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Automated Analysis of the Watershed of Yarmouk Basin Using ASTER (DEM) Data and GIS

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ABSTRACT

The aim of this study was to analyze the geomorphological characteristics of Yarmouk River Basin. Shuttle Radar Topography Mission Elevation (ASTER) satellite data were used for preparing digital elevation model (DEM) for the morphometric measurement, which is available globally in Geo TIF format of 90m resolution. Geographical Information System (GIS) was used in the evaluation of linear, areal and relief aspects of morphometric parameters. Parameters such as watershed boundary, flow length, and stream ordering have been prepared using Arc Hydro Tool and the Contour, slope-aspect, and hillshade have been prepared using Surface Tool in ArcGIS-10.1 software. In this study, the geomorphological characteristics were analyzed for watershed properties, along with the network within an area differences in terms of geology, climate, and topography. The total catchment area is about 6790 km² including Syria, Jordan, occupied Golan Heights, and occupied Palestine. The main results of the study could be summarized as follows: (1).Area classified by relief to three main parts:- the western part of the Jordan Rift Valley (JRV) drops from 0 – 270 m below mean sea level (b.m.s.l), the mountainous area reaches a height of 1200 m above mean sea level (a.m.s.l), in the northern Jordan and southern Syria rising up to1800 m (a.m.s.l) (2).Variation in slope degrees ranging between flat (level) accounted for 32 % of the study area, to the severe cliffs by 10%, (3). Drainage density 0.68 km \ km ², (4). Different areas of Sub-watershed the largest of which (A) forms 32.5% of the total study area, and the smallest of which (E) forms only 4%, (5). Stream of 7th order with 5 km in length, the total length of the tributaries from first order – seventh order is 4567 km. and (6). Basin relief is 12.6 m \ km.

Keywords: Yarmouk Basin, Slope, ASTER, DEM, GIS.

Introduction

Yarmouk River flows from Syria and Jordan, and constitutes part of the Jordan Rift Valley, (JRV) which also forms part of the Asian - African Rift Valley (ARV). The altitudes of the study area range from 1800 m above mean sea level (a.m.s.l) in southern Syria to -270 m below mean sea level (b.m.s.l) at base level (outlet) in the Jordan River, south of Tiberia Lake at a distance of 6 km, the river forms natural border between Jordan - Syria and Jordan - Occupied Palestine its mouth reaches the Jordan River, covering an area of 6790 Sq Km. Over the last decade, geographical information systems (GIS) and digital elevation models (DEMs) have been widely used in drainage basin analysis: (Akawwi, 2013; Kuldeepand and Upasana, 2012; Alcicek, et al, 2005;vogt, et al, 2003, Zeiler, 1999; Bolch, et al, 2004) have been used the remote sensing data for determining the quantitative description of the topographic and basin geometry. The drainage network is represented by a network of connected line features, which can be digitized using GIS techniques can be derived automatically from a Digital Elevation Model (DEM), (Hui-Ping, et al, 2006; Lipng Yang, et al., 2011; Tamll, et al., 2011; Vitmal,et al,2012;Waikar,et al,2014; Magesh, et al, 2012; Abubaker *et al*., 2012; Paul, 2008; Sreedevi, et al, 2009; Kumetaitienė, 2005) Using automated GIS hydrological tools applied on the DEM to derive streams network and watershed catchment and sub-catchment categories.

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Study Area:

Yarmouk basin (YB) is the largest tributary of the Jordan River (Holy River) which joins the Jordan River between the Tiberius Lake and the Dead Sea, at 6km southern of Tiberius Lake. It drains from Hauran Plateau in southern Syria at 1800 m (a.m.s.l) altitude drops to -270 m (b.m.s.l) in the northwest of Jordan, it forms natural border between occupied Golan Heights and Jordan close to the Jordan Valley and between Syria and Jordan further upstream, and is located between (°31.´15 to °33.'30 N) latitude and (°34.´50 to °36.´54 E) longitudes. The climate is semi-arid in the east with an annual rainfall of less than 150 mm; while the amount of rainfall goes up to 600 mm³ per year in the mountains, and the average annual rainfall is 354 mm/ per year; while the average amount of annual runoff is 203 million m³, and temperature rises up to 37°C in summer and drops to 17°C in winter. The Yarmouk River flows in a narrow valley on to the plain of Jordan, and its drainage basin has developed under the influence of the rejuvenation given to the plateau by down-faulting of the Jordan Rift. Basalts of plateau-type cover 78% of the surface of the Basin in all the riparians (Burdon, 1954).The basin is underlain by chalk, limestone, chert, and marl of the Balqa and sandstone of the Kurnub Group. In the eastern part of the basin, basaltic flows cover rocks of the Balqa Group,(Bender,1975), Groundwater flow is controlled by two major faults that cut across the basin-part of the flow generally northward toward the Yarmouk River, and partly westward toward the Jordan River. Figure (1) DEM shows the location map of the study area, and the major wades, and figure (2) Shows the lower Yarmouk basin.

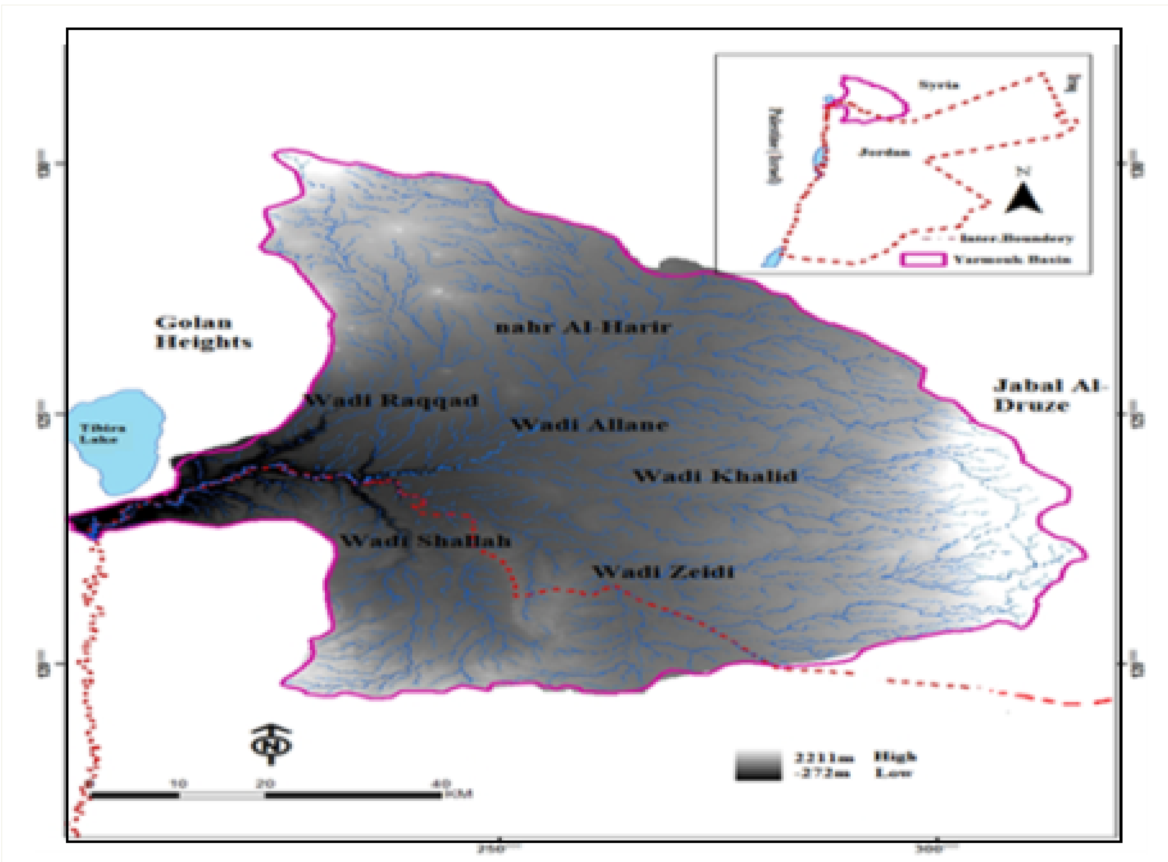

Figure (1) DEM shows the location map of the study area, and the major wades.

Figure (2) the lower Yarmouk basin (1.Border between Jordan and Occupied Golan heights, 2.Valley, and 3.Active channel)

Methodology:

ASTER data model has been used for preparing digital elevation model (DEM), downloaded from (GLCF) Global land Cover Facility, Maryland, which is available in Tiff format with 90 meter ground resolution at the website http://glcf.umd.edu/data/landsat/, which is widely used in drainage basin analysis (Tamll, et al, 2011; Hiu-Ping, et al, 2006).The lengths of the streams, areas of the watershed were measured by using ArcGIS-10.1 software, and stream ordering has been generated using Strahler's System (Strahler 1952) and Arc Hydro Tool in ArcGIS-10.1 software. The linear aspects were studied according to Horton Methods (Horton, 1945), along with the areal aspects using those of)Schumm 1956). And the relief aspects applying the techniques of Horton (Horton, 1932).The Drainage density and frequency analysis of the watershed area were done using the spatial analyst tool in ArcGIS-10.1 software.

Results:

Network Characteristics include stream number, length, order, bifurcation ratio, frequency, drainage density, and stream pattern. Besides watershed Characteristics; area, shape, elongation, circulation, form factor, basin slope, and relief, are essential in analyzing the geomorphology of the study area. These geometric characteristics reflect the conditions of climatic, (flash floods, rainfall intensity), geomorphic (river morphology, valley morphology, surface gradient), geologic (structure and lithology), and related drainage basin has developed under the influence of the rejuvenation given to the plateau by down-faulting of the Jordan Rift. Basalts of plateau-type cover 78% of the surface of the basin in all the riparian's (Burdon, 1954), (Hassan and Kilen, 2002).

4.1. Drainage Network:

Total channel length, stream number, and bifurcation ratio est. is determined according to distribution of drainage networks extracted from the DEM at the scale of sub-basins with a morph metric parameter statistically analyzed by using the attribute tables of different ArcGIS features, such as polylines and polygons.

Stream Number:

Total number of stream is 4222, about 49.5% percentages are $_1$**st** order, and 28% are $_2$**nd** order, 13.3% are $_3$**rd** order and 9.1% are $_4$**th** order. The total number of stream segments is decreased as the stream order increases in both of the main and sub -basins. The study reveals that the development of $_1$**st** and the $_2$**nd** form more than 77.5% of the total Stream Number in the mountain zones, and the rest in the Jordan Rift Valley (JRV) zone where alluvial plains and the badlands are located. Figure 3 demonstrates the relationship between stream number and stream order.

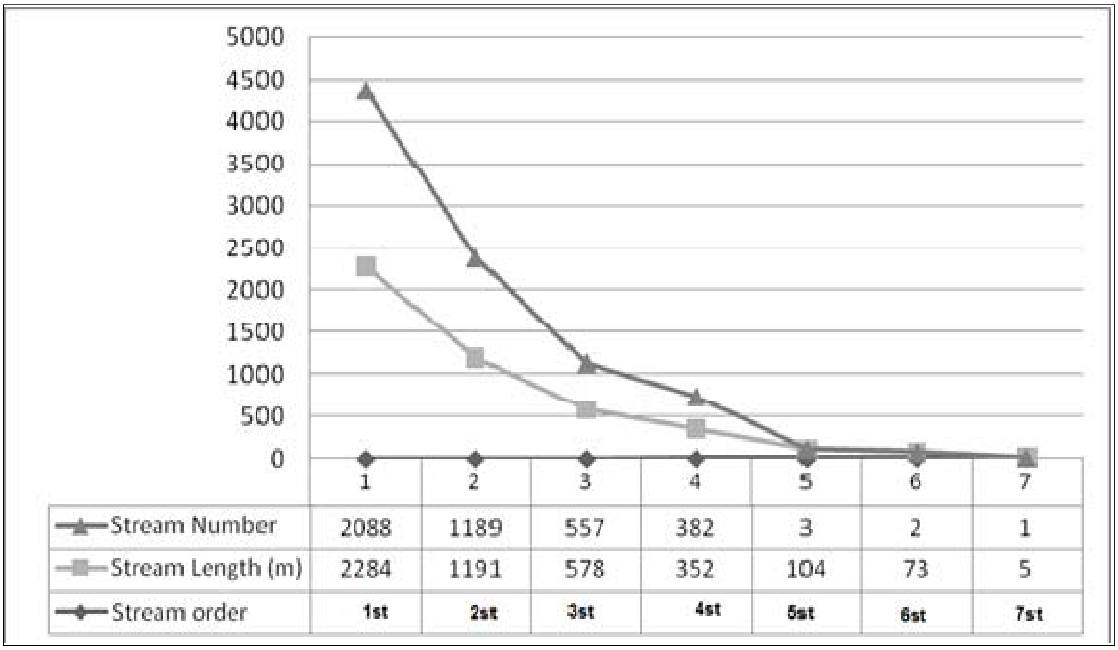

Figure (3): Relationship between stream number and stream order

Stream Length

The total stream length from the 1st order to 7th was 4587km. Stream length decreases as the stream order increases (Horton,1945) particularly as the total stream length percentage for the 1st order goes up to 50% of the total length, and 26% for the 2nd order, while only 24% for the rest from 3rd order to 7th.

Stream Order

The total Yarmouk drainage basin boundary and major river system are diverted from the SRTM-DEM. The whole stream network was ordered according to Strahlers system (Strahler, 1952). The study area is a 7th order basin with the 1st order basin numbering 2088 about 49.5%, and 1189 about 28.2% for the 2nd order, and the rest 945, 22.3% for the 5th stream order. Results of stream Order are presented in Table 1. Figure 4 shows the streams of various orders and drainage pattern of the study area.

Bifurcation Ratio

The bifurcation ratio is the ratio of the number of stream segments of a given order Nu to the number of segments of the higher order **Nu+1** (Schumm, 1956).

$$Rb = Nu/Nu+1$$

The number of streams at different orders in a watershed decreases with increasing order in irregular way see (table 1). According to our study, the bifurcation ratio ranges from 5.5 for the 4th order to 1 for the 7th order. The increase in bifurcation ratio for 4th order is due to the result of the nature of relief, and the highest elevation in the watershed follows the bifurcation ratio as indicated in the index of relief (Sreedevi, et al, 2009). The sudden decrease of the bifurcation ratio between the 4th and the rest reflects unsuitable geological structures. These irregularities depend on the geological and lithological development of the drainage basin (Strahler 1964).

Table (1): Stream order, stream number and Bifurcation Ratio

Stream order	Stream, Number	Bifurcation Ratio
1st	2088	1.76
2nd	1189	2.1
3rd	557	1.5
4th	382	1.5
5th	4	5.5
6th	2	2
7th	1	1
	4222	Total

Stream Frequency

Stream frequency gives the number of stream per unit area. **Fs = N/A,** Where **N** = Total number of streams from all orders, and **A** = Total area of the basin, or sub-basin (Horton, 1945). Stream frequency for the Yarmouk watershed is about 0.62 stream\km², but in fact there are major differences at the level of sub-basin. Thus, we can classify the sub-basins according to stream frequency in three categories particularly as the first one consists of 2 sub- basins (A and B) with a high stream average Frequency of up to 1.3. The second category decreased to 0.33 stream\km² on average for (D and C). The last one (F) is the lowest 0.25 stream\km² in **Fs** due to dry and hot climate. In general, the stream frequency increases with decrease in stream order. It is found that stream frequency bears no direct relationship to the degree of relief and that spatial distribution of stream frequency is influenced by resistance to erosion, permeability, climatic conditions and tectonics and structure of the rock types in a basin (Sreedevi, et al, 2009**).**

Drainage Density

Drainage density is the total length of the stream from all orders within the basin per unit of area. Drainage density has been calculated by using Spatial Analyst Tool in ArcGIS-10.1and can also be calculated by using this formula: D **=** ***Lk/Ak w***here, **Lk** is the total length of the channel from all orders and **AK** is the total basins area (Horton, 1945). The drainage density (Dd) of the study area is 0.68 km/km² and is affected mainly by geology, climate, soil permeability, surface gradient, and precipitation properties. (Dd) varied between the sub-basin ranging from 1.6 km/ km² for A, B, C and D to 0.12 for F. From above results, the drainage basins characteristics and sub-basins low density are determined according to permeable rock and chalk, limited rainfall, gentle slopes, and lower channel frequency.

Drainage Pattern (DP)

The drainage network of the basin is mainly trellis in the lower part of the basin affected by the faulting system, with dendritic pattern in the middle and the upper drainage basin which indicates the homogeneity in texture and lack of structural control, Figure 4. Drainage pattern reflects the influence of slope, litho logy and structure, and identifies the stage of the cycle of erosion (Strahler, 1952).

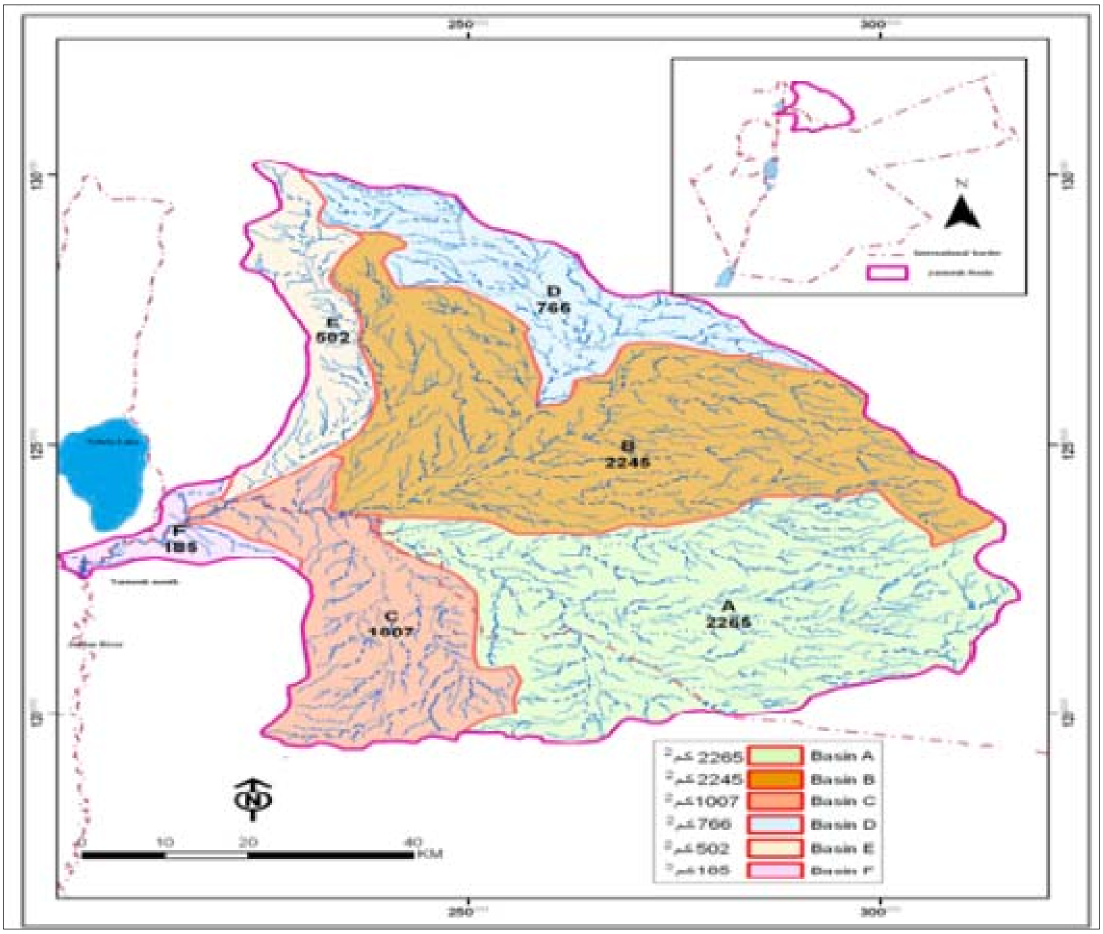

Figure (4): Spatial distribution of various sub-basins in Yarmouk Basin.

Table (2): Computed stream number, stream Length, and stream order

Stream order	Length (m)	length Percentage%	Stream number	Stream Percentage%
1st	2284	50	2088	49.5
2nd	1191	26	1189	28.2
3rd	578	12.6	557	13.2
4th	352	7.7	382	9
5th	104	2.3	3	0.07
6th	73	1.6	2	0.05
7th	5	0.1	1	0.03
Total	4587m	100%	4222	100%

Drainage Basin Geometry:

Basin and sub-basins area:

The total area of the watershed is 6790 Sq km, within (Jordan, Syria, and occupied Palestine). The watershed is divided into sixth sub-basins, ranging in areas between the largest 2268 Sq. Km for sub-basin (A) to the smallest (F) about 185 Sq Km, see figure 4.

Basin shape

The shape of the basin mainly governs the rate at which the tributaries are connected to the main channel. The main indices used to analyze basin shape and relief is the elongation and relief ratios (Horton, 1932). Form factor is calculated using this formula $Rf = A / L_b^2$, where **A** is the total basins area, and L_b^2 is the basin length square (Horton, 1932) and is commonly used to represent different basin shapes. Form factor for the main basin is about 0.62, but the form factor for all six sub-basins is low and ranges between 0.56 for the sub-basin A to less than 0.10 for the sub-basin F. As the value of form factor is small for all basins, the basis is more elongated.

Basin Relief

Maximum relief within a region is naturally the difference in elevation between the highest and lowest points in the basin (Chorley, et al, 1984). Yarmouk basin altitudes range between -270 m, (b.m.s.l) to 1800 m, (a.m.s.l) (BR) about 2070m. As the study area has a high relief, it can transfer high energy into the drainage system. Table 3. and Figure (5**)** show the Yarmouk Basin relief by area of which only about 6% represents the Jordan Rift Valley, and 93% extended from 300m-to more than 1200m. The eastern and northern parts of the area are very steep with a relief ranging from 900-more than 1200m in Druse Mountains in the upper part of the Basin. The contours are very close to each other and dense with high gradients towards the western part of the area studied, and the steepness suddenly decreases with an altitude varying from 600m a.s.l to -270 m (b.m.s.l.) the contours are widely spaced with small gradients.

Slope Analysis

Slope maps play a crucial role in addition to flow direction and flow accumulation in hydrological modeling (Eadara and Karanam 2013). Slope is one of the important terrain parameter which is explained by horizontal spacing of the contours. Slope values were calculated for each grid, percentage slope classes and their areal extents were calculated at sub basin level. The steeply sloping frequencies in the upstream part in southern Syria, and in lower basin as forms apart of Jordan Rift valley figure 6, and table 4. Show that about 59.5% from the Yarmouk basin is nearly level, where the slope aspect towards the west and northwest. Figure 7.

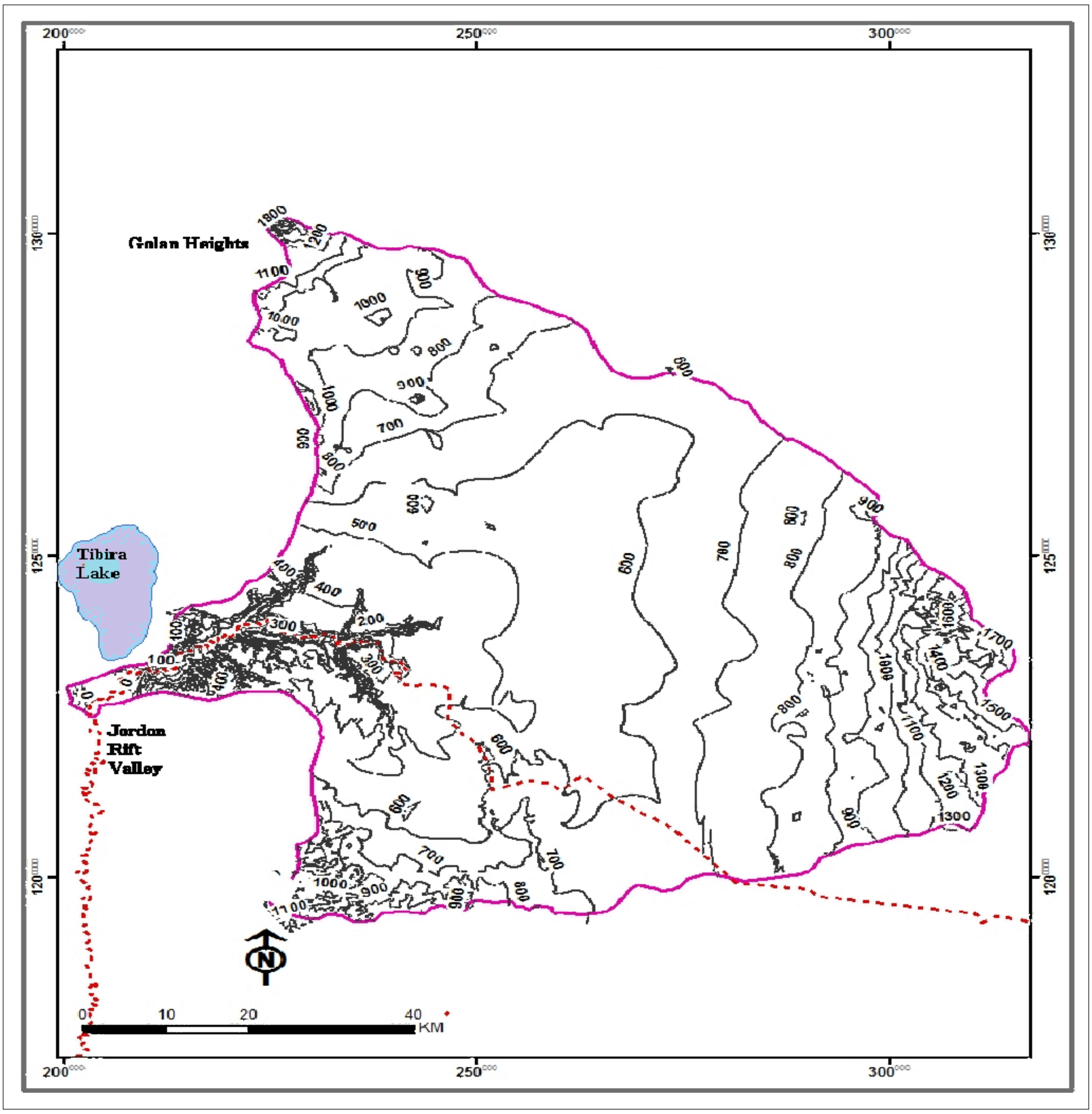

Figure (5): Contour map of Yarmouk basin from DEM

Table (3): Yarmouk basin relief by area and percentage

Elevation (m)	**271-_ 0**	**0-300**	**301-600**	**6001-900**	**901-1200**	**>1200**	**Total**
Area (km²)	61	330	1982	1141	3012	444	6970
Percentage (%)	0.89	4.7	28.4	16.4	43.2	6.4	100

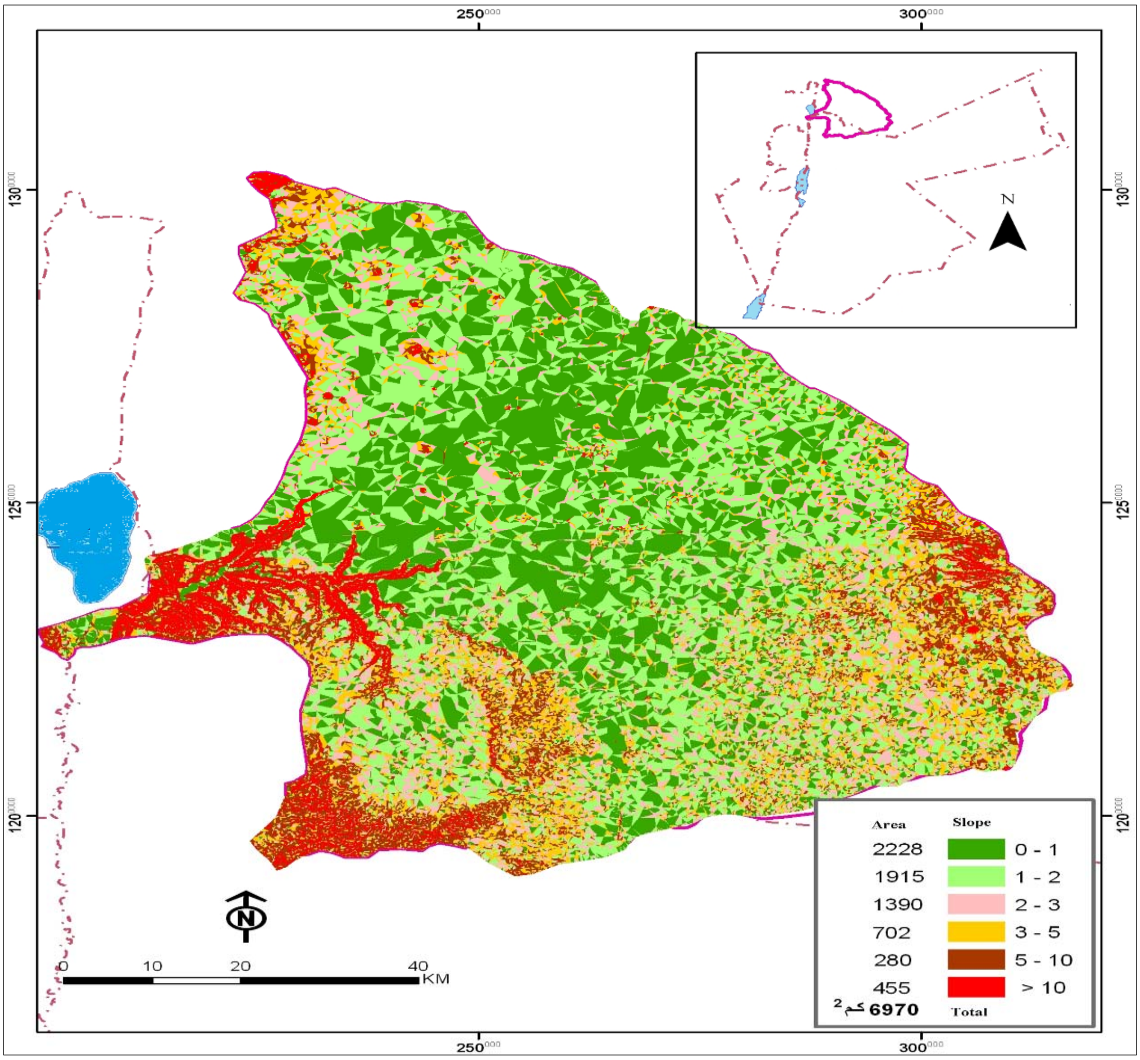

Figure (6): Slope of the Yarmouk Basin from DEM

Table (4): Slope characteristics of Yarmouk Basin

Slope Degree	**0-1**	**1-2**	**2-3**	**3-4**	**5-10**	**10<**	**Total**
Area Sq km	2228	1915	1390	702	280	455	6970
%Percentage	32	27.5	20	10	4	6.5	100

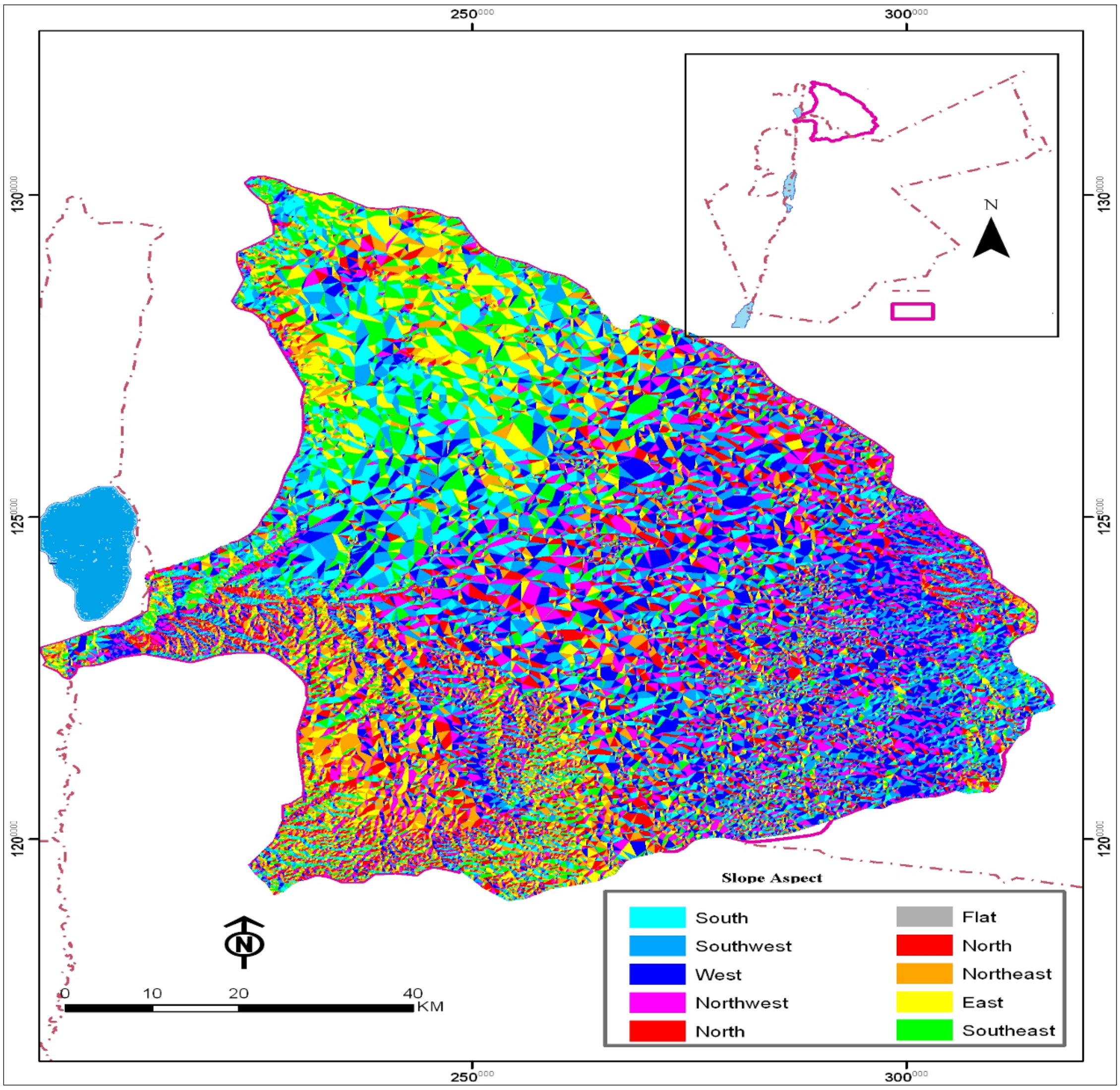

Figure (7): Slope aspect for study area.

Discussion

The quantitative and qualitative analysis of geomorphometric parameters of the Yarmouk watershed and six sub-basins justifies the utilization of ASTER DEM and GIS tools for geomorphic evaluation of a drainage basin extended from high land to the Jordan rift valley. The drainage network of the study area has been significantly influenced by lithologic, structure tectonic factors and the decline of the Dead Sea level. The drainage network of the basin is mainly trellis with sub-dendritic types, and the watershed has been classified as a seventh -order basin. The drainage density (Dd) value for the basin is 0.68 and the Dd values for the sub-basins are ranged between 1.6 to 0.12 which indicates that the fissured and jointed rock strata are relatively permeable. The stream length, number varies for both the main basin catchment and the sub-basins as a result of local variation in morphology (changes and breaks of slope), slope steepness, relief and the stage of geomorphic evolution of landforms as a result of uplifting and rejuvenation affecting by the decline of the Dead Sea level for about 31m since the late eighties of the twentieth century, (Alhusban, 2014). Low values of stream frequency 0.62 stream/km² denote that a significant proportion of surface water infiltrates to the subsurface strata, and thus the groundwater potential is relatively high.

Conclusion

The automated and diverted geomorphologic characteristics using (GIS) have facilitated and yielded methodology for drainage and morph metric analysis especially in case of large basins. Based on the results of analysis of the (ASTR- DEM) in the Yarmouk drainage basin, the main geomorphologic characteristics are as follows:

- Irregular decrease in the local topographic relief from north to south and from east to west as a results of the significant differences in structure and lithology, deposition of the Quaternary sediments along the Yarmouk River and the overall uplift of the eastern margin of the Jordan Rift Valley.
- Large area of drainage sub-basins.
- Total channel length is 4567km.
- The Watershed had low drainage density of 0.68 Km/Km2 indicating lowly permeable soil.
- Slope Aspect of the area varies from flat to south with a dominant Aspect west and northwest.

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التحليل الآلي لحوض نهر اليرموك باستخدام نموذج التضرس الرقمي ونظم المعلومات الجغرافية

يسرى الحسبان، آية علوان*

ملخص

هدفت هذه الدراسة إلى تحليل الخصائص الجيومورفولوجية لحوض نهر اليرموك بالاعتماد على نموذج التضرس الرقمي المتوفر بدقة تمييزية مقدارها 90 م، والمشتق من (ASTER) ونظم المعلومات الجغرافية لتحليل الخصائص الخطية (الشبكة المائية)، والمساحية (مساحة الحوض والأحواض الداخلية)، والتضاريسية (الخريطة الكنتورية، والخريطة الانحدارية).

تبلغ مساحة حوض منطقة الدراسة 6790كم² يمتد بين الأردن وسوريا، والجزء المحتل من هضبة الجولان ونظراً لكبر مساحة الحوض فقد تباينت خصائصه الجيولوجية، والمناخية، والطبوغرافية، مما انعكس على الخصائص الجيومورفولوجية.

وأبرز نتائج الدراسة فيما يلي:1. قُسِمت منطقة الدراسة وفقاً للارتفاع إلى ثلاثة أقسام، هي: الجزء الغربي الذي يمثل جزءاً من الصدع الأردني وينخفض إلى –270م، والمنطقة الجبلية في شمال الأردن ويصل ارتفاعها إلى 1200، في حين يصل ارتفاعها في جنوب سوريا إلى 1800م.2. تباين الخصائص الانحدارية ما بين المنطقة المستوية بنسبة 32% من منطقة الدراسة إلى المناطق الجرفية بنسبة 10%.3. بلغت الكثافة التصريفية 0.68\كم² 4. تباين مساحات الأحواض المائية الثانوية من الحوض (أ) الأكبر مساحة بنسبة 32.5% من مساحة منطقة الدراسة إلى الحوض الثانوي الأصغر(د) بنسبة 4% من مساحة منطقة الدراسة 5. الرتبة النهرية السابعة بطول 5كم، ومجموع أطوال الروافد من مختلف الرتب 4567كم 6.مقدار التضرس 12.6م\كم.

الكلمات الدالة: حوض اليرموك، الانحدار، نموذج التضرس الرقمي، نظم المعلومات الجغرافية.

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