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Assessment of Morphometric Characteristics of Wadi Al-Shumar Catchment in Jordan

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Abstract

The Geographic information system and Aster DEM data with 30 m resolution have been used for the derivation of the morphometric parameters of the Al-Shumar watershed in Jordan. It is an area of 330 km^2, and it has seven sub-catchments. The drainage pattern of the watershed shows a dendritic and parallel pattern, with a drainage density value of 1.49 - 1.85 km/km^2. The bifurcation value of the sub-watersheds varies from 2.679 to 4.434, which reveals homogeneous drainage networks that formed on rocks when the influence of geologic structure on the stream network is negligible. The form factor value is near the rectangular shape except for the Al-Shiah and Al-Zarnouk watershed, these values are close to the circular shape and therefore they are vulnerable to flood risk in case of frequent rainfall events. The results are important in understanding the process of rainfall-runoff in Dryland environments and in adaptation of suitable water management practices on the sub-catchment level.

Keywords

River Morphometry, DEM, GIS Analysis, Dryland Regions, Jordan

1. Introduction

The water catchment is a space of ground where its inner water draws toward all lands reaching the lowest point known as drain [1]. A Morphometric characteristic description is the most common technique in basin analysis and it refers to the quantitative evaluation of the earth surface landform [2]. Morphometry is the measurement of the configuration of the earth's surface, shape and landforms dimensions using mathematical models [3]. Studying the morphometric features of catchments is very important; in order to investigate the metric measurements of the water network and hydrological properties of the catchment

[4]. The geologic and climatic properties are considered the most effective agents in determining the fluvial pelvic; therefore, it is important to understand the hydrologic and geologic structures of the basin [5] [6]. It is worth noting that modern practical studies point to the importance of investigating quantitative hydrologic studies to predict the natural hazards that may affect watersheds such as water floods and pollution, in addition to improving effective methods for reducing the environmental damage as well as deducing social and economic losses [7] [8].

Many countries suffer from water scarcity and they concentrate on developing strategies to conserve water in pelvises and catchments in efficient ways [9] [10]. Thus, these countries can draw developmental plans that are suitable to the produced volume of water [11]. Digital elevation models (DEM) are used to derive the morphometric parameters of fluvial pelvic like the characteristics of slope, flow and drainage system [12]. Therefore, managing natural sources and conserving soil from erosion are considered the greatest interests of quantitative studies of draining pelvises [13]. Considering the hydrologic manner of water inside a fluvial pelvic, it should suit human uses of water and the water management system of the watershed management.

In the last years, there have been many geomorphometric analyses of floods, soil erosion, morphotectonic, and limnology [14]-[19]. The development of geographic information systems and space technologies, digital elevation models are now mainly used in geo-morphometric analyses [20] [21] [22]. Spatial analysis technique is used to understand and evaluate the various aerographic shapes that form pelvic conditions and which directly affect the quantitative results of the morphometric features of drainage pelvis [23] [24]. It helps in an Authigenic analysis that is related to pelvic characteristics and the prediction of the hydrological manner of water catchment.

Furthermore, the novelty of this research is taking into consideration the effects of natural characteristics that form the morphometric characteristics of the basin and the influences on the floods' vulnerability in the catchments level [25]. This study aims to derive the morphometric properties of Wadi Al-Shumar using GIS techniques in order to improve the watershed management and maintain the sustainability of natural resources in Jordan.

2. Study Area

Wadi Al-Shumar catchment is located in north of Jordan within Longitude (35˚55'0" - 36˚6'0") E and Latitudes of (32˚20'0" - 32˚42'0") N, with a total area of 330 km^2 as shown in **Figure 1**.

In general, the climate is classified as a semi-arid Mediterranean type with a rainfall amount that does not exceed (350 - 400) mm/year and it is characterized by significant variations within the catchment. Elevation of the catchment ranges from 1018 m in the southern part to 262 m in the northern part.

This difference in topography is reflected on climatic characteristics of the

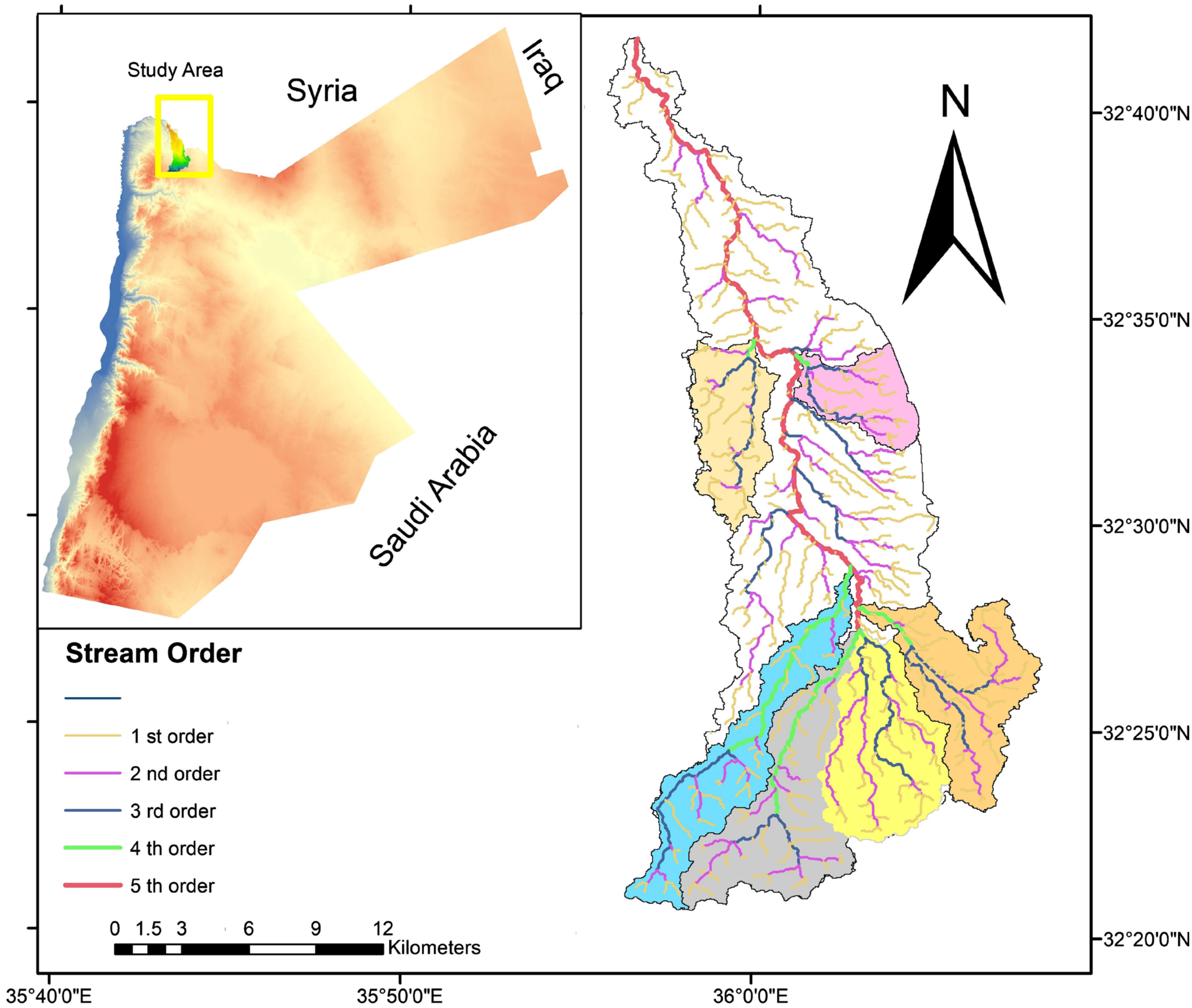

Figure 1. Location map of the Wadi Al-Shumar catchment in Northern Jordan [26].

catchment in the way that the northern part had always received more rainfall than the southern part. Accordingly, the study area is characterized by a great diversity of soil types, biodiversity, and land use pattern and vegetation density.

3. Methods

The statistical analysis of pelvic variables was investigated to describe the relationship between the morphometric variables and the ground surface composition on a sub-catchment basis. This enables understanding the ground constitutions of the water pelvis including pelvis boundary, rock types, geologic constitution, soil types, porosity size and the enforceability of the rock.

The catchment and sub-catchment boundary were delineated based on the topographic maps of 1:25,000 scale, and the DEM derived from Advanced Space Borne Thermal Emission and Reflection (ASTER) images with resolution of 30 m. The hydrologic analysis is processed using GIS to derive the slope degree, aspect, flow direction, drainage density, drainage rank, and the pattern of flow in the catchment. All of these analyses are carried out on the main catchment of Wadi Al-Shumar and its sub-catchments to determine its morphometric and hydrological characteristics.

The spatial characteristics of the morphometric variables of the catchment and sub-catchments are investigated, these include linear, areal and relief aspects. These variables are related to catchment length, total length of waterways, and to the average length of watercourses. In addition, the correlation between the morphometric characteristics of the river drainage catchment and its sub-catchments was investigated using statistical techniques for morphometric variables, which are represented, by the mathematical equations for the linear, areal, and relief parameters. The previous parameters were analyzed according to the equations shown in Table 1.

Detailed description of the related morphological network analysis consists of a number of waterways, length of the watercourses, and the rate of the ratio of

Table 1. The morphometric variables that were measured in this study [22] [27].

	Morphometric parameters	Methods	References
Linear aspects	number of Stream (Nu)	Hierarchical ordering	[28]
	Stream order (u)	Hierarchical Rank	[28]
	Stream length (Lu)	Length of the stream	[29]
	Mean stream length (Lm)	Lm = Lu/Nu	[29]
	Stream length ratio (Rl)	Rl = Lu/L(u-1), where Lu is stream length order u and L(u_1) is stream segment length of the next lower order	[29]
	Bifurcation ratio (Rb)	Rb = Nu/N(u-1), where Nu is number of streams of any given order and N(u-1) is number in the next higher order	[29]
	perimeter (P)	Perimeter of the watershed in (km) measured by GIS	[30]
	Basin length (lb)	Length of watershed (Km) measured by GIS	[29]
Areal aspects	Drainage density (Dd)	Dd = L/A, where L is total stream length, A is area of the watershed	[29]
	Stream frequency (Fs)	Fs = N/A, where N is the total number of streams and A is area of the watershed	[29]
	Drainage texture (Dt)	T = Dd 9 Fs	[31]
	Lemniscate Ratio (K)	k = L2/4A	[31]
	Form factor (Rf)	Ff = A/Lb2	[29]
	Circularity ratio (Rc)	Rc = 4pA/P2	[30]
	Elongation ratio (Re)	Re = 2H(A/p)/Lb, where A is area of the watershed, p is 3.14 and Lb is basin length	[31]
Relief aspects	Basin relief (R)	R = H − h, where H is maximum elevation and h is Minimum elevation within the basin	[31]
	Relief ratio (Rr)	Rr = R/Lb	[32]
	Ruggedness number (Rn)	Rn = R 9 Dd	[33]
	Dissection index (Dis)	Dis = R/Ra, where R = Relative relief and Ra is absolute relief	[34]
	Drainage intensity (Di)	Di = Fs/Dd	[35]

the diffusion, discharge density, river frequency, and the length of water flow. It includes also parametric descriptions of the pelvis constitutions such as semi-calcification, degree of rigidity, pelvic texture, and vertical depth. The total variables consist of semi-flattening, integration coefficient, form factor, semi-rotation, and semi-elongation and elongation ratio.

4. Result and Discussion

The morphometric investigation incorporates measurement and mathematical analysis of the area, altitude, volume, slope, as well as profiles of the land and drainage basin characteristics of the catchment area concerned. The water network of basins is developed because of rock composition, climate determinants and active structural movements under previous and current environments. The differences in the formal patterns of the water network from one sub-catchment to another within the catchment are reflected in the characteristics and values of the morphometric variables of the sub-catchments. The drainage pattern of the watershed shows a dendritic and parallel pattern as given in **Figure 2**, which represents a tree drainage that spreads over the northern, eastern and southern region of the pelvis, and which is mainly associated with the presence of cracks in the catchment.

This section describes the main results of the morphometric variables analysis which includes network patterns, perimeter, catchment length, stream order, number of streams, length of stream, stream length ratio, bifurcation ratio, drainage density, drainage texture, stream frequency, elongation ratio, lemniscate ratio, form factor, basin relief, relief ratio, ruggedness number and dissection index.

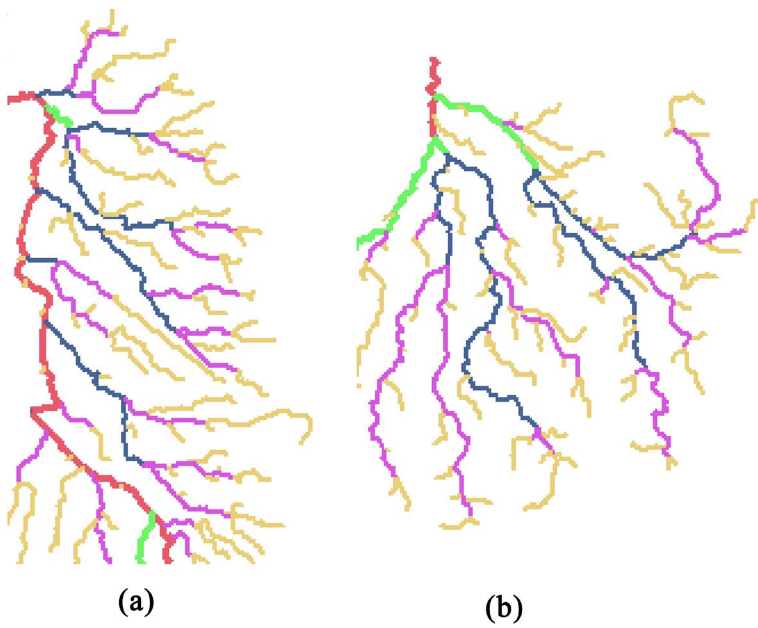

Figure 2. The drainage pattern of the watershed shows a parallel shape (a) and dendritic shape (b) pattern.

4.1. Linear Aspects

Wadi Al-Shumar catchment was divided into seven sub-catchments as given in Figure 3; these are Wadi Al-Shumar, Braiqa, Mashqam, Zarnouk, West of Ramtha, Al-Shiah, and Al-Mashro.

Analysis of the linear aspects in this study includes the Area (A), Perimeter (P), Basin Length (Lb) and the number of stream. Table 2 shows the linear aspects values of the catchments and the sub-catchments. The results show that

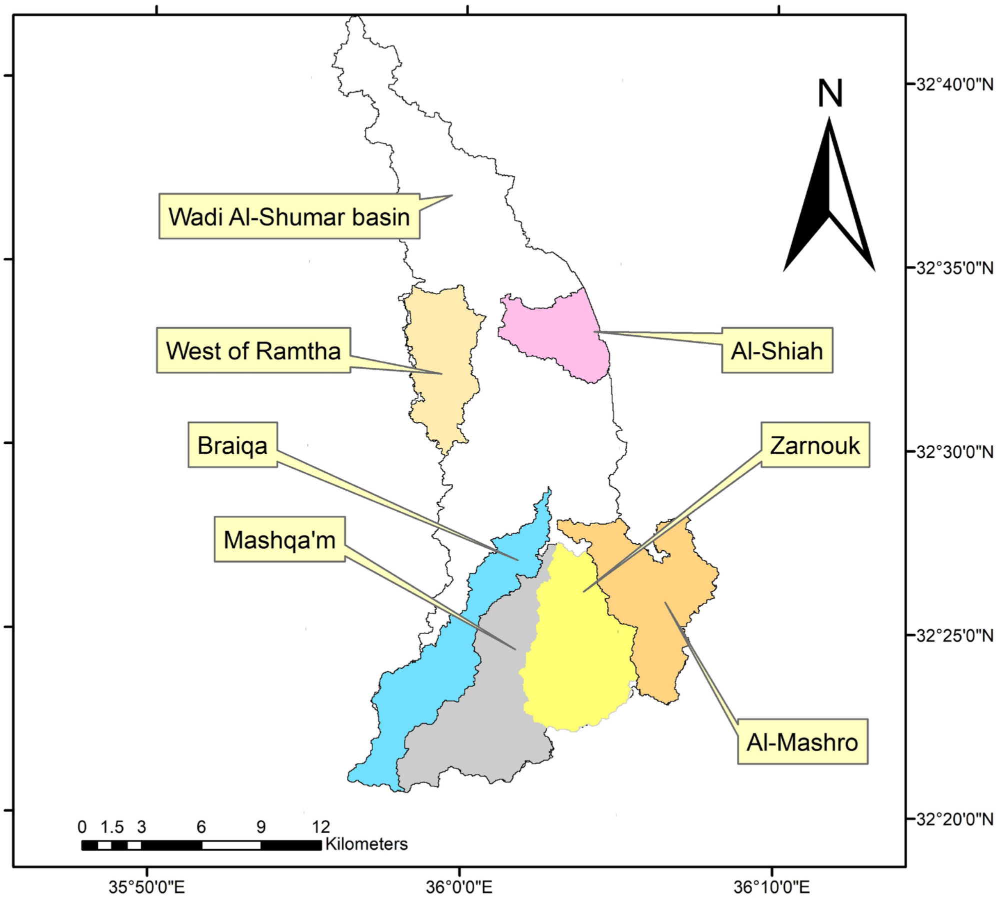

Figure 3. Wadi Al-Shumar main catchment and sub-catchments.

Table 2. The linear aspects values of the catchment and the sub-catchments.

Name of watershed & sub-watershed	Perimeter (p) km	Area (A) Km^2	Basin Length (Lb)	Number of Stream (NU)
Wadi Al-Shumar basin	187.09	329.75	37.6	489
West of Ramtha	38.017	22.536	8.63	40
Al-Shiah	27.122	15.846	6.558	29
Braiqa	67.284	34.014	17.606	49
Mashqa'm	58.301	40.019	11.604	59
Zarnouk	39.64	36.998	9.601	62
Al-Mashro	54.302	34.799	14.665	59

the area of sub-catchments ranges from 15 to 329 km^2, while the perimeter of the sub-catchments ranges from 27 to 187 km. These relationships indicate a significant difference between shape properties on the sub-catchments level. The basin length is the horizontal distance between the upstream and downstream points of the metric basin [33]; in this study, the length of the main valley in Al-Shumar catchment is 37.6 km. On the other hand, the ponds' length for other sub-catchments ranges from 6.5 km in Wadi Al-Shayyah to 14.6 km in Wadi Mashqum sub-catchment.

Stream order and number (Nu) is defined as a measure of the position of a stream in the hierarchy of tributaries. The classifications of streams are being useful indicators of stream size, discharge and drainage area [28]. The concourse of tributaries of the second level cause the formation of a tributary of the third rank, while the tributaries begin to form with each other at the confluence of the small water channels building a higher river tributary than the rank [33]. High number of tributaries in the catchment are attributed to the amount of precipitation and low-vegetation density in the river catchment environment.

The river tributaries are used as a logical indication of the formation related to river tributaries of large river ranks [29]. The analysis of the DEM data of the study area revealed that the total number of river canals of the main study catchment was 489 strands of different ranks, which indicates that the study basin is classified as a fifth level basin. While the number of streams of the first class is 321 tributaries which accounted for 65.6% of the total number of water network ways, it is noticeable that the number of waterways decreases by the river level as shown in Figure 4.

Stream length (Lu) indicates the contributing area of the basin for a given order [29]. The length of stream segments is high for first order streams and decreases as the stream order increases. The total length of the catchment tributaries is 521 Km, with the length of first-class tributaries reaching 8.18 km, the second reaching 0.838 km, the third reaching 4 km and the fourth is 4.67 km, while the fifth is 37.78 km.

The length of the lower stratum is 50.4% of the length of the tributaries, with

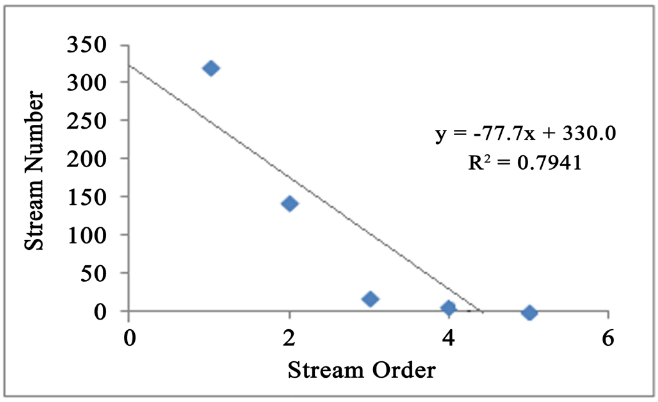

Figure 4. The relationship between the number of streams and stream orders in Al-Shumar catchment.

23% for the third, 13.9% for the fourth, 5.3% for the fifth, and 7.2% for the tributaries. This means that the tributaries of the lower levels are of low length values as shown in **Figure 5**, and they increase with increasing the level of rank that they represent.

Stream length ratio (RL) is the ratio of the average length of the one order to the next lower order of the stream segments [29]. The stream length ratio, among (7) sub-watersheds, varies from 0.456 to 1.384. The fourth-level ponds were between 34 and 1.902. This difference in values explains the change in the falling value of the basins. The analysis shows that the level of relief increases on the southern side of the basin and it decreases as moving towards the northern direction, which leads to an increase in the soil erosion severity in the basin.

Bifurcation ratio (Rb) is defined according to [36] as a ratio of the number of streams of a given order (Nu) to the number of streams of the next higher order (Nu + 1). In this study, the bifurcation ratio fluctuates in Wadi Al-Shumar basin from 2.2 to 7.9, but the average bifurcation ratio (Rbm) is 3.71. On the other hand, the RB ratio of the sub-catchments ranges from 1.56 to 11.5, and the Rbm value ranges between 2.679 and 4.434. According to the above results, one of the fourth-level basins has emerged from narrowing, which has a class value of RBM up to 3 - 5. This means that this time is susceptible to rapid seasonal floods, while other basins are geologically homogenous and are still vertically and horizontally capable of absorbing movements.

Under these conditions, the flash floods, which may suddenly form in arid and semi-arid regions, can be considered as one of the most dangerous geomorphological hazards to human constructions. It forms because of rapid watercourses with a relatively large hierarchical classification, which leads to high soil erosion rate in the basin and a great loss of plant and animal wealth [3].

4.2. Areal Aspects

Analysis of the areal aspects includes the drainage density (Dd), Drainage texture

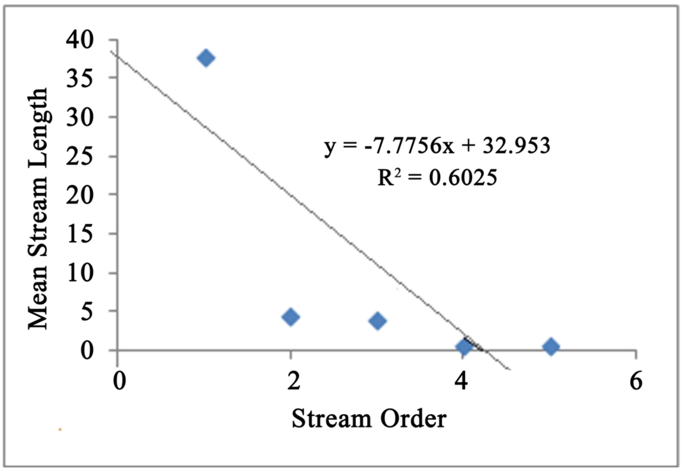

Figure 5. The relationship between the stream lengths and stream orders in Al-Shumar catchment.

(Dt), Stream frequency (Fs), Elongation ratio (Re), Lemniscate Ratio (K), and Form factor (Rf). **Table 3** shows the areal aspects of values of the catchments and the sub-catchments.

The drainage density (Dd) is a measure of total stream length over the total area in a given basin [36]. It is affected by the factors that control the characteristic of watershed length and it is one of the most significant morphometric variables that explains the volume of water flow within the main and sub-tributaries of the basin [37]. Slope factor, soil permeability and resistance of surface materials are the main factors influencing this variable. Kant *et al.* classify the draining density value into three categories, these are, the low, medium and high classes [38]. In this study, the drainage density value of the catchments and sub-catchments ranges between 1.49 and 1.85 as shown in **Table 3**. These values are classified in the low discharge ponds.

The drainage texture (Dt) is the relative spacing of the streams in a unit area along a linear horizontal distance between water tributaries of the basin [31] [39]. It depends on the geological structure, soil types, vegetation cover, relief, infiltration rate and the amount of precipitation in the basin [29] [40].

The value of this variable is explained by the structure and nature of the river sediments that scattered in the estuary. According to Smith's classification, the value of sediment thickness can be summarized as following: Less than 2 corresponds to very rough, 2 - 4 corresponds to rough, 4 - 6 is average roughness, 6-8 is fine, while more than 8 correspond to very fine. In this study, the value of the pelvic texture in Wadi Al-Shumer basin is 2.6, which is classified as rough, while the rest of the sub-basins ranged between 0.73 and 1.56, which were classified as very rough.

Stream frequency (Fs) is the ratio of waterways in the river basin to the basin area, where the variable explains the ability of falling water to cause surface water runoff in the structure of the basin [41]. In addition, this value can explain the percentage of water that leaked to the soil profile to enhance groundwater resources. In this study, the river recurrence value in Wadi Al-Shumar basin was 1.4, while in the other sub-basins it fluctuated between 1.44 and 1.83. The relatively

Table 3. The areal aspects values of the catchments and the sub-catchments.

Name of watershed & sub-watershed	Drainage density (Dd)	Drainage texture (Dt)	Stream frequency (Fs)	Elongation ratio	Lemniscate ratio (K)	Form factor (Rf)
Wadi Al-Shumar basin	1.58	2.61	1.48	0.54	1.07	0.23
West of Ramtha	1.49	1.05	1.77	0.62	0.83	0.30
Al-Shiah	1.85	1.85	1.83	0.68	0.68	0.37
Braiqa	1.57	0.73	1.44	0.37	2.28	0.11
Mashqa'm	1.53	1.01	1.47	0.49	1.34	0.19
Zarnouk	1.61	1.56	1.68	0.71	0.62	0.40
Al-Mashro	1.60	1.09	1.70	0.57	0.97	0.26

low values that can be explained due to the existence of the basin under semi-arid conditions and receive low amounts of precipitation, which is the main factor influencing the stream frequency.

Elongation ratio (Re) is the ratio of diameter (D) of a circle of the same area as the basin (A) to the basin length (L) [32] [33]. It reflects the variations of geological and climatic composition of the basin structure, and the presence of steep slopes in the catchment [30], and varies according to the age of the basin [42]. The elongation ratio varies from zero, which indicates a highly elongated basin with low relief, to a ratio of one, that point out to the presence of a circular basin with high relief [43] [44]. The higher value of elongation ratio of a basin the higher the indication of an active denudation process that is accompanied by high infiltration capacity and low run-off in the basin. On the other hand, a low Re value is indicative of higher elevation of the basin, a susceptible-to-high head-ward erosion along with indications of tectonic lineaments [45]. The elongation value of Wadi Al-Shumar basin ranges from 0.54 to 0.47, while the rest of the ponds range from 0.37 to 0.71. This indicates that these ponds are closer to the rectangular shape than the circular shape; therefore, Al-Shumar valley is classified as a rectangular shape and the rest of the ponds are classified as elongated and very elongated.

Lemniscate Ratio (K) value varies between 0 - 1; it is used to facilitate the interpretation of the life stage and the erosion cycle of the basin [31]. In this study, the value of K in Al-Shumer catchment is 1.07 and ranges between 0.62 - 2.28 in the rest of the sub-basins.

These results show that the sub-catchments are mostly formed the rectangle shape and they are still in the early period of its erosion cycle, which can be developed with the structure of the basin.

Form factor (Rf), is the coefficient of basin shape which is associated with the area factor and the pelvic length square [41]. This form factor variable helps to predict the flood hazards and the ability of water to carry mud deposits from the upstream to the downstream position. In most of the morphometric studies, the reference value of the shape of coefficient ranges from 0.1 to 0.8. The form factor value of the Wadi Al-Shumar catchments is 0.23 while in the rest of the sub-catchments is in the range from 0.11 to 0.40. The form factor variable value that is close to 0.8 indicates the rotation of the basin, which causes speediness degree of exposure to the flood risk and vice versa [45]. In this study, the form factor value is near the rectangular shape except for the Shihya sub-catchment, which is equal to 0.37 and the Hernouk sub-catchment with value of 0.40. These sub-catchments values are close to the circular shape and therefore they are vulnerable to flood risk in case of frequent rainfall events.

Analysis of the relief factor includes the basin relief (Bh), relief ratio (Rr), Ruggedness number (Rn), and Dissection index (Dis). **Table 4** presents the relief aspects values of the catchments and the sub-catchments.

Basin relief (Bh) variable indicates the value of the height difference between

Table 4. The relief aspects values of the catchments and the sub-catchments.

Name of watershed & sub-watershed	Basin relief (Bh)	Relief Ratio (Rr)	Ruggedness number (Rn)	Dissection index (Dis)
Wadi Al-Shumar basin	756	20.11	1.19	0.74
West of Ramtha	124	14.37	0.18	0.20
Al-Shiah	163	24.86	0.30	0.25
Braiqa	453	25.73	0.71	0.45
Mashqa'm	472	32.19	0.72	0.46
Zarnouk	352	36.66	0.57	0.38
Al-Mashro	239	20.60	0.38	0.30

the lowest and the highest area in the basin structure, and it explains the similarity and differences in the spatial environment of the basin. This value relates to the geological structure, extent of rock resistance against the fragmentation processes, and to the impact on the sediments' quality (4). The steep slope is closely related to the geological structure and the ability of rocks to resist the erosion, however, the high value indicates a very steep and high erosion force [5]. In this study, the basin relief was extracted from the DEM, and the value of it is in the range from 756 m in the main catchment to 126 m in the west of Ramtha sub-catchment.

These values display that these ponds are still able of carving streams and river valleys, and able of increasing the rock carving as well.

The concept of the **Relief Ratio (Rr)** has been introduced in the interpretation of morphometric variables by [31], as a dimensionless ratio between basin relief and basin length and widely accepted as an effective measure of gradient aspects of the watershed [46]. The relief ratio indicates the overall steepness of a drainage basin and is an indicator of the intensity of erosional processes operating on the slopes of the basin [22]. This increase in the sediments' amount is resulting from the flow of the river level horizontally and vertically; thus, ponds are added to the stage that it reaches in the current cycle. The rate of relief at Wadi Al-Shumar basin was 20.11 meters, while the lowest value in the sub-catchments was 14.37, and the highest was 36.66. These values indicate that there is a significant erosion force resulting from the erosion processes with a high slope value.

Ruggedness number (Rn) is one of the morphometric variables that was obtained from the total density of the river drainage [39] [41]. This variable provides explanation of the positive relationship between the total calcification and density of drainage in the catchment. In general, the increase in the value of rationale pruning that is associated with an increase in the degree of roughening reflects the age of the erosion cycle in the catchment. The high degree of roughening means an increase in the capacity of water for soil erosion, and consequently, an increase in the river load of the sediments [24]. In this study, the degree of ruggedness was found to be 1.19 in the main catchment, while in the secondary ponds it ranges between 0.18 and 0.72; which means that Al-Shumar catchment is characterized by the value greater than (1) that represents a high roughness level. On the other hand, the other sub-catchments were classified as low-reared, and two other basins were medium-bumped. These results can be explained by the difference in the geological structures across sub-catchments, which directly affect the degree of basins roughness. Accordingly, the northern and eastern areas of the catchment were characterized as low pelvic areas and by a low bump degree.

Dissection index (Dis) is the vertical depth indication of the effective morphometric variables and which is considered an effective measure in determining water viability to make a change in the vertical depth of the river channel. The value of the (Dis) variable varies from (0 - 1); where the value of (1) shows a strong vertical setting, the value of (0) shows a weaker one. In this study, the vertical depth value was 0.74 of Wadi Al-Shumar catchment. This indicates a deep vertical depth that is directly linked to the high level of pelvic drainage and the relatively small catchment area.

These results suggest that Wadi Al-Shumar basin suffers from the exposure of the soil to erosion risk, in addition to the conclusion suggesting that the spreading risk of soil erosion is resulting from heavy rainstorms and low coverage of vegetation under semi-arid areas.

5. Conclusion

Watershed drainage network is an important geomorphological unit, which reflects topographic and hydrological unity. Hydrological characterization of Al-Shumar watershed and its sub-watershed revealed the importance of morphometric analysis in terrain depiction and basin evolution. In this regard, the GIS technique provided high accuracy in the mapping and the measurement of morphometric analysis. The analysis presents a medium-developed drainage network and an immature geomorphic stage in the watershed. The drainage density value indicates moderate slope terrain with sparse to dense vegetation, a higher infiltration rate, a moderate surface runoff and less dissection. The watershed and its sub-watersheds have elongated shape making them less prone to flood, lower erosion, and to sediment transport capacities. The differences in relief level results explain the dominance of the arid and semi-arid climatic environments in the study area; thus, they tend to reduce the water's ability to cause any changes in the watershed environment. The elongation variable value shows that the watershed passes through its youth stage of erosion as an increase in length, which is an occurring that was observed in the main course of the valley. This explains the vulnerability to floods in the river valley to the length of the distance traveled by water compared to the area of the river valley. The results show that the morphometric parameters are able to provide relevant information about vulnerability of the watershed for floods, and management plans. The study results can be improved by using higher resolution DEM data, which might have proficient means for the management of the water resources on sub-watersheds levels.

6. Data Availability

Some or all data, models, or analysis used during the study are proprietary or confidential in nature and are available with restrictions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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