Analysis of morphometric parameters of Wadi Araba Basin in Jordan Using GIS and DEM Model

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Abstract: Analysis of the basin surface geomorphometrical characteristics is important for their impact on landscape processes, erosion characteristics and water management. Topographic maps and digital elevation model were used for analyzing of morphometric and landform characteristics of Wadi Araba basin. The analysis allows derivation of the main catchment and sub-catchment. Catchments that take the numbers 1 and 2 are associated with high density dentritic drainage pattern because of high slope and accordingly have high surface runoff. Sub-catchments with the numbers 3,4,5,6, are associated with a low density dentritic drainage pattern due to the flat topography. It is found that, the average stream frequency is 0.2 and the drainage density in study area is 0.79 km/km². The morphmetric analysis was carried out at sub catchment level and different landforms were derived based on visual exposition of 3D digital elevation model with 30 m spatial resolution using GIS hydrological analysis tools. Identification of the landform classes is based on reclassify of slope and relief, and profile index. The main landform types that derived in the study area: valley floor, Qaa, Playa, level hills, escarpment, high mountains,

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1. Introduction

Morphometric characteristics of the surface basins and catchments are one of the driving factors that influence soil erosion and the underlying regolith. Drainages network contributes to the erosion process by affecting the differences of the topographic characteristics which can be reflected by stream length, slope degree and flow density. Therefore, it is very useful to describe the aspects of the catchments, drainage network and its variables for watershed management issues. Remote sensing and GIS techniques has been used in morphometric studies, (Akawwi, 2013) studied the hydrological basin characteristics of the Jordan Valley River using the remote sensing techniques and Global mapper, also (Alcicek, et al, 2005; Vogt, et al, 2003; Zeiler, 1999) have been used the remote sensing data for determining the quantitative description of the basin geometry. The drainage network is represented by a network of connected line features, which can be derived automatically using GIS techniques and Digital Elevation Model (DEM). Different studies have been used the automated GIS hydrological tools applied on the DEM to derive streams network and watershed catchment and sub-catchment. (Hui-Ping, et al, 2006; Jurgen, et al, 2003; Magesh, et al, 2012; Abubaker *et al*., 2012; Gregory, et al, 2001; Kuldeep and Upasana, 2011; Tina, et al, 2011; Eadard, and Karanm, 2013). The digital elevation models were used by many researchers for various applications related to flood control, mapping of risk hazard, water harvesting management and delineations of watersheds using mathematical algorithm (Wise, 2000; Selvan, and Rashid, 2011; Alhusban and Makhamreh, 2014; Chu, et al. 2010). Currently, the applications of the hydrological algorithms on the DEMs becomes the basics of scientific research associated to geomorphological studies, catchment characteristics and watershed management. One of the main uses of DEM model in Geography and Geoscience is in geomorphological and hydrological analysis of the watershed management. Therefore, the objective of this study is to describe the morphological and hydrological characteristics of Wadi Araba basin and identify the patterns of landforms using DEM and GIS hydrological analysis tools.

2. Study area:

Figure (1) show the study area, it extend from the Gulf of Aqaba in the south, and to the south of Dead Sea, and located between 29º 5´ to 31º 00 N latitude and 35º 25´ 00 to 35º ´35 000 E longitudes. It consist of three main surface basins from north to south: Dead Sea Rift side wadis, North wadi Araba and South wadi Araba. Wadi Araba–Dead Sea–Jordan Rift Valley separates the Sinai–Palestine micro plate in the west from the Arabian Plate in the east. (Bender, 1974). The watershed represents typical rift / highland topography and covers an area of about 10011km^2. Terrain elevation varies from −400 meters below mean sea level in the valley floor, and increases towards the east to 1734 m above mean sea level at Al-Ahagery Mountains in the southern part of the study area, after that the elevation decreases to 172 m in Al-madbeh mountains in the northern part of the study area, whereas the elevation in the western chain is reached around 300 m (AMSL). The higher elevation of eastern chain referred to as an immediate upwarping along the DST fault during NNE horizontal movement of the Arabian plate (Abed and Al-Hawari, 1991), and mainly characterized by the existence of structurally controlled scarps exerted by normal faulting (Atallah, 2002). Most of the study area are covered by Holocene and Pleistocene fluvial, aeolian dunes, and lacustrine sediments. (Bender, 1975, 2004; Tina, et al, 2001). The side wadis feeding into the Wadi Araba tend to be deep and steeply incised and are prone to occasional large flash floods. The study area highly faulted and has a complex pattern of fault structures of which three categories of faults and fault zones cut the study area from north to south. The dominant fault zones (known as Border fault) strike north, northeast and north–northwest (El-Naqa, et al, 2009).

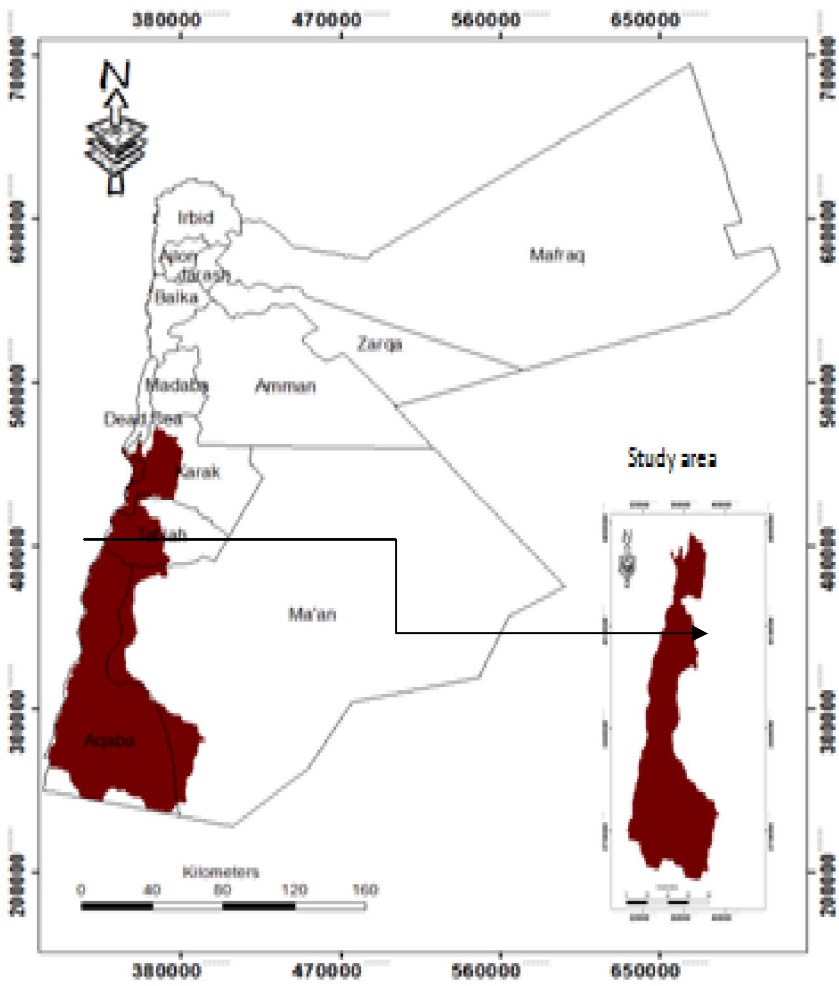

Figure 1. Location of the study area.

3. Methodology

The Arc GIS software was used to extract stream-nets, watersheds and landforms for the study area using the hydrological analysis tools. Arc Hydro surface water is a conceptual design implemented from an Arc-GIS geo-database model. Geographic Information Systems (GIS) can be used also to build three-dimensional models for any geographical location on the surface of the Earth. The representation of terrain topography of any site needs data form three-dimensions (z, y, x), which is known as Digital Elevation Model (DEM). Thus, the DEM are applied in several applications to derive many components, such as slope, drainage systems, and low-lands. The concept behind establishing DEMs implies the treatment of elevation ether points from digital elevation model or contour lines. Hence, Triangulated Unregulated Network (TIN) must be primarily constructed, which represents digital data structure used in GIS of surface attributes of the physical land. Landform classification is mainly based on two parameters: the slope, and the relief value, and profile index (Merina et al, 2011).

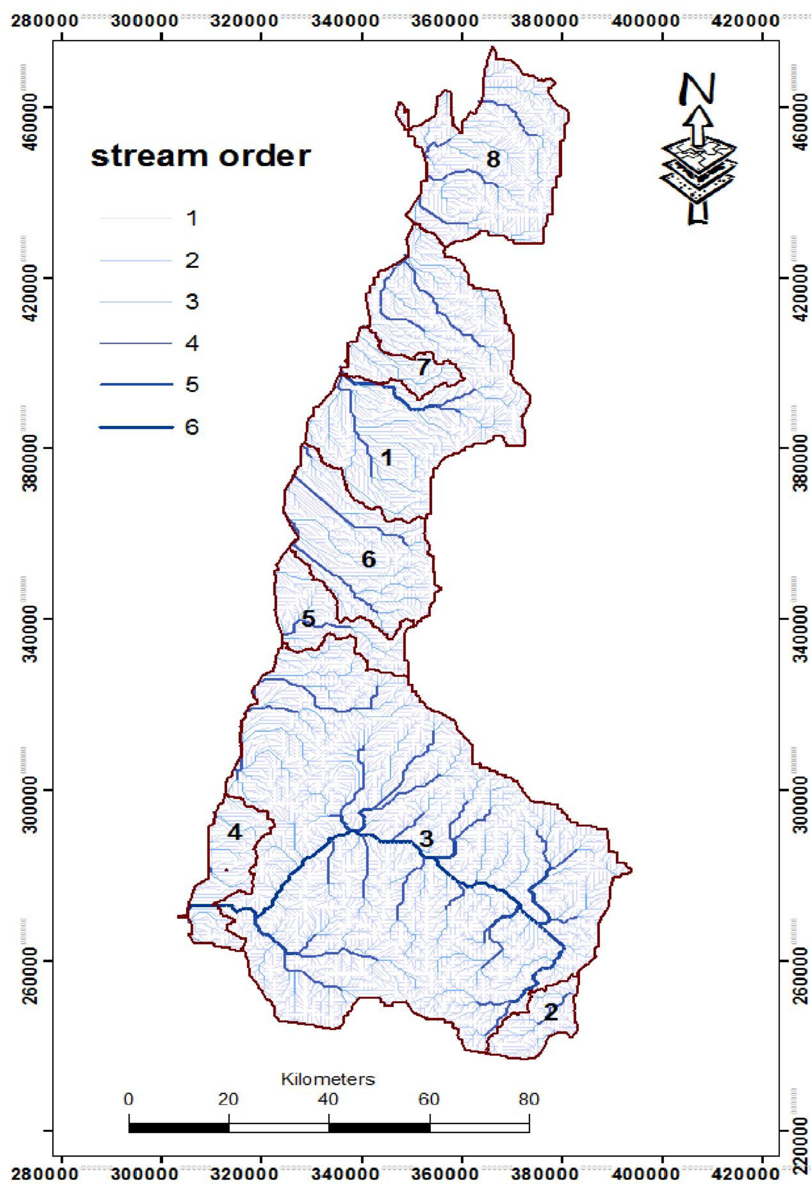

Figure 2. The main catchment, sub-catchments and stream order in the study area.

4. Results and Discussion

In this study the digital elevation model from of the USGS was used with a 30m spatial resolution, a 3D view of the study area are shown in figure (1). The DEM was used to derive the basic morphometric parameters including the linear aspects, areal aspects, relief aspects of the drainage basin, drainage network, and sub-catchments characteristics.

1.4. Basin Geometry:

The drainage system in Jordan consists of three main flow directions, this study area represent the first one and the main drains direction is towards the Jordan Rift Valley (JRV), which discharging ultimately into the Dead Sea and the Red Sea. The drainage area of the watershed is 10011 km², and constitutes from sixth order drainage basins. The total number of streams is 2071, and the study area was divided in to eight sub-catchments with ten main streams. The sub-basins area ranges from number three the highest basin area (Wadi Alyotom) and forms about 33.3% from the total study area, to the smallest one number 2 (Wadi Qhweiba) which forms only 1.2% of the study area. The commonly observed drainage patterns are the trellis and dendritic pattern; dendritic pattern recognized in the upper catchment. The drainage pattern and the semi-linear alignment of main and branching drainage indicate the prominent influence fault system, which is characterized by irregular branching of tributary streams in many directions which joining the main channel as shown in figure (2).

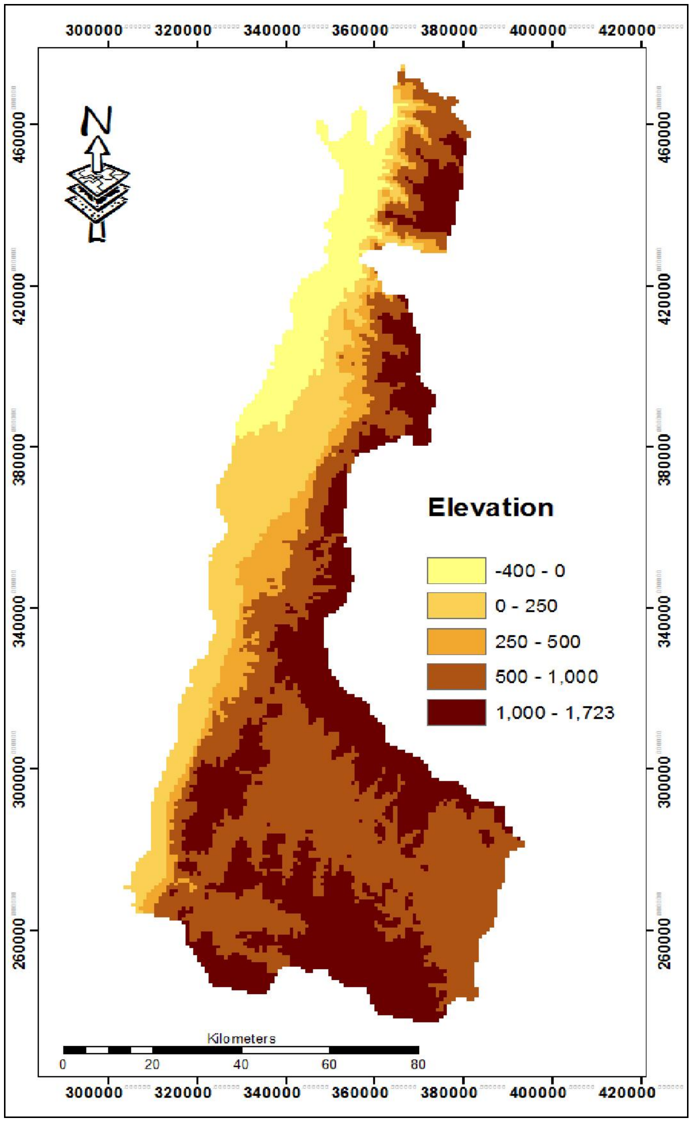

Figure. 3. The elevation map of the Wadi Araba Surface Basin.

1.1.4 Form factor (Rf)

According to Horton form factor defined as the ratio of basin area to square of the basin length (Horton,1932). Form factor is used to represent basins shape. The value of form factor lay between 0.1- 0.8. Low value of form factor mean that the basin is more elongated. Thus, elongated drainage basin accompanied with low form factors give lower peak flow for longer duration. On the other hand, the basins with high form factors above 0.8 give high peak flows for shorter durations (Schumm, 1956). The form factor values of the different basins in the study area are varies between 0.22 and 0.67 as given in table (1). According to form factor values the sub-basins have been classified into three categories: the first category represent the very low values of form factor (0.22-0.39), and includes the basins that take numbers 3, 4, 6, and 7, it classified as alluvial region and characterized by elongated basins and low relief value. The second category represent with low-medium values (0.52-0.55), and includes the basin number 2 and 5. The third category represent the basins with high values of form factor (0.67), and includes basins number 1 and 8.

Table 1. Sub-basin classes and form factor of the Wadi Araba Surface Basin.

Sub-Basin Index	Sub-Basin Area (km²)	Form Factor (Rf)
1	3334	0.67
2	186	0.52
3	4903	0.35
4	211	0.22
5	276	0.55
6	486	0.39
7	360	0.32
8	118	0.67
Total	10011	

2.1.4 -Basin Relief

The contour map has been created by using Surface Analysis Tool in ArcGIS-10.1. Basin Relief or "total relief" of the basin is defined as the difference in elevation between the highest and lowest points on the basin, (Schumm, 1956). The area of computed basin relief are given in table 2. The relief decreases gradually from east to west direction within the study area. The elevation of the study area is ranges from -400 m in the western part to 1723 m in the eastern part. Figure (3) show the elevation map of the study area, and table (2) represent the area of each class. The sub basins relief range from 0 – 400 m and classified as low land represent 8.3% of the study area, the hills and mountains class ranges from 600 m to 1723 m and form about 45.4 % of the study area. The high relief value indicates high capability for water flow, low permeable and high runoff conditions.

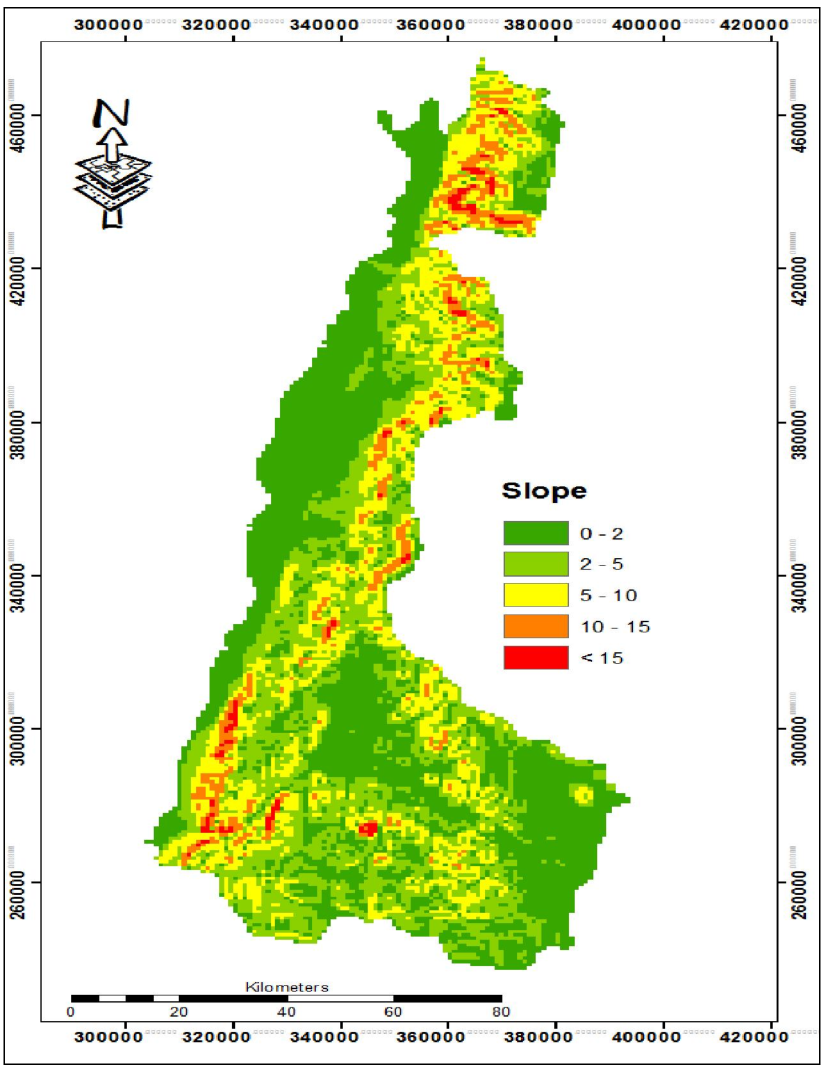

Figure 4. Slope map of the Wadi Araba Surface Basin.

Table2. The area of elevation classes of the Wadi Araba Surface Basin.

Elevation Class (m)	Area (km2)	Percent %
0 _ - 400	832	8.3
0 - 250	1480	14.8
250 - 500	3156	31.5
600 - 1000	3289	32.9
1000 - 1723	1254	12.5
Total	10011	100

3.1.4- Slope and slope aspect:

The slope percent and slope aspect maps was derived based on DEM data. Slope grid is identified as "the maximum rate of change in value from each cell to its neighbors؛ from the slope map it can be indentified that the region with high runoff and high erosion rate are from higher degree of slope. The slope percent in the study area is varies from flat to deep slope. The flat or gently slope area is ranges from (0 to 2) % which form more than 37.4% of the study area. The deep slope class with value higher than 15% represent about 10.9 % of the study area. The higher slope values are found in the eastern and northeastern parts of the study area as shown in figure (4).

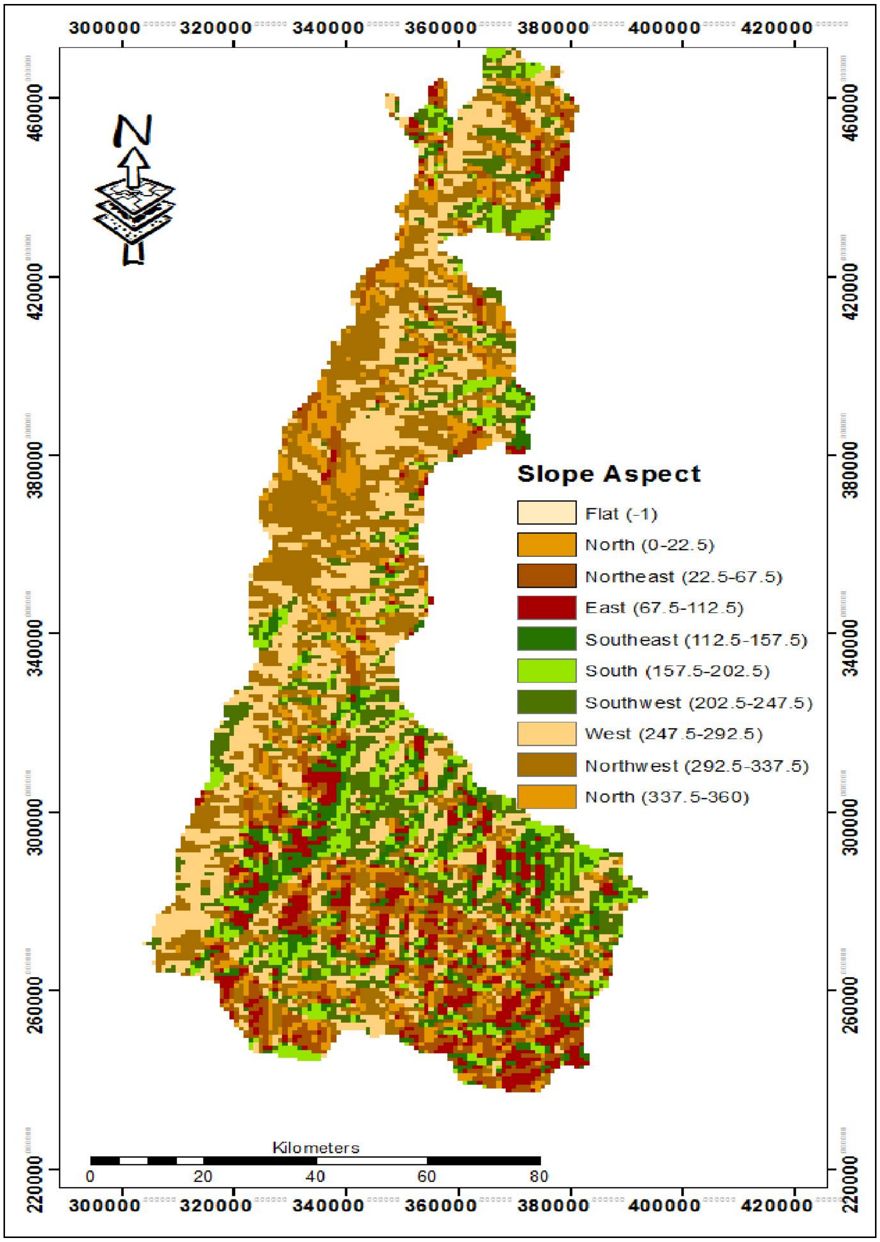

Figure 5. Spatial distribution of slope aspect of the wadi Araba basin.

Table 3. The slope by area of the Wadi Araba Surface Basin.

Slope degree	Slope Class	Area (km2)	Percentage (%)
0 – 2	Level \Flat	3746	37.4
2 – 5	Gently sloping	2743	27.4
5 – 10	Strongly sloping	1567	15.6
10 – 15	Moderately steeply sloping	867	8.7
< 15	Steeply sloping	1088	10.9
Total		10011	100

The slope aspect refers to the direction side to which the mountain slope faces. The value of the output raster data set represents the compass direction of the aspect. For instance 0º is to north; 90º is to the east. The aspect of a slope can make very significant influences upon climate, and agriculture in general. The slope aspect of the study area is varies from flat to south with a dominant Aspect to north as can be realized from table 4. and figure (5).

Table 4. Aspect of the W. Araba by area

Aspect	Aspect Class	Area (km2)	Percentage (%)
(-1)	Flat	810	8.0
(0-22.5)	North	447	4.5
(22.5-67.5)	Northeast	782	7.8
(67.5-112.5)	East	692	8.9
(112.5-157.5)	Southeast	584	5.5
(157.5-202.5)	South	766	7.7
(202.5-247.5)	Southwest	1020	9.2
(247.5-292.5)	West	187	1.2
(292.5-337.5)	Northwest	202	2.0
(337.5-360)	North	4521	45.2
		10011	100

5. Drainage Network:

The network characteristics and distribution was extracted from the DEM for different drainage sub-basins; it includes total channel length, stream number, and stream order and drainage density. These properties are essential in analyzing the geomorphological pattern of the study area. The geomorphological pattern was developed by influenced and reflection of climatic conditions, flood types, rainfall intensity, geologic structure and lithology (Selvan and Rasied, 2011). The drainage network of the basin is mainly trellis affected by more than 16 fault system, with sub-dendritic type which is characterized by irregular branching of tributary streams in many directions that joining the main channel. Based on the drainage pattern the basin was divided in to 8 sub-basins. The total area of the basin is 10011 km², with total streams number of 2071 from all orders. All channels and gullies in the study area drain to the west direction.

1.5. Stream Number and Order

Total number of stream is 2071, the whole stream network was ordered according to Strahlers system (Strahler, 1952), it was found that about 48.8. % consists mainly from the first order, 35.5% are second order, 10.4 % are third order, 3.1% are forth order, 1.5 are fifth order, and 0.58 are sixth order. The total number of stream segments is decreases as the stream order increases. It is found that the development of streams from first and second order types forms 84.3% from the total stream number in the mountains zones, and the rest is in the Jordan rift valley (JRV) zone.

2.5. Bifurcation Ratio (Rb)

According to Horton (1945) the bifurcation ratio is the ratio of the number of the stream segments of given order to the number of streams in the next higher order Rb=Nu+Nu+1), the bifurcation ratio considered as index of relief and climatic conditions. In the present study, it was realized that the Rb is different from one order to its next order; these irregularities are dependent upon the geological and lithological characteristics of the drainage basin (Strahler 1964). The bifurcation ratio in the study area is ranges from 1.4 to 3.7, while lower value of the bifurcation value is found in the flat areas which represent the valley floor of the study area, where the higher values it found in eastern mountains part.

3.5. Drainage Density

Drainage density (Dd) is the total length of the stream from all orders within the basin per unit area. It has been calculated using Spatial Analyst Tool in

ArcGIS-10.1 and can Caudated by using this formula; D = ***Lk/Ak*** Where, **Lk** is the total length of the channel from all orders and, **AK** is the total basins area (Horton, 1945; Solomon, et al, 2012; Gregory, et al, 2001). The calculated (Dd) of study area is about 0.79 km/km², which is affected mainly by geology, climate, permeability of soil, surface gradient, and the characristics of precipitation**.** (Dd) varied between the sub-catchments, it reaches to its highest values for the sub-catchment numbers 2 and 8 with a values ranges between 4.3-3.8 km/km². The lowest values for the rest of sub-catchments 3, and 6 is ranges between 0.45-0.48. Km/km². The above mentioned results of the drainage basins and sub-basins characteristics show in general low density as Permeable rock, chalk, limited rainfall, and lower channel frequency.

Table 5. Summary of the main parametric elements of the drainage network of the study area.

Stream order	Stream number	Percentage %	Drainage density	Stream frequency	Bifurcation ratio
1st	1011	48.8	1.0	0.09	1.4
2nd	736	35.5	1.0	0.63	3.4
3rd	215	10.4	0.6	0.34	3.3
4th	65	3.1	0.5	0.42	2.1
5th	32	1.5	0.6	0.33	3.7
6th	12	0.6	4. 3	3.50	2.6
Total	2071	100%			

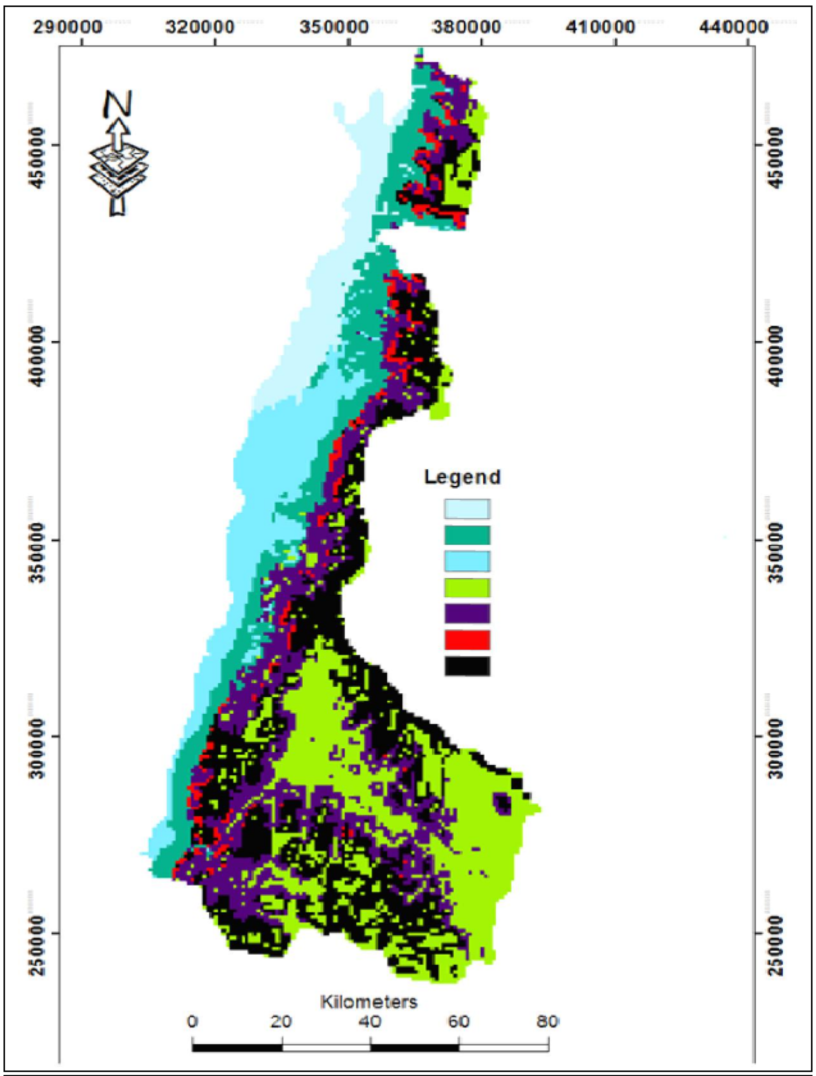

Figure 7. The major landforms types in the study area.

6. Landforms

The Landforms are defined as specific geomorphic features on the earth`s surface, ranging from large-scale features as mountain to minor features such as playa, and valleys (Blaszczynski, 1997). Landform carried out using classification of three morph metric parameters؛ relief, slope and profile index (Seif, 2014). Landforms in the study area classified according to recluses of slope, relief and profile index values into seven classes that shown in figure 7. And table 6.

Table 6. The main landforms classes in W.Araba by area.

Class	Area (km²)	Percent (%)	Landform Type
11	1985	17	Flat area/Valley floor (B.M.S.L)
12	987.65	9.9	Escarpment/ Steeply sloping
13	2810.72	21	Flat area/ Qaa or Sabkha
14	931	9.3	Gently sloping/ Plateau
15	1866.6	17.2	High altitude Plateau
16	1131,56	11.3	Low altitude Plateau
17	1430	14.3	High altitude mountains
Total	10011		

Conclusion

Using automated hydrological modelling tools of the GIS applied on the digital elevation model are very effective in deriving the morphometric basin parameters. Eight sub-catchments area were derived representing the major wadies in the wadi Araba region. The stream network was classified into 6th major orders. The dentritic drainage pattern covered most of the study area with about 85% of coverage. The high density dentritic drainage pattern was found at area characterized with high slope. The slopes of the area are ranges from zero at the foot of the wadi araba plain to more than 15% at the highland area at the eastern part of the Wadi Araba. The slope Aspect of the area is varies from flat to south with a dominant Aspect of north direction.

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