawilah Group of the Cretaceous age, the Tertiary Volcanics Group of the Tertiary age, the Quaternary Volcanics of the Quaternary age, and the Alluvial deposits of the Quaternary age. The surface distribution and outcrops of these lithostratigraphic units are shown in the geological map Fig. 2. The structural trends which controlled the formation of the SB are inherited from the proterozioc trends which have been rejuvenated during the early Jurassic time where a deep depression was formed by NW-SE trend. The SB is subjected to different tectonic trends of compressional and extensional regimes. The extensional regime is the most dominant structures in the area and obscured all the old structures.

MATERIALS AND METHODS

The materials used in this paper were collected through carrying out 40 field trips in SB during the period 2006-07. These field trips were achieved with the team work of the SBWMP project carried out by HYDROSULT and NWRA-Sana'a branch team work. The basic hydrologic data of these sites were obtained during these field trips. In addition, the archival data such as long term rainfall records were collected from the WEC library beside the recent rainfall records from the 7 installed rain gauge stations and monitoring monthly periodic records. 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 4.5 computer programs to estimate the four dependent parameters of the runoff coefficients, i.e., the quantity of rain, the intensity of rainfall and ground configuration.

Recurrence period of rainfall in SB

Twenty field trips were achieved in SB during 2006-07 to collect the materials used in this paper. The basic data of the SB were obtained during these field trips. In addition, the archival data such as long term rainfall records were collected from the WEC library beside the recent rainfall records from the different rain gauges installed by SBWMP project, Table 1. These rainfall records were used in estimating the recurrence period, rainfall hyetograph and rainfall event distribution in SB according to Weibull, (1932) ranking method and Raghunath, (1990), Figs. 3, 4, 5 & 6.

In the other hand, drainage network and watershed boundaries shape files of SB was automatically delineated by Watershed Modeling System (WMS 7.1) package using TOPAZ (Topographic Parameterization) technique (Garbrecht, and Martz, 1993) from the 90 m DEM. In addition, Shuttle Radar Topography Mission (SRTM3) data are used to trace and convert the drainage network and sub-basin boundaries to lines and polygons by WMS drainage coverage (Nelson et al, 2000). Fig. 7 shows the delineated sub-basins in SB while Table 2 summarizes the terrain characteristics of the 22 sub-basins extracted from DEM applying WMS model.

The hydro-morphological parameters of the different sub-basins in the SB were 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 15 hydro-morphological variables, basic statistics and correlation matrix of the transformed data input of these different variables are given in Table 3 and Table 4.

Moreover, the cluster analysis was carried out on the non transformed input data matrix of 22 sub-basins and 15 hydro-morphological parameters applying STATISTICA software. The results are given as R-mode and Q-mode dendrograms with amalgamation rule of single linkage and

Euclidean distance of (1-Pearson r) method (Fig. 8).

Hydro-morphological parameters of SB catchments

Any area under development that is subjected to flash flood hazards had to be protected against flood events, these events are estimated based on a certain recurrence interval. However, some sub-basins may be subject to more danger than other sub-basins. This is why a risk assessment from the flash flood event point of view, has to be carried out prior the design or proposing the storm protection scheme (USDT, 1996). As a result, the high-risk locations will receive more intention than sub-basins with lower risk or even their protection works may be designed with a higher recurrence interval. 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 parameters are the drainage area (A), drainage density (D), basin slope (BS), Basin relief ratio (Rr), average overland flow (AOFD), basin shape factor (Shape), and basin sinuosity factor (Sin).

Drainage area (A) is the area of the basin in the units specified prior to computing basin parameters. It is the most important watershed characteristic that affects runoff. The larger the contributing drainage area, the larger will be the flood runoff. Regardless of the method utilized to evaluate flood flows, peak flow is directly related to the drainage area.

Drainage density (D) is defined as the total length of streams of different orders per unit of area (A) (Horton, 1945) has a strong influence on both the spatial and temporal response of a watershed to a given precipitation event. If a watershed is well covered by a pattern of interconnected drainage channels, and the overland flow time is relatively short, the watershed will respond more rapidly than if it were sparsely drained and overland flow time was relatively long.

Basin Slope (BS) is the average basin slope, or average slope of the triangles comprising this basin. A triangle's slope is computed as the change in elevation divided by the change in XY or plan distance. It 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. 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.

Basin relief ratio (Rr) is the ratio between Mean Basin Elevation in km (AVEL) and the Basin Length in km (L) (Schumm, 1956). The circular basins with small Rr are potentially more susceptible to flash flood (Patton, 1988).

Average Overland Flow (AOFD) is the average overland flow distance within the basin. This is computed by averaging the overland distance traveled from the centroid of each triangle to the nearest stream. It is a measure of erodability. The shorter AOFD value, the quicker the surface runoff is, **Basin shape factor (Shape)** is the shape factor of the basin, or the length divided by the width. **Basin sinuosity factor (Sin)** is defined as the length of basin path divided by the shortest distance between mouth and source of stream (Gregory and Willing, 1973). Sinuosity factor of the stream in the basin. Defined by dividing the maximum stream length in the basin by the length.

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 no effect on the damage at the catchment outlet point such as the catchment perimeter.

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 (Heun, 2008 and Baptista et al., 2007).

Drainage Area Standardized Risk Factor

$$(A_{SRF}) = \frac{Area - Area\ Min.}{Area\ Max - Area\ Min} \quad (1)$$

Drainage Density Standardized Risk Factor

$$(D_{SRF}) = \frac{D - D\ Min.}{D\ Max - D\ Min} \quad (2)$$

Basin Slope Standardized Risk Factor

$$(BS_{SRF}) = \frac{Slope - Slope\ Min.}{Slope\ Max - Slope\ Min} \quad (3)$$

Basin Relief Ratio Standardized Risk Factor

$$(Rr_{SRF}) = \frac{Rr - Rr\ Min.}{Rr\ Max - Rr\ Min} \quad (4)$$

Average Overland Flow Standardized Risk Factor

$$(AOFD_{SRF}) = \frac{AOFD - AOFD\ Min.}{AOFD\ Max - AOFD\ Min} \quad (5)$$

Basin Shape Ratio Standardized Risk Factor

$$(Shape_{SRF}) = \frac{Shpe - Shape\ Min.}{Shape\ Max - Shape\ Min} \quad (6)$$

Basin sinuosity Ratio Standardized Risk Factor

$$(Sin_{SRF}) = \frac{Sin - Sin\ Min.}{Sin\ Max - Sin\ Min} \quad (7)$$

Where; Max. refers to the maximum value of the mentioned parameter and Min. refers to the minimum value of the mentioned parameter.

The weighted sum was then applied to standardized parameters. The principle is that the standardized parameters for the individual criteria 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 assume in this study constant for all factors and equal to 1/(No. of parameters) for simplification, before being added up. The resulted sum is the Weighted Standardized Risk Factor (WSRF).

$$WSRF = W \times (A_{SRF} + D_{SRF} + BS_{SRF} + Rr_{SFR} + AOFD_{SRF} + Shape_{SRF} + Sin_{SRF}) \quad (8)$$

RESULTS AND DISCUSSION

It is obvious from the isohyetal map (Fig. 5) that the annual rainfall depth in the SB decreases in the NE-SW direction. As a general, Wadi Dahr and Al-Ghayl sub-basins receive more rainfall amount than Wadi Al-Qotob and Al-Ma'adi sub-basins. Moreover, the chatchment of Wadi Dahr and Al-Ghayl sub-basins receives average annual rainfall depth of 270 mm while the catchment of Wadi Al-Qotob and Al-Ma'adi sub-basins receives 190 mm based on the Sana'a airport station records during 1938-2008. In addition, Table 1 shows that the relation between the maximum rainfall depth in one day and the recurrence period is directly proportional. It is clear from the table and the curve (Fig. 4). The maximum rainfall in one day depth records during the tested period (12/2-10/4/2007) ranges from 0.2 and 7.6 mm with the mean 2.76 mm. The statistical analysis of these records shows that the maximum rainfall in one day with a probability level of 33 percent of exceedance is 4 mm (Table 1). In addition, on average a maximum rainfall in one day of 7.6 mm or more can only be expected in 1 year out of 15.

On the other hand, the drainage characteristics of terrain surfaces of the 22 sub-basins (Table 2) reflect great tendency of these catchments to receive flash floods with peak runoff as a result of weathered and fractured nature of the volcanic bedrock. The drainage area (A) of the extracted sub-basins ranges from 35.9 to 362 km^2 (Al-Furs and Rjiam sub-basins & Dahr and Al-Ghayl sub-basins respectively) with mean value of 141.82 km^2. Otherwise, the basin slope (BS) ranges from 0.03 (Al-Qasabah sub-basin) to 0.17 (Lasef and Asser sub-basins) with mean value 0.08 and standard deviation 0.03 (Table 3). The high BS value characterizing Lasef and Asser sub-basins reflects high tendency to generate great runoff and sediment load yields (Gad and Abdel-Latif, 2003). The basin length of overland flow (AOFD) can be described as the length of flow of water over the surface before it becomes concentrated in definite stream channels (Krishnamurthy et al. 1996). It ranges between 0.76 and 1.058 km with mean value 0.866 (Lasef and Asser sub-basins & Al-Qasabah sub-basin respectively). The basin shape factor (Shape) ranges between 1.5 (Mawrid and Al-Ashash sub-basins) and 7.3 (Al-Mashamini and Madar sub-basins) with mean value 3.33 and standard deviation 1.44. The sinuosity factor (SIN) ranges between 0.98 (Kholaqa sub-basin) and 1.5 (Hamadan and Al-Sebra sub-basins) reflecting lithological and structural control. The maximum stream length (MSL) of the 22 extracted sub-basins ranges from 12.34 to 41.66 km (Al-Furs and Rjiam sub-basins and Dahr and Al-Ghayl sub-basins respectively) with average value of 23.55 km.

The correlation analysis between the different hydro-morphological parameters, Table 4 shows that the marked correlations by red color are significant at probability less than 0.05. This means that the basin catchment area (A) is direct positively correlated with L, P, SIN, MFD, MSL and CSD (0.68, 0.81, 0.47, 0.75, 0.75 & 0.59 respectively). The Basin Slope (BS) is direct positively correlated with MFS and CTOSTR (0.64 & 0.47 respectively) and reverse correlated with the Basin Average Over land Flow (-0.65). The Basin Shape factor (Shap) is direct positively correlated with L, CSD (0.47 & 0.43 respectively) while SIN factor is direct positively correlated with Area, P, AVEL, MFD, MSL and CSD (0.47, 0.44, 0.46, 0.57, 0.59, & 0.51 Respectively). Moreover, the correlation coefficient of unity characterized to the relation between Basin Max Flow Distance (MFD) and Basin Max Stream Length (MSL) reflects the effect of the geological structures of these streams to form peak flow and receives flash floods (Gad, 2001 and Gad 2010).

In addition, the R-mode dendrogram exhibits four clusters when interpreted at similarity level with a linkage distance 0.4 (Fig. 8). The first cluster domains BS & MFS and the second cluster domains MSS and CSS hydro morphological parameters with linkage distance 0.48 (1-person) and one independent parameter (CTOSTR). This two linked clusters reflect the strong relation between these four hydro morphological parameters and the impact of basin slope to generate runoff component. The third cluster domains L, MFD, and MSL parameters. This cluster reflects the impact of both stream length and flow distance to generate peak flow (Gad et al, 2002 and Hassan and Gad, 2010) The fourth cluster domains P and Catchment area (A). All these drainage characteristics describe both length and area.

Otherwise, the Q-mode dendrogram exhibits four clusters when interpreted at similarity level with a linkage distance 1500 (Fig. 8). The first cluster domains Al-Furs and Rjiam sub-basins, Kholaqa sub-basin, Al-Miliki and Al-Hamal sub-basins, and Hizyaz sub-basin. While the second cluster domains Ghayman sub-basin, Al-Mashamini and Madar sub-basins, Al-Kharid sub-basin, and Mawrid and Al-Ashash sub-basins. This second cluster represents the inland sub-basins which form the discharge area of the surrounding high lands. Also, it is characterized by its moderate potentiality to form flash flood. The third cluster domains Shahik and Al-Sahah sub-basins, Al-Iqbal and Al-Shaab sub-basins, and Bani Hawat sub-basin. The three sub-basins are identical in the most of the drainage characteristics. The fourth cluster domains Sa'wan sub-basin, Al-Madini and Al-Ghulah sub-basins, Akhwar sub-basin, and Hamadan and Al-Sebra sub-basins, Yahees and Al-Huqqah sub-basins, and Thumah and Sheraa sub-basins. The three independent variables in the Q-mode statistical analysis are Al-Qotob and Al-Ma'adi sub-basins, Lasef and Asser sub-basins, and Dahr and Al-Ghayl sub-basins. Table 5 represents the results of the MCA analysis technique for the watersheds of the 22 sub-basins in the studied SB. The WSRF was classified into 5 categories on a quantile basis (Fig. 9).

As a general, WSRF values of the studied sub-basins to receive disasters from flash floods (Table 5) exhibit high risk of Hamadan and Al-Sebra sub-basins (category five), while moderate to high risk sub-basins (class four) include Al-Sirr, Dahr and Al-Ghayl, Al-Iqbal and Al-Shaab, and Mawrid and Al-Ashash sub-basins. The moderate risk sub-basins (category three) represents 73% of the studied sub-basins (16 sub-basins). The low to moderate risk category includes the rest of the studied sub-basins (Al-Qotob and Al-Ma'adi sub-basins).

From the results in Table 5, it was found that all catchments with large drainage area have a high WSRF value, and as a result, it causes skewness to the resulted WSRF values for all the other sheds. Therefore, almost all of watersheds have a low to moderate flood risk factor (category 2).

The drainage area (A), as a main parameter directly affecting the value of flood peak flow, was plotted to test it for extreme high values that may affect the results (Fig. 10) . From the plot, it was noticed that one main sub-basin area is extremely high (362 km^2) while all the other values falls below 230 km^2. In addition, the Basin Slope (BS), as another main parameter directly affecting the value of flood peak flow, was noticed from Fig. 10 that two main sub-basins areas are extremely high (0.17 and 0.12) while all the other values falls below 0.11.

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

$$\text{Mild higher outlier} = UQ + 1.5\ IQR \qquad (9)$$
$$\text{Extreme higher outlier} = UQ + 3\ IQR \qquad (10)$$
$$IQR = UQ - LQ \qquad (11)$$

Where; UQ is the upper quartile, LQ is the lower quartile and IQR is the inter-quartile range for each data set. Then the extreme higher outlier was considered as the highest parameter value when calculating WSRF. This technique was adopted for all other parameters and the WSRF for each of them was recalculated and their risk level was estimated based on the new results (Fig. 11).

CONCLUSION

Flash flood protection measurements 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. The paper presented the use of multi criteria analysis technique to use these parameters when defining the design flash flood events. It was noticed during the analysis that the drainage basin area and basin slope have great effect on the floods generated at its outlet while other factors have less effect than the drainage area and basin slope such as the shape factor and sinuosity factor.

During the analysis, a higher limit for all the parameters values was adopted based on the sample that was concerned 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 especially for small parameter values. However, using regression techniques, a maximum values can be calculated/estimated for any region for the purpose of defining the upper limit of each parameter depending on the meteorological characteristics of this region.

The weighted standardized risk factor obtained can be used during the design of flash flood protection measurements 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. However, 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.

Acknowledgements

The data of this work were presented from the Sana'a Basin Water Management Project (SBWMP). Assistance from project team work is gratefully acknowledged. We thank Eng. Saleh El-Dubbi and the NWRA-Sana'a Branch team for the use of their data and their support and cooperation.

REFERENCES

Baptista et al. (2007): "Multicriteria evaluation for urban storm drainage". First SWITCH scientific meeting University of Birmingham, UK, 9-10 Jan 2007.

Gad, M. I. M. (2001): "Statistical approach for the determination of hazard degrees of flash floods, Red Sea Wadi systems, eastern desert, Egypt." Ain Shams Science Bull., Vol., 39 – 2001 pp 37-61.

Gad, M. I. M., Farag, M. H. and Zaki, M. H. (2002): "Simulation of direct runoff volumes and peak rates for some catchments in El Qasr-Umm El Rakham area, northwestern coastal zone, Egypt". III-Regional Conference on Civil Engineering Technology and III-International Symposium on Environmental Hydrology Proceeding, 8-10 April 2002 (proceeding in CD).

Gad, M. I. M. and Abdel-Latif, A. (2003): "Hydrology of some drainage basins in the area between Quseir and Marsa Alam , Eastern Desert, Egypt." Giessener Geologische Schriften Nr. 70 215S. Giessen 2003, Germany pp 195-215.

Gad, M. I. M. (2010): "Estimation of the Recharge Component to the Shallow Aquifer from Flood Hydrograph of Wadi Sudr sub-basin by using Mass Balance Technique" Proceedings of the 7th Int. Engineering Conference Fac., of Eng.-Mansoura Univ., Mansoura/Sharm El-Sheikh March 2010, 20-33.

Gad, M. I. M., (2010): "Assessment of surface water runoff in some wadis of west Sidi Barani area, Northwestern coastal zone, Egypt". Egypt. J. P. Sci. Vol. 48: 66-80 (2010).

Garbrecht, J., and L.M. Martz, (1993): "Case application of the automated extraction of drainage network and subwatershed characteristics from digital elevation models by DEDNM," AWRA Proceedings of the Geographic Information Systems and Water Resources, March 1993, 221-229.

Gregory, K. J., and Willing, D. E. (1973): "Drainage basin form and process." New York, Halsted press Div. of John Wiley and Sons 456p.

Hassan, G. H. G., and Gad, M. I. M., (2010): "Water resources management in the area of wadis Gasus and Gawasis (south Safaga-Red Sea) through the geophysical and hydrological studies." Egypt. J. P. Sci. Vol. 48: 50-66 (2010).

Heun, J. C. (2008): "A Frame Work for Analysis for water resources planning and analysis", UNESCO-IHE, p.p. 43-55, LN0058/08/01, 2008

Horton, R. E. (1945): "Erosional developments of streams and their drainage basins- hydrophysical approach to quantitative morphology" Geol. Soc. Am. Bull., V. 56, pp. 275-370.

HYDROsult Inc. in Association with WEC and TNO-NITG, (2010): "Assessment of the Water Resources of the Sana'a Basin Strategic Options for the Sustainable Development of the Basin's Water Resources. Activity 1:

Aquifer Storage Investigations and Assessment, Part I". Final report of a Sana'a Basin Water Management Project (SBWMP) in Two Parts, Submitted to Ministry of Water and Environment, Republic of Yemen, April 2010, 1120 P.

John, C. Davis, (1986): "Statistics and Data Analysis in Geology". John Willey & Sons, Inc. 653 P.

Krishnamurthy, J., Srinivas, G., Jayaraman, V. and Chadrasekhar, M. G. (1996): "Influence of rock types and structures in the development of drainage networks in typical hardrock terrain." ITC Journal 1996, 3/4 Enschede, The Netherlands, 252-259.

Kruseman G. P., and Vasal L., (1996): "Source for Sana'a Water Supply". SAWAS Project. Wellfield Investigation, Kohlan and Wajid sandstone 1996. SAWAS

Nelson, James E., Woodruff Miller A., and Eric Dixon, (2000): "Mud Canyon Fire: A Hydrologic Evaluation of Rainfall Runoff from a Burned Watershed," Int. J. of Wildland Fire, V. 9, (1), 2000.

Patton, P. C. (1988): "Drainage basin morphometry and flood-in Flood geomorphology". Wiley Inter Sci., Publ., New York, pp. 51-64.

Raghunath, H. M., (1990): "Hydrology: principles analyses and design". Wiley Eastern Limited New Delhi, 482 p.

SAWAS (1996): "Sources for Sana'a Water Supply". SAWAS Final Technical Report and executive Summary National Water and Sanitation Authority Sans'a, Republic of Yemen. Netherlands Institute of Applied Geosciences TNO, Delft, the Netherlands.

Schumm, S. A. (1956): "Evolution of drainage systems and slopes in badlands at Preth Amboy, New Jersey." Amer. Geol. Soc. Bull. 67, pp. 597-646.

STATISTICA for Windows: Release 4.5 B, Copyright @ StatSoft, Inc. 1993.

Stephen A. Nelson, (2004): "Flooding Hazards, Prediction & Human Intervention", p.p. 1-8, EENS 2004.

United States Department of Transportation (USDT)- Federal Highway Administration, (1996): "Highway Hydrology", Hydraulic Design Series No. 2 (HDS-2), Chapter 2, p.p. 38-60

Watershed Modeling System WMS v 7.1 (2005): Comprehensive environment for hydrologic analysis developed by the Environmental Modeling Research Laboratory of Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station.

Weibull, W. (1932): "A statistical study of the strength of materials."Ing. Vetenskaps Akad. Handl. (Stockholm). Sited in Chow, 1964.

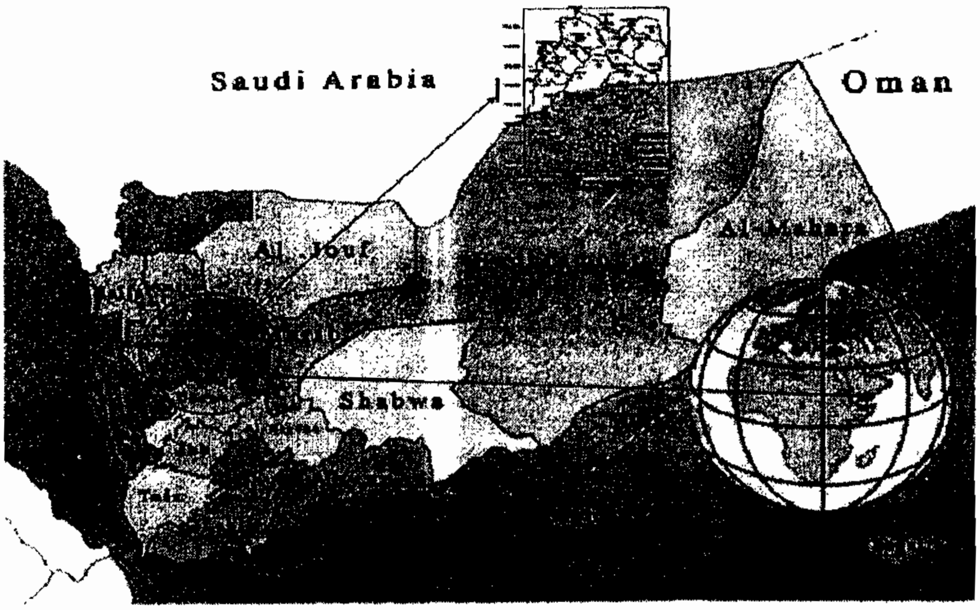


Figure 1: Location map of Sana'a Basin, Yemen

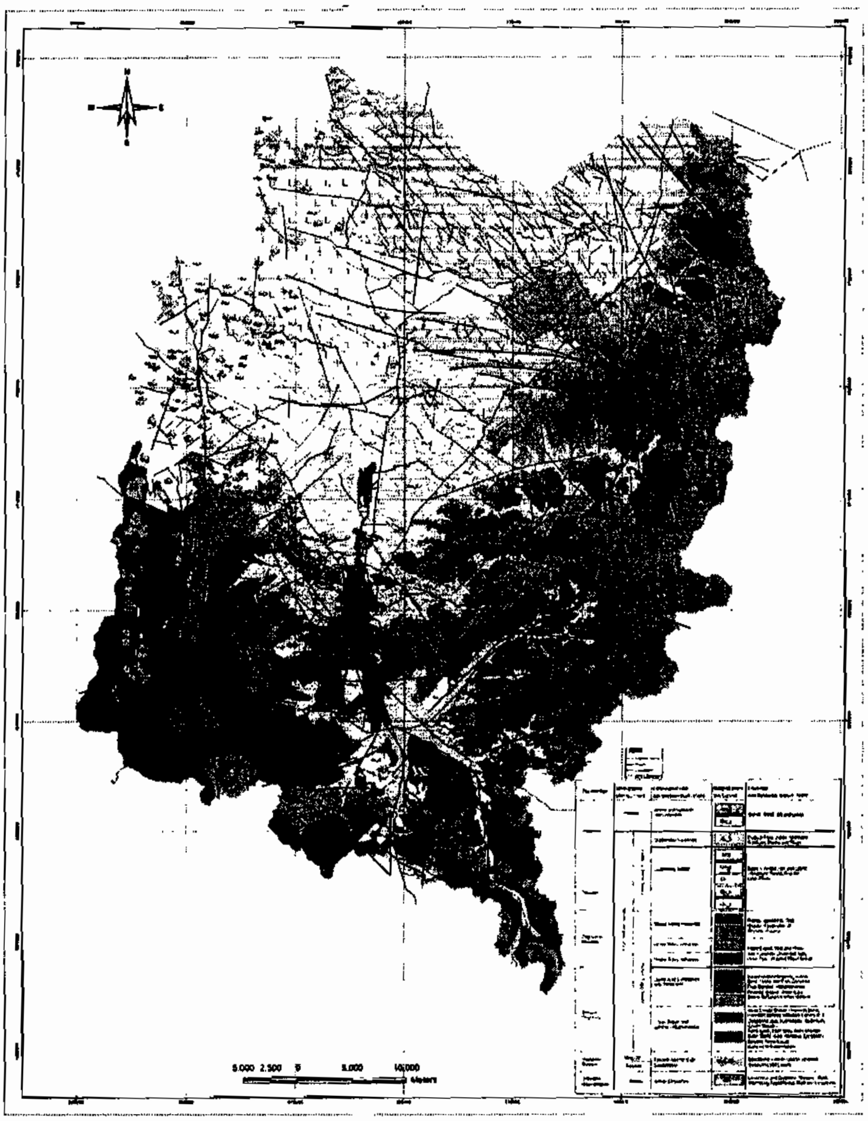


Figure.2: The geological map of the Sana'a Basin (HYDROsult, 2010)

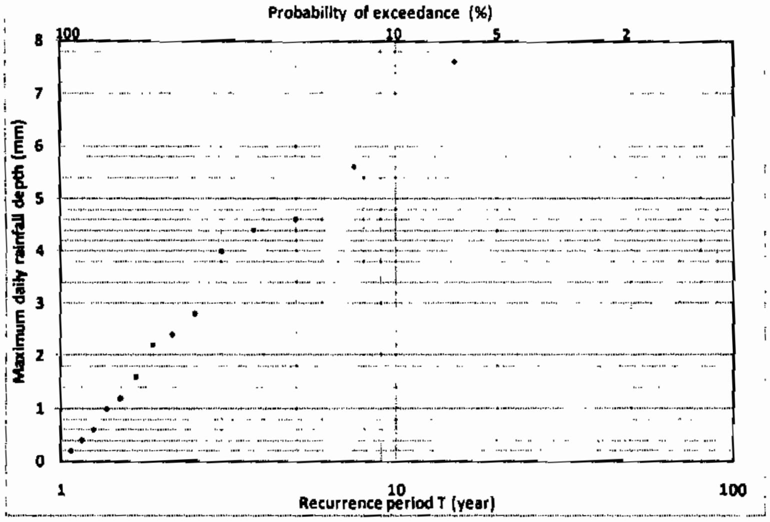


Figure 3: Recurrence period of events (years) vs maximum daily rainfall depth (mm) in SB

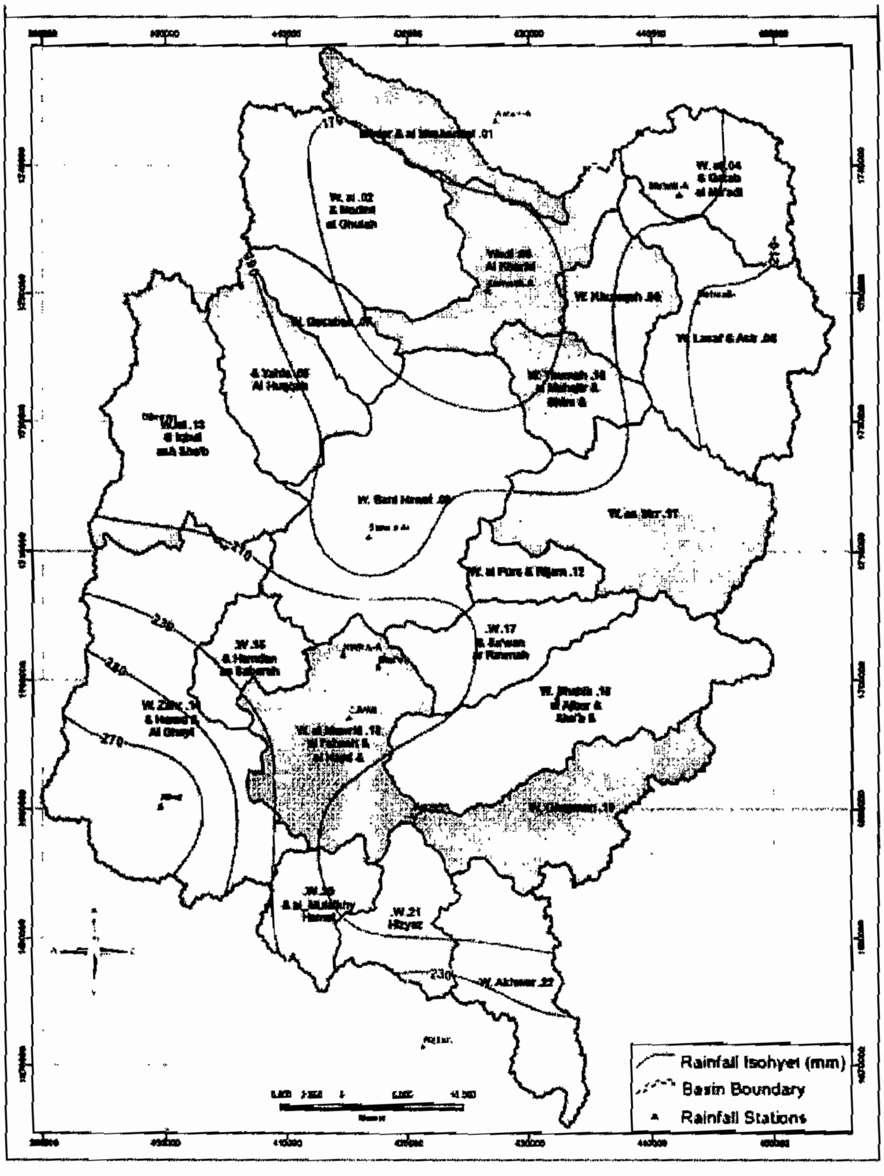


Figure 4: Annual Rainfall (mm) Isohyetal Map in SB

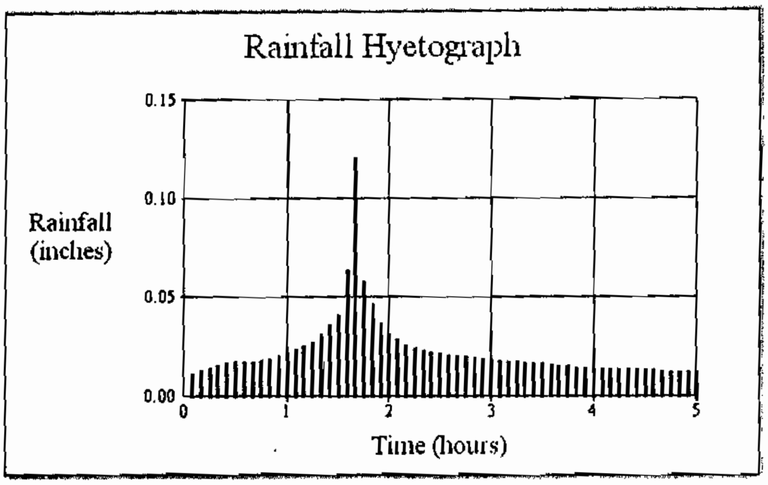


Figure 5: Rainfall hyetograph for storm pattern at Darselm rainfall station, based on pattern type IA

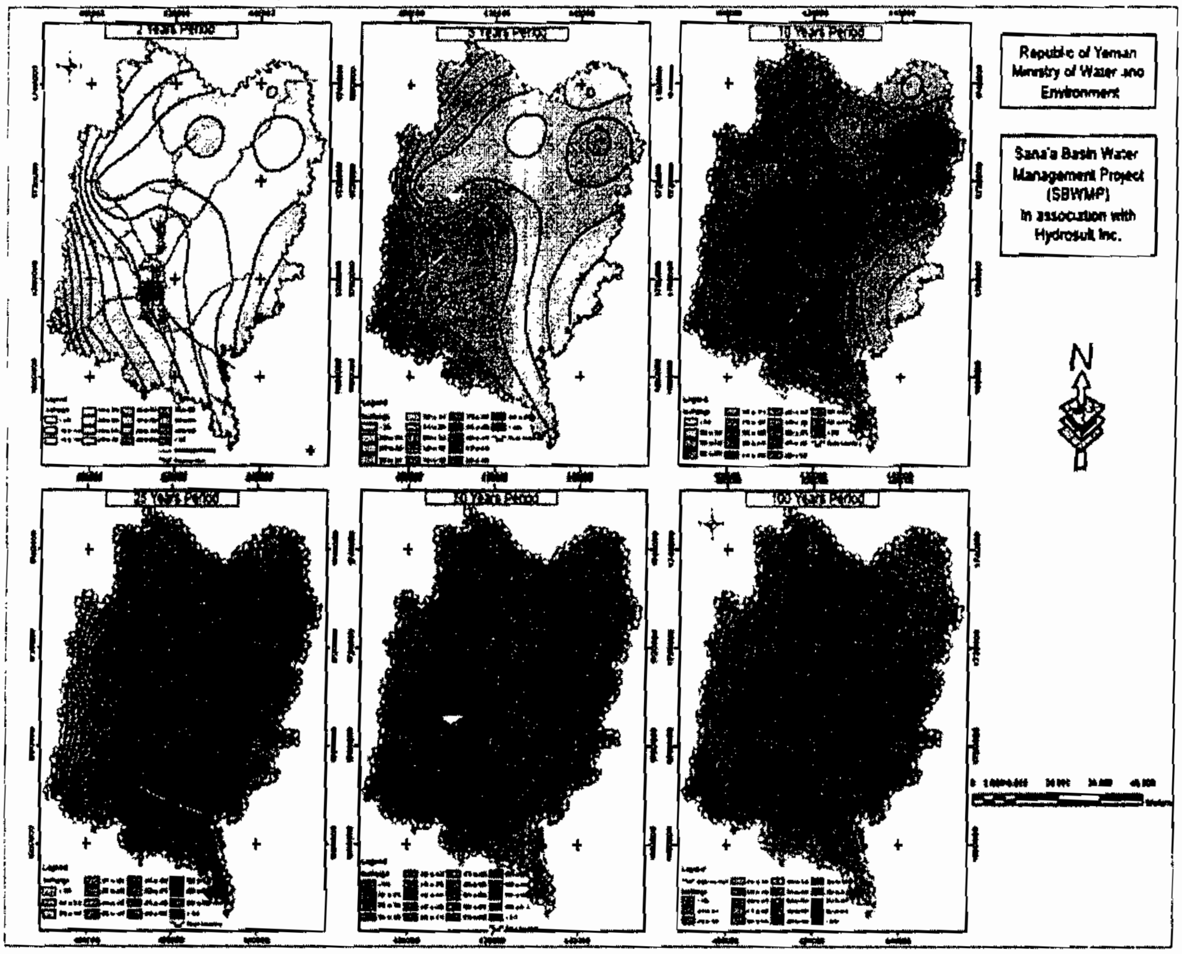


Figure 6: 2-year, 5-year, 10-year, 20-year, 25-year, 50-year and 100-year rainfall event distribution in the SB (HYDROsult, 2010)

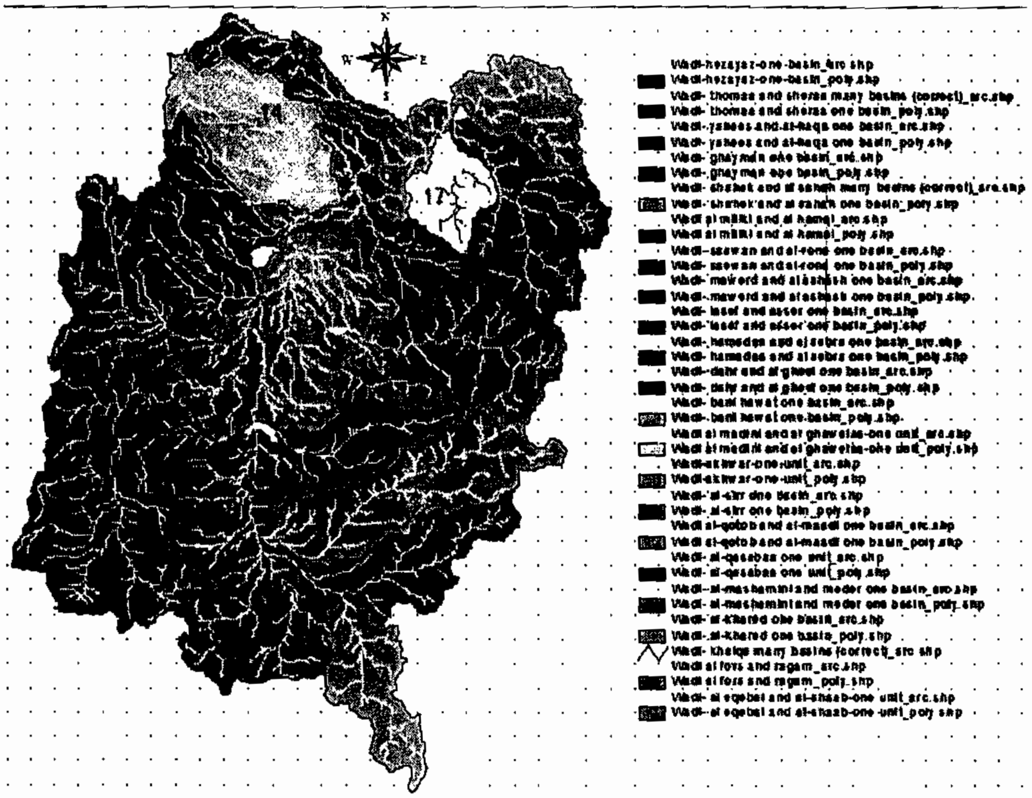


Figure 7: The 22 extracted sub-basins from DEM file of SB applying WMS model

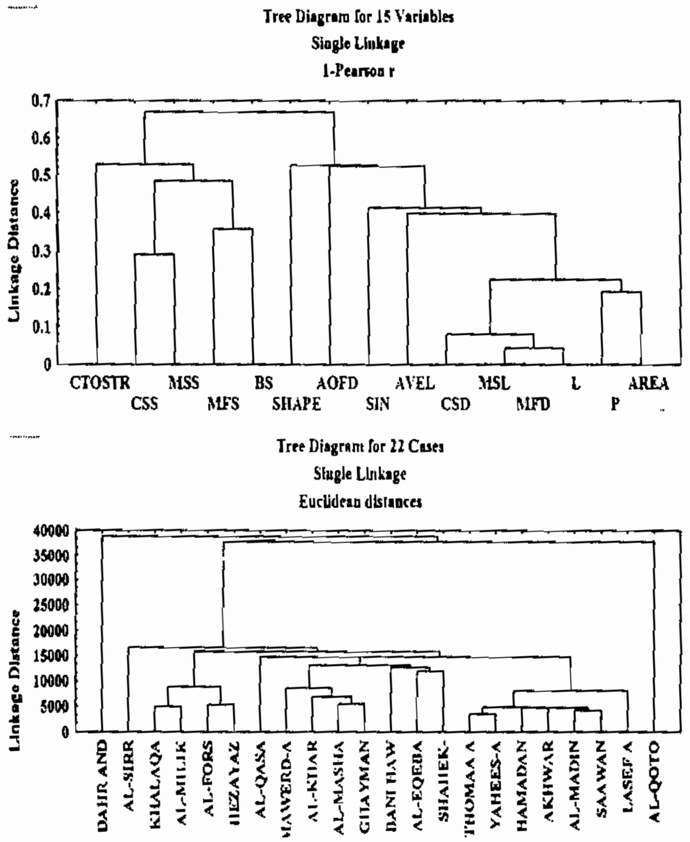


Figure 8: The R-mode dendrogram between different hydro-morphological parameters (upper graph) and Q-mode dedrogram between 22 sub-basins in SB (Lower graph)

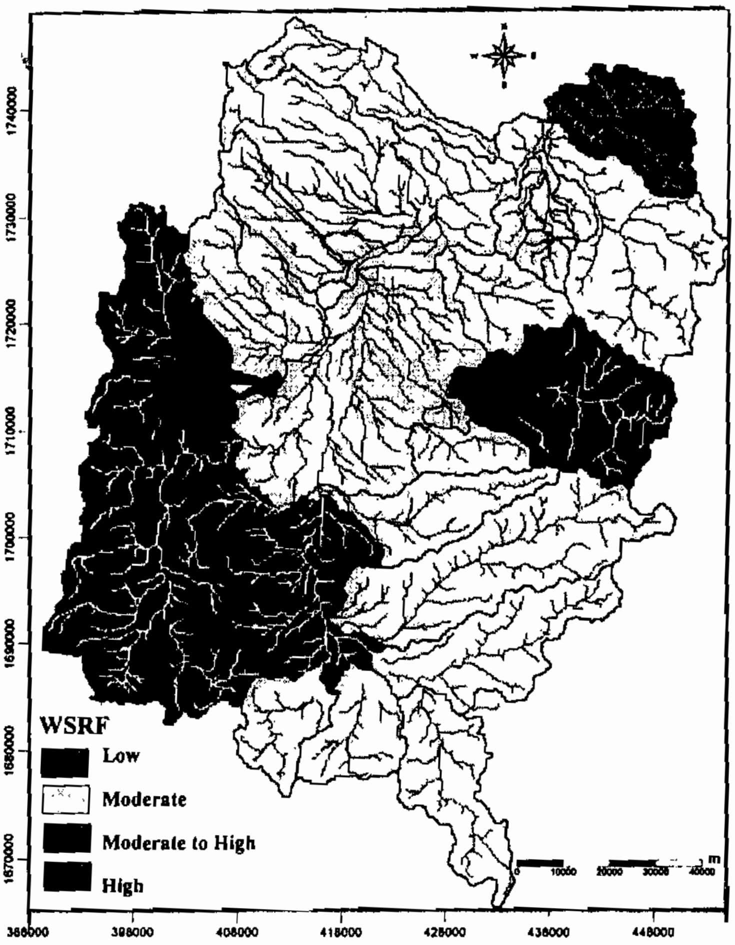


Figure 9: The flash flood risk categories of the 22 studied sub-basins in SB depending on WSRF for the seven tested hydro-morphological parameters

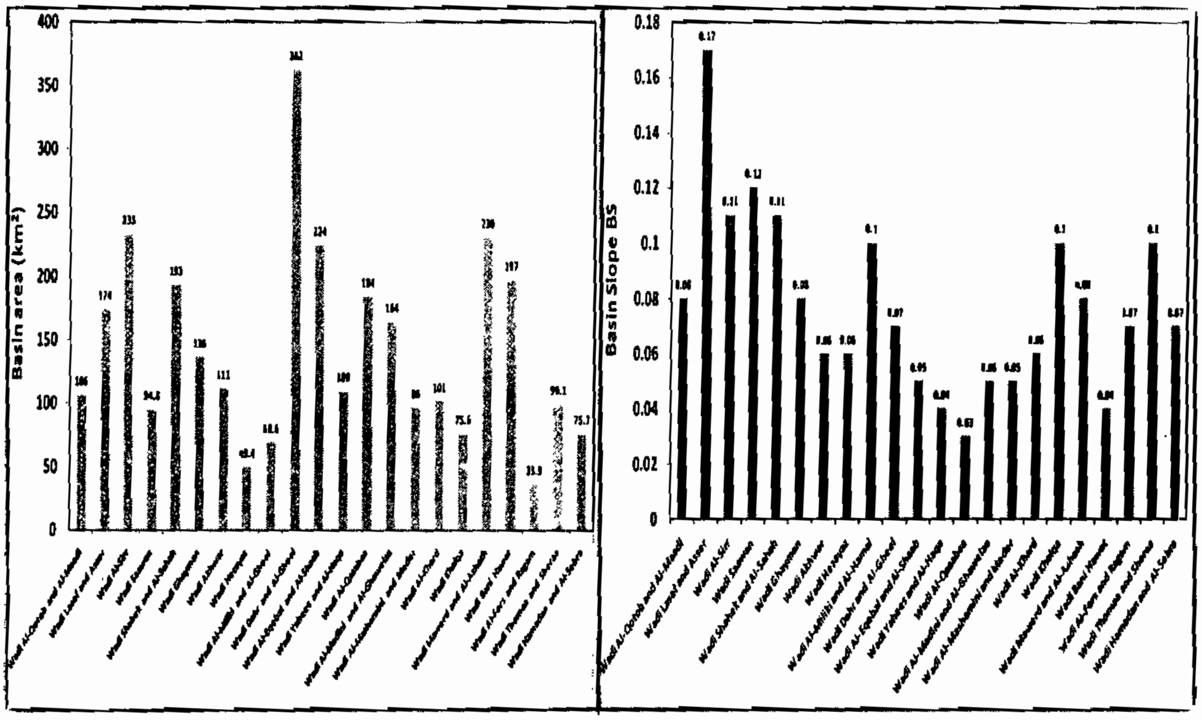


Figure 10: Drainage areas (left chart) and basin slope (right chart) parameters of the tested sub-basins in SB

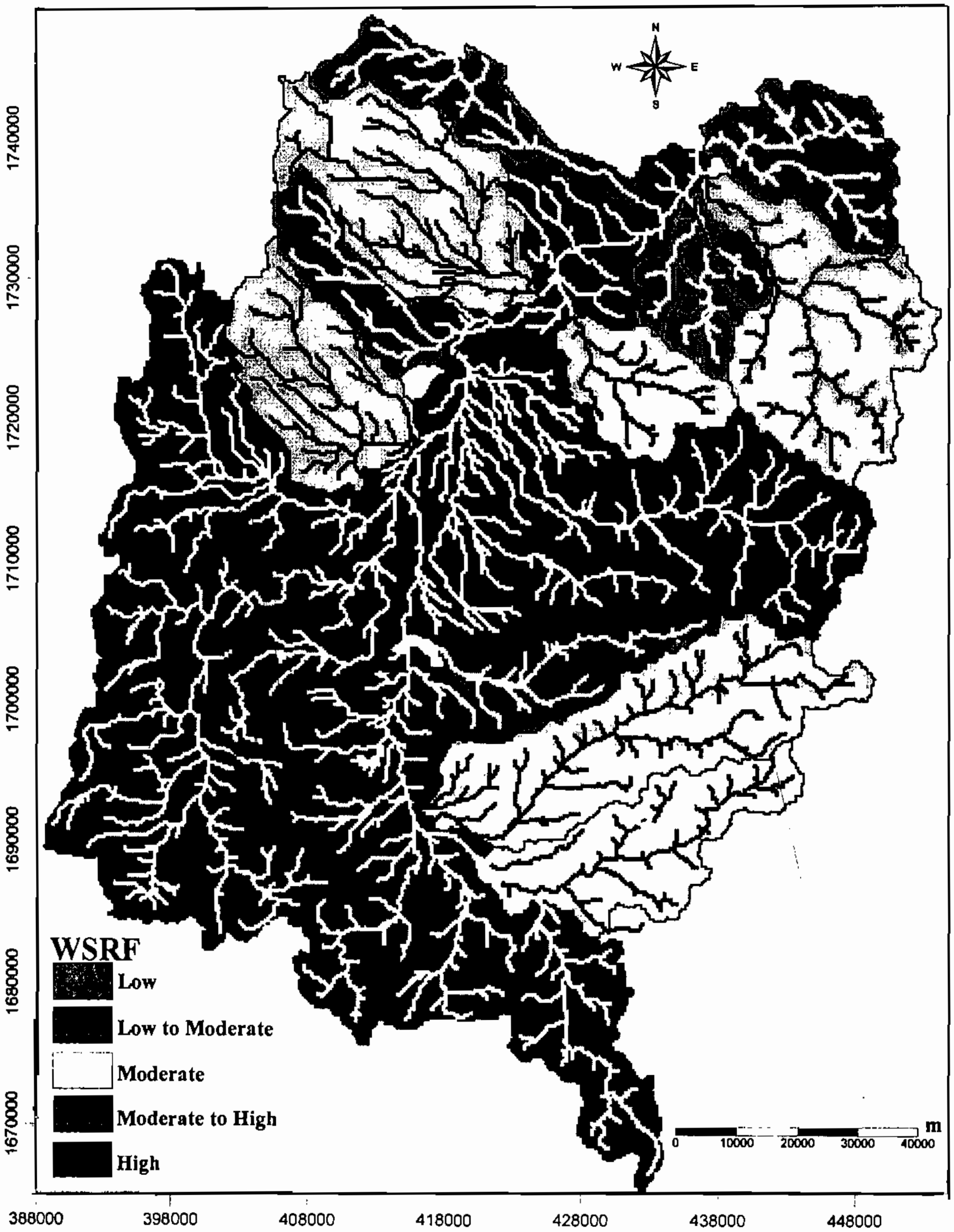


Figure 11: Flash flood risk categories of the 22 studied sub-basins in SB depending on the reevaluated WSRF for the seven tested hydro-morphological parameters

Table 1: Recurrence period and probability of exceedance for maximum daily rainfall (2007)

Date of record	Max daily Rainfall (mm)	Max. daily rainfall (descending)	Rank (m)	Recurrence period (T) (year)	Probability of exceedance (%)
2/12/2007	[illegible]	7.6	1	15	7
2/13/2007	[illegible]	5.6	2	7.5	13
2/17/2007	2.2	4.6	3	5	20
2/19/2007	[illegible]	4.4	4	3.75	27
3/7/2007	0.2	4	5	3	33
3/23/2007	1.2	2.8	6	2.5	40
3/24/2007	[illegible]	2.4	7	2	47
3/26/2007	2.4	2.2	8	1.88	53
3/27/2007	[illegible]	1.6	9	1.67	60
3/29/2007	1.2	1.2	10	1.5	67
3/30/2007	[illegible]	1	11	1.36	73
4/5/2007	0.6	0.6	12	1.25	80
4/6/2007	[illegible]	0.4	13	1.15	87
4/10/2007	7.6	0.2	14	1.07	94

Table 2: The drainage characteristics of terrain surfaces of the 22 sub-basins in SB

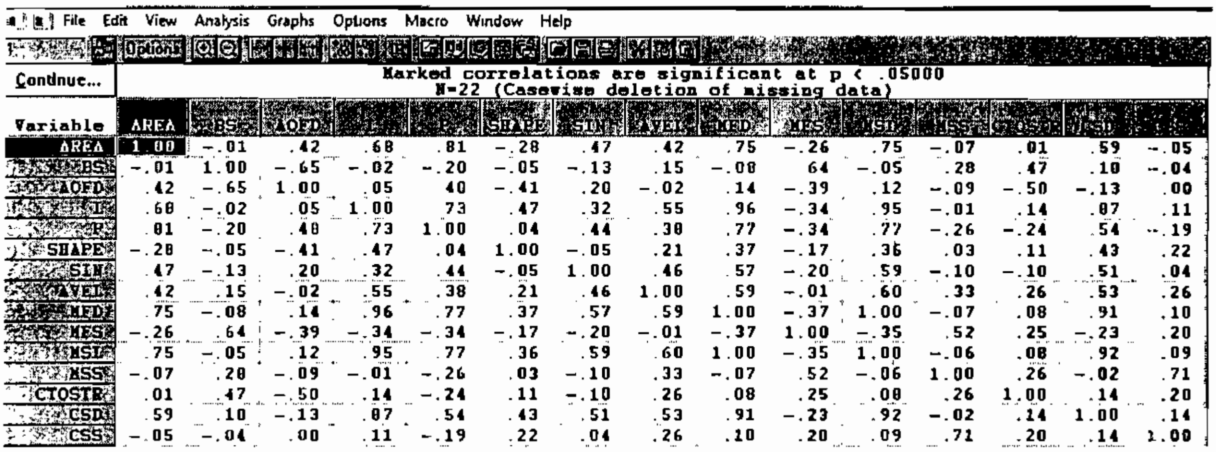
S.N	Sub-basin Name	A	BS	AOFD	L	P	Shape	SIN	AVEL	MFD	MFS	MSL	MSS	CTOSTR	CSD	CSS
1	Al-Qolob and Al-Majdi	106	0.08	796	15760	0	2.06	1.06	2188	17181	0.02	15594	0.02	1136	[illegible]	0.0165
2	[illegible]	174	0.07	761	16900	74611	1.64	1.08	2438	19959	0.06	18304	0.03	1136	[illegible]	0.0153
3	[illegible]	233	0.1	835	29935	1E+05	5.85	1.28	2434	39883	0.02	38276	0.01	401.6	[illegible]	0.0075
4	Salwah	94.8	0.12	859	21934	67330	5.08	1.09	2506	25543	0.03	23839	0.02	602.5	[illegible]	0.0138
5	Shahik and Al-Sahah	193	0.1	778	30588	97689	[illegible]	1.08	2619	35075	0.03	33136	0.02	1136	[illegible]	0.0104
6	[illegible]	136	0.08	763	25058	88549	[illegible]	1.14	2515	30432	0.02	28493	0.01	1004	15500	0.0106
7	[illegible]	111	0.06	895	19978	66126	[illegible]	1.11	2520	25142	0.03	22046	0.01	1136	[illegible]	0.0099
8	[illegible]	49.4	0.06	823	[illegible]	42503	2.46	1.14	2425	14300	0.02	12527	0.01	0	[illegible]	0.0075
9	Al-Miliki and Al-Hamal	68.6	[illegible]	832	[illegible]	49952	2.83	1.19	2564	17948	0.03	16576	0.02	568	[illegible]	0.0117
10	Dahr and Al-Ghayl	362	0.07	942	30109	1E+05	[illegible]	1.38	2652	43362	0.01	41658	0.01	635	[illegible]	0.0144
11	Al-Iqbal and Al-Shaabe	224	0.05	956	[illegible]	1E+05	2.39	1.32	2451	32734	0.01	30441	0.01	200.8	[illegible]	0.0109
12	Yahees and Al-Huqqah	109	0.05	971	18038	67196	2.99	1.07	2355	21877	0.02	19370	0.02	284	[illegible]	0.0124
13	Al-Qasabah	184	0.04	1058	[illegible]	1E+05	[illegible]	1.05	2290	21761	0.02	19586	0.01	0	[illegible]	0.0097
14	Al-Madini and Al-Gholah	164	0.05	958	22181	70938	3.01	1.12	2472	27401	0.03	24776	0.03	284	[illegible]	0.0298
15	Al-Mashamin and Madar	96	0.05	783	26178	83682	[illegible]	1.11	2471	31149	0.02	29494	0.02	200.8	[illegible]	0.0167
16	Al-Kharid	101	0.06	844	23371	93461	5.39	1.07	2152	28424	0.01	25064	0.01	401.6	23125	0.0095
17	Khalaqa	75.6	0.1	813	13312	51082	2.34	0.98	2125	14742	0.04	13087	0.01	284	[illegible]	0.0014
18	Mawrid and Al-Ashash	230	0.08	937	18599	99216	[illegible]	1.28	2382	25659	0.02	23838	0.01	284	10145	0.0033
19	Bani Hawat	197	[illegible]	955	[illegible]	1E+05	[illegible]	1.16	2264	26749	0.02	24859	0.02	284	[illegible]	0.0042
20	Al-Foros and Rijam	35.9	0.07	829	16310	37405	[illegible]	1.09	2107	14281	0.03	12341	0.01	803.3	[illegible]	0.0147
21	Thumal and Sheraa	99.1	[illegible]	834	16190	65252	2.65	1.12	2238	19902	0.03	18129	0.01	0	[illegible]	0.0104
22	Hamadan and Al-Sehra	75.7	0.07	850	[illegible]	72434	[illegible]	1.45	2463	28725	0.03	26737	0.02	568	13065	0.0157

A is Basin Area (km^2), BS is Basin Slope, AOFD is Average Overland Flow (m), L is Basin Length (km), P is Basin Perimeter (m), Shape is Basin Shape Factor, SIN is Basin Sinuosity Factor, AVEL is Mean Basin Elevation (m), MFD is Basin Max Flow Distance (m), MFS is Basin Max Flow Slope, MSL is Basin Max Stream Length (m), MSS is Basin Max Stream Slope, CTOSTR is Basin Distance From Centroid To Stream (m), CSD is Basin Centroid Stream Distance (m), and CSS is Basin Centroid Stream Slope (km).

Table 3: Descriptive statistics of the 15 hydro-morphological parameters of the 22 sub-basins in SB

Parameter	Valid N	Mean	Minimum	Maximum	Std. Deviation
AREA	22	141.82	35.9	362	[illegible]
BS	22	0.08	0.03	0.2	0.03
AOFD	22	866.90	760.85	1058.0	[illegible]
L	22	20233.64	11028.51	30587.0	[illegible]
P	22	78717.36	0.00	149862.1	[illegible]
SHAPE	22	3.33	1.50	7.3	[illegible]
SIN	22	1.15	0.98	1.5	[illegible]
AVEL	22	2392.21	2107.27	2651.6	[illegible]
MFD	22	25555.83	14280.73	43361.7	[illegible]
MFS	22	0.02	0.01	0.1	0.01
MSL	22	23553.31	12341.40	41657.7	[illegible]
MSS	22	0.02	0.01	0.0	0.01
CTOSTR	22	515.90	0.00	1136.0	389.02
CSD	22	12503.39	3277.24	25269.1	[illegible]
CSS	22	0.01	0.00	0.00	0.01

Table 4: The correlation matrix of 15 hydro-morphological parameters applying STATISTICA



Marked correlations are significant at p < .05000
N=22 (Casewise deletion of missing data)

Variable	AREA	BS	AOFD	L	P	SHAPE	SIN	AVEL	MFD	MES	MSL	MSS	CTOSTR	CSD	CSS
AREA	1.00	-.01	.42	.68	.81	-.28	.47	.42	.75	-.26	.75	-.07	.01	.59	-.05
BS	-.01	1.00	-.65	-.02	-.20	-.05	-.13	.15	-.08	64	-.05	.28	.47	.10	-.04
AOFD	.42	-.65	1.00	.05	40	-.41	.20	-.02	.14	-.39	.12	-.09	-.50	-.13	.00
L	.68	-.02	.05	1.00	73	.47	.32	.55	.96	-.34	.95	-.01	.14	.07	.11
P	.81	-.20	.48	.73	1.00	.04	.44	.38	.77	-.34	.77	-.26	-.24	.54	-.19
SHAPE	-.28	-.05	-.41	.47	.04	1.00	-.05	.21	.37	-.17	.36	.03	.11	.43	.22
SIN	.47	-.13	.20	.32	.44	-.05	1.00	.46	.57	-.20	.59	-.10	-.10	.51	.04
AVEL	.42	.15	-.02	.55	.38	.21	.46	1.00	.59	-.01	.60	.33	.26	.53	.26
MFD	.75	-.08	.14	.96	.77	.37	.57	.59	1.00	-.37	1.00	-.07	.08	.91	.10
MES	-.26	.64	-.39	-.34	-.34	-.17	-.20	-.01	-.37	1.00	-.35	.52	.25	-.23	.20
MSL	.75	-.05	.12	.95	.77	.36	.59	.60	1.00	-.35	1.00	-.06	.08	.92	.09
MSS	-.07	.28	-.09	-.01	-.26	.03	-.10	.33	-.07	.52	-.06	1.00	.26	-.02	.71
CTOSTR	.01	.47	-.50	.14	-.24	.11	-.10	.26	.08	.25	.08	.26	1.00	.14	.20
CSD	.59	.10	-.13	.07	.54	.43	.51	.53	.91	-.23	.92	-.02	.14	1.00	.14
CSS	-.05	-.04	.00	.11	-.19	.22	.04	.26	.10	.20	.09	.71	.20	.14	1.00

Table 5: The results of Multi Criteria Analysis (MCA) of SB sub-basins

S.N	Sub-basin Name	A SRF	D SRF	BS SRF	Rr SRF	AOFD SRF	Shape SRF	Sin SRF	WSR
1	Al-Qotoh and Al-M[illegible]adi	0.21	0.48	0.36	0.17	0.12	Min	0.10	L-M
2	Lasel and Asser	0.42	0.45	Max	0.21	Min	0.05	0.02	M
3	Al Sir	0.60	Min	0.57	0.64	0.25	0.17	0.41	M-H
4	Sa'wan	0.18	0.24	0.64	0.23	0.33	0.09	0.62	M
5	Shahik and Al Sahah	0.48	0.03	0.57	0.21	0.06	0.17	0.58	M
6	Chayman	0.31	0.14	0.36	0.54	0.01	0.15	0.53	M
7	Akhwar	0.23	0.33	0.21	0.28	0.45	0.12	0.35	M
8	Hizyaz	0.04	Max	0.21	0.34	0.21	0.05	0.17	M
9	Al-Milki and Al-Hamal	0.10	0.74	0.50	0.45	0.24	0.08	0.23	M
10	Dahi and Al-[illegible]	Max	0.05	0.29	0.85	0.61	0.36	0.17	M-H
11	Al-Iqbal and Al-Shaah	0.58	0.18	0.14	0.72	0.66	0.33	0.15	M-H
12	Yahees and Al-Huqqah	0.22	0.36	0.07	0.19	0.71	0.20	0.26	M
13	Al-Qasabah	0.45	0.30	Min	0.15	Max	0.21	0.07	M
14	Al-Madini and Al-Ghulah	0.39	0.22	0.14	0.30	0.66	0.30	0.26	M
15	Al-Mashamin and Madan	0.18	0.09	0.14	0.28	0.07	0.35	Max	M
16	Al Kharab	0.20	0.08	0.21	0.19	0.28	0.33	0.67	M
17	Khalaqa	0.12	0.57	0.50	Min	0.18	0.14	0.14	M
18	Mawrid and Al-Ashath	0.60	0.34	0.36	0.64	0.59	0.39	Min	M-H
19	Bani Hawat	0.49	0.18	0.07	0.58	0.65	0.41	0.14	M
20	Al-Rut and Rijam	Min	0.76	0.29	0.23	0.23	0.21	0.36	M
21	Thumah and Sheraa	0.19	0.41	0.50	0.30	0.25	0.47	0.20	M
22	Hamadan and Al-Sebra	0.12	0.38	0.29	Max	0.30	Max	0.51	H

H = High, M-H = Moderate to High, M =Moderate, L-M = Low to Moderate