WATER HARVESTING USING MORPHOMETRIC ANALYSIS AND GIS TECHNIQUES: A CASE STUDY OF THE HRH TASNEEM BINT GHAZI FOR TECHNOLOGY RESEARCH STATION

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ABSTRACT:

In HRH Tasneem Bint Ghazi for technology research station, there is an urgent need to manage and utilize the water resources in order to comply with the immediate and projected water demand in the study area. Water harvesting is a national priority as water supplies are being depleted by intensive pumping. The color aerial photographs, topographic maps are being used with GIS techniques as a research tools for these mapping requirements in the study area. The topographic data preparation started in delineation the major basin and sub-basins in the study area. The total resulting areas of 89 sub-basins were delineated. Strahler’s technique is used to map these sub-basins, and resulted in a detailed morphometric analysis. From the results of the morphometric drainage analysis, there is a recent rejuvenation of a mature valley. As a result, the stream has incised its channel especially in third and fourth stream orders, which exhibit sheet erosion and severe headwords erosion progress upstream, and a youthful valley has been formed within the older mature valley. Loss of topsoil can reduce site productivity and increase sediment in our waterways, often producing degradation of water quality and increase sedimentation of the proposed reservoirs. The whole watershed major area was overlaid by drainage pattern and topographic map layers using GIS software to divide the whole basin into five major drainage basins and delineate the sub-basins in each region. The total resulting areas of 89 sub-basins were measured. As a result, furthermore, the whole major basin was overlaid by water precipitation layer using GIS software to measure the initial volume of water at each sub-basin. As a result, nested flow-chart relating stream discharge to basin area was developed, and one practical use is that it enables the hydrologist to estimate mean discharge at any point in the system by measuring the watershed area lying above that point. Such knowledge would be essential in designing irrigation diversions in the study area.

STUDY AREA

The basin used in this study is the drainage area of the Wadi Umm AL-Qutffa ephemeral stream, a small catchment's of 6 Km^2 which extends from 550,000 N to 552,500 N and from 368,000 E to 373,500 E located in the western part of the Jordan (Figure 1).

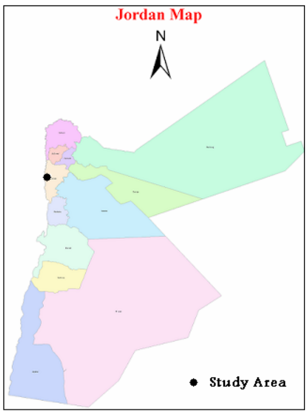

Figure 1: Location map of the study area

The catchment's has an elongated and asymmetrical shape (elongation rate 0.36, mark relief over 38 percent of the area has slopes steeper than 35˚, 36 percent of the area has slopes "Between" 6-34 and 26 percent of the area has slopes between 1-5). The study area includes major segments of two physiographic provinces, the Jordan Rift and Hilly Terrain. The first terrain system comprises part of the Jordan Rift, 200 m below sea level. This is a tectonic depression filled by Upper Tertiary and Quaternary deposits (such as Lacustrine Marl, the alluvial fan deposits of the Pleistocene age, and the recent fluvial deposits related to the river Jordan and its tributaries). The second terrain system comprises a hilly terrain reaching up to 337.85 m in elevation (Figure 2).

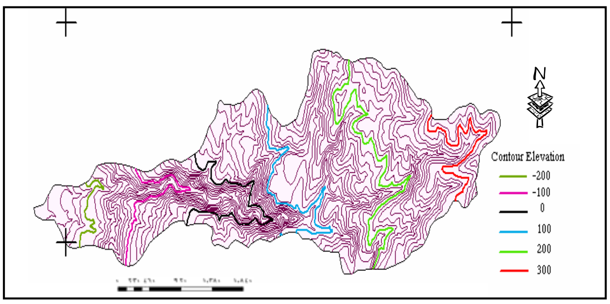

Figure 2: Topographic map of the study area

The climate of the hilly terrain area is different from that of the Jordan Rift (i-e., Ghor area) (Table 1).

Rain fall				Month				Annual
Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Dafali	23	28.2	156.2	68.6	140.6	135.6	29.4	581.6
Bee	22.8	27	155.4	68.4	134	128.2	28.6	564.4
Green House	22	26	150.8	66.2	128	124	27.6	544.6
Date Palm	21.8	25.6	152.6	65.6	118	118.4	26.6	528.4
Mintar	21	25	147.6	65.6	113.2	114.6	22.2	512.2

Table 1: The average precipitation (mm) for the study area (2002/2003)

Vegetation is varied due to the climatic variations. Cereal crops are grown in thick soil areas (Ghor area). On the rain-fed areas scanty trees and shrubs are grown. Irrigation is needed in the hilly terrain and Jordan Rift areas, especially on the western part of the study area.

STATEMENT OF OBJECTIVES

The study has three major objectives:
1. To generate thematic maps of various natural resources.
2. To integrate the thematic maps through the GIS software ArcGIS.
3. To compute the water harvesting at each sub-basin area and the total water harvesting in Wadi Umm AL-Qutffa Basin.

METHODOLOGY

The major goal of this study is to develop a viable methodology for producing GIS data model for preliminary location of water-lock and water-storage at the end of each sub-basin, using ArcGIS. In this way, efficient management of irrigation water can be suggested using mapping information of the command area by developing water harvesting at each sub-basin area. The approach adopted in this study has therefore the following steps illustrated in Figure 3.

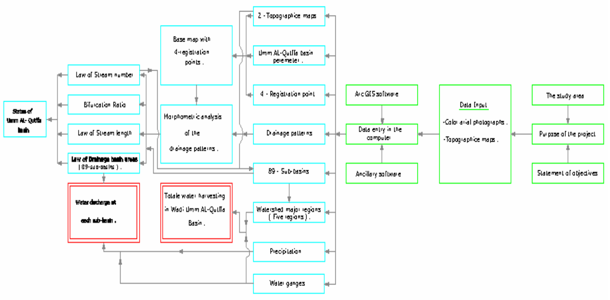

Figure 3: Flowchart illustrating the methodology adopted in the study

MANUAL DELINEATION OF DRAINAGE NETWORK

Traditional, manual methods of delineating drainage networks require questions related to the scale of the work, sources of information, and the techniques available to be taken into consideration before selecting the most appropriate method. Difficulties can appear when delineating first-order channels, as some criteria must be established to discriminate between gullies and real channels (Gardiner, 1975; Zavoianu, 1985). While for small scales the method of “blue lines“(printed stream networks on topographic maps) can be appropriate, for detailed scales it is convenient to complete the network by adding small valleys, whose presence is indicated by crenulations in the contour lines (Mark, 1983). Errors arise whatever method is used to manually delineate drainage networks because the exact representation of the network is never possible. However, as observed by author, photo interpretation of large scale stereoscopic pairs combined with fieldwork leads to more accurate delineation. The network of the Wadi Umm AL-Qutffa catchment's was drawn from photo interpretation of 1: 5,000 scale color aerial photographs combined with fieldwork. Subsequently, the network was transposed onto a topographical map at 1: 5,000 scales in order to help compute watershed parameters. The criterion used to define first-order channels was that they have channel morphology and a length of over 100m. This length was proposed by the author after he had studied the very high density of channels in the upper reaches of the basin as the most suitable for this catchment for identifying small tributaries. The use of a short length for first-order channel detection guarantees detailed and reliable network delineation, as shown in Figure 4. The Umm AL-Qutffa network as interpreted manually by the author represents the real, present-day drainage network. The channels are becoming entrenched in their own sediments and the network is well organized.

MORPHOMETRIC ANAYSIS OF THE DRAINAGE BASINS

Strahler’s system of stream analysis is probably the simplest and most used system. His stream ordering method is given below: Each finger-tip channel is designated as a segment of the first order. At the junction of any two first-order segments , a channel of the second order is produced and extends down to the point where it joins another second order channel , whereupon a segment of third order results , and so forth .

However, should a segment of the first order join a second or third order segment, no increase in order occur at that point of junction? The trunk stream of any watershed bears the highest order number of the entire system. Channel of the first and second order usually carry flowing streams only in the wet weather. In the area under consideration, Strahler's method of stream ordering is used , it follows that the trunk stream of the Umm AL-Qutffa basin, through which all the discharge of the basin finds its outlet, is the stream segment of the highest order. In fact, the drainage basin itself is designated after the highest order stream segment that it contains, plus numerous fourth, third, second and first order segments, is referred to as a fifth order drainage basin (Figure 4).

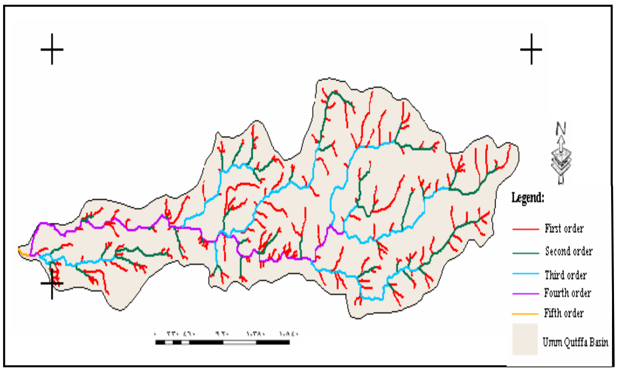

Figure 4: Drainage pattern map of Wadi Umm Al-Qutffa Basin

SREAM ORDERS

In a carefully surveyed, large-scale map of a single drainage basin in the Wadi Umm AL-Qutffa was made. All stream segments were assigned orders (Figure 4). The number of segments of each order was then counted to yield the figures in Table (2).

Stream order	Stream numbers	Bifurcation ratio
1	334	
		4.64
2	72	
		5.5
3	13	
		3.25
4	4	
		4
5	1	
Average Bifurcation Ratio =		4.347

Table 2: Stream order in Wadi Umm Al-Qutffa Basin

In the example from the Wadi Umm AL-Qutffa basin, the author computes the bifurcation ratio (i-e; this is a relationship between the number of streams of one order and those of the next higher order. It is obtained by dividing the number of streams in one order by the number in the next highest order). There are just 4.64 times as many first order segments as second order; 5.5 times as many second order segments as third order ; 3.25 times as many third order as forth order, and just 4 times as many fourth order as fifth order . The differences in these bifurcation ratios can be attributed to chance variations in the shape of any stream network. An average of the four bifurcation ratio is close to 4.347 which is good representative value for the series. Studies of manage stream networks confirm the principle that in a region of uniform climate, rock type, and uniform history of geologic development, the bifurcation ratio tends to remain constant from one order to the next, hence that a single ratio characterize the entire networks. Commonly the values of bifurcation ratio fall between three and five are characteristics of natural stream systems (Strahler, 1975). Rarely is the theoretical minimum possible value of two approached. In the area under consideration, except for the bifurcation ratio between second and third stream order is higher than five, whereas the rest three bifurcation ratios are within the natural stream systems. This exceptional case (i-e., 5.5) is most probably due to recent rejuvenation or structural controlled in the area which leads to the allometric growth in the number of the second stream order. There follows from observation a law of stream number (i-e., the law of stream number states that the number of streams of different orders in a drainage basin tends closely to approximate an inverse geometric series in which the first term is the number of streams of order one). Figure (5) shows the data of Table (2) plotted on such a graph know as semi logarithmic plot. Except for the second and third order segments, all points fall on a remarkably straight course. This is good evidence that the second and third order segments are structurally controlled. The general trend of the third stream order is directed towards N 80˚ E – S 80˚ W, which announce the trace of the general orientation dip joins in the underlying bedrock. Referring again to the drainage network map Figure (4), it is apparent that the first order channel segments have, on the average, the shortest length, and that segments become longer as order increases. The law of stream length states that: "the average lengths of the streams of each of the different order in a basin closely approximate a direct geometric series in which the first term is the average length of streams of the first order".

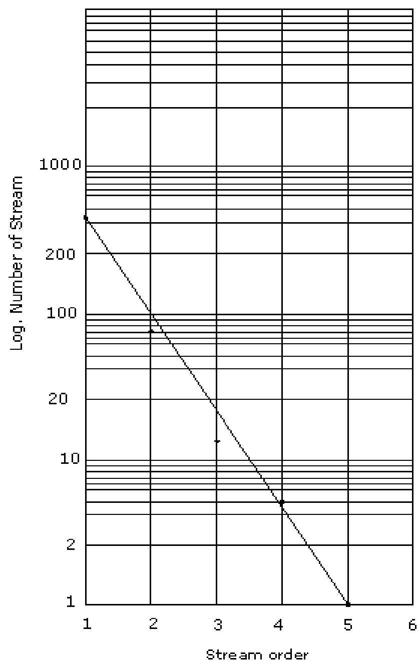

Figure 5: Log number of streams versus stream order.

Table (3) gives measurements of stream order, mean length of streams (km), cumulative mean length (km) and length ratio for the Wadi Umm Al-Qutffa basin.

Stream Order	Mean Length of Streams (km)	Cumulative Mean Length (km)	Length Ratio
1	0.097	0.097	
			1.74
2	0.169	0.266	
			4.39
3	0.742	1.008	
			0.88
4	0.653	1.661	
			6.62
5	4.329	5.99	
Average Length Ratio =			3.4

Table 3: Mean and Cumulative Mean length of Streams (km) In Wadi Umm Al-Qutffa Basin.

The mean length of stream segments, in kilometers, increases by a ratio of roughly three times with each increase in stream order (Strahler, 1975). This proportion of length increase is known as the length ratio, and tends to be approximately constant for a given drainage system. Chance variations to be expected in the configuration of any drainage system will produce inequalities of observed length ration from one order to the next. In the case of the Wadi Umm Al-Qutffa basin data in Table (3) and Figure (6), points for order one, two and five lie very close to the fitted straight line, whereas the points for order three and four deviates substantially. Notice the mean lengths and length ratio; differ greatly from one order to the next within the same basin. This fact leads to the conclusion the segments of stream system cover a wide range dimension of structural and lithological control and especially in the segments of order three and order four.

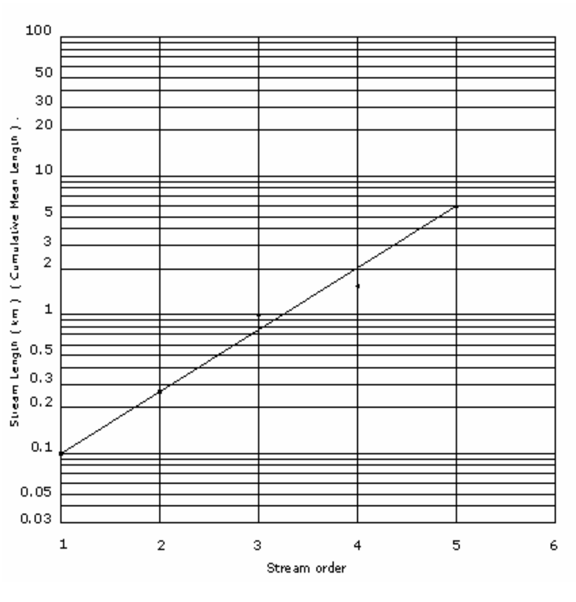

Figure 6: Stream length (km) (cumulative mean length) versus stream order.

DRAINAGE PERIMETER OF UMM AL-QUTFFA BASIN AND SUB-BASINS

The fundamental unit of virtually all watershed and fluvial investigations is the drainage basin (catchment or watershed) is a finite area whose runoff is channeled through a single out let (Zavoianu, I, 1985). In it is simplest form; a drainage basin is an area that funnels all runoff to the mouth of Wadi Umm Al-Qutffa Basin. Drainage perimeter of Umm Al-Qutffa Basin was delineated on two topographic maps at scale (1: 5,000) by tracing their perimeters or drainage divides. A drainage divide is simply a ridgeline on either side of which water flows to different streams (Jarvis, R.S., 1977). Therefore, we can begin drawing our perimeter line by tracing its crest. Ridges are most easily recognized as a series of bent contour lines which are apex point downhill. Choosing the correct ridge is simply a matter of determining which ridge sheds water into the Wadi Umm Al-Qutffa Basin. The whole major basin was overlaid by drainage pattern and the topographic data thematic layers using GIS software to divide the whole basin into five regions and to delineate the sub-basin in each region. The total resulting area of 89 sub-basins was delineated in Figure (7).

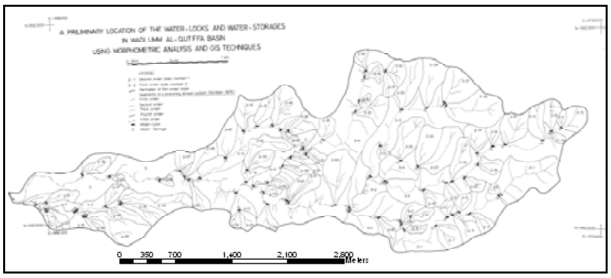

Figure 7: 89 sub- basins where delineated in Wadi Umm Al-Qutffa basin.

Turning next to the areas of drainage basins, we can study the relationship between average area of the sub-basin of a given order and the order itself. The law of drainage basin areas state that the mean drainage basin areas of streams of different orders tend closely to approximate a direct geometric series in which the first term is the mean area of the first order basins (Strahlers, 1975). Figure (8) shows the data of Table (4) plotted on such a graph know as semi logarithmic plot. Except for the third and fourth order basins, all points fall on remarkably straight course.

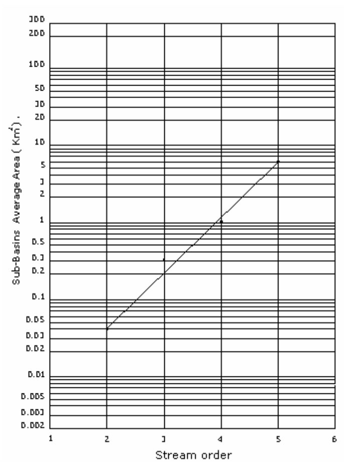

Figure 8: Sub- basins average area (km^2) versus stream order.

Stream Orders	Total Number of Stream	Total Sub-Basin Area (km2)	Average Sub-Basin Area (km2)
2	72	2.966	0.041
3	13	4.188	0.322
4	4	4.095	1.023
5	1	6.004	6.004

Table 4: Average Area of Stream Sub-Basins (2, 3, 4, and 5).

This observation is a good result that agrees with the previous results (i-e., log. number of streams versus stream order and cumulative mean length versus stream order). Figure (9) shows a nested group of sub-basins of orders 2, 3 and 4. There are 72 basins of second-order; 13 basins of third-order, and 4 basins of fourth-order. The second order basins are shown to contribute to a stream channel of the third-orders. The third order basins are shown to contribute to a stream channel of the fourth-orders. The total 89-basins are shown to contribute to a stream channel of the fifth order (i-e., Umm Al-Qutffa Basin). In practice, it is only required that a single perimeter be located for a basin of a given order, and that area can be measured with using popular computer programs like GIS software Arc GIS.

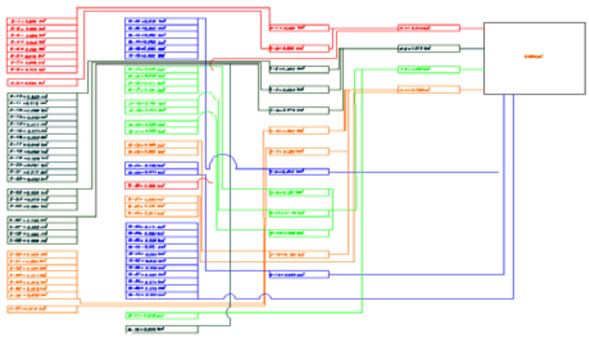

Figure 9: Flowchart shows a nested group of 8 sub- basins of stream orders in Umm Al-Qutffa Basin.

WATER HARVESTING

In Wadi Umm Al-Qutffa Basin, there is an urgent need to manage and utilize the water resources in order to comply with the immediate and projected water demand in the HRH Tasneem Bint Ghazi for Technology Research Station. Water harvesting is a national priority as water supplies are being depleted by intensive pumping. The main concern is to optimize the utilization of the ground water resources and to protect them against depletion and pollution. For this reason it is necessary to map in detail the hydrogeology of the aquifers. The color aerial photographs are being used with GIS techniques as a research tools for these mapping requirements in Wadi Umm Al-Qutffa Basin. The topographic data preparation started in delineation the major basin and sub-basins in the study area (Figure 7). The resulting area of 89 sub-basins were measured (Figure 9) and further overlaid by precipitation layer using GIS software to measure the initial volume of water at each sub-basins. Therefore, the water harvesting at the end of each sub-basin can be collected by locating water-locked and further down water storage. In this way, efficient management of irrigation water can be suggested using this recent information of the command area by developing water harvesting at each sub-basin area, and also we can measure the volume of surface water discharge at each sub-region in the main Umm Al-Qutffa Basin.

RESULTS AND DISCUSSION

One of the purposes of fluvial morphometry is to derive information in quantitative form about the geometry of the fluvial system that can be correlated with hydrologic information. In our example in this paper we need further investigations to determine the relationship of stream discharge to area of watershed. Common sense tells us that the discharge of a stream increases with increasing drainage basin area. It remains to be determined what mathematical model applies to such an increase. If stream systems were fitted with gauges at the lower end of each channel segment of each order, the investigation could proceed according to basin areas by order. In practice, gauges are situated at the points on streams at the end of the watershed of the five major regions. Therefore, we can only relate streams discharge to the total contributing area of watershed above the gauge. In another word, the discharge of a stream is a direct logarithmic function of the area of the drainage basin of the stream above the point at which discharge was measured. One practical use of the nested flow-chart relating stream discharge to basin area is that it enables the hydrologist to estimate mean discharge at any point in the system by measuring the watershed area lying above that point. Such knowledge would be essential in designing hydraulic structures, such as dams, bridges and irrigation diversions.

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