

Morphometric Analysis of the southern Al Jabal Al Akhdar Watersheds NE Libya

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ABSTRACT

The study aimed to quantify the morphometric characteristics of 11 watersheds in south Al Jabal Al Akhdar area (Green Mountain) located on northeast Libya. Where Digital Elevation Model (DEM) data of 1 arcsec resolution for the study area downloaded from USGS Earth Explorer and processed to extract the watershed attributes using ArcGIS software. In addition, the linear, areal, and relief aspects parameters and indices were computed. The stream number for the watersheds varies from first orders to seventh orders, where a large number of streams was found in the first, second, and third orders. Drainage networks of the watersheds are a dendritic pattern reflects the subsurface lithology. The total lengths of streams in the study area are 35757.8 km. Also, the correlation coefficients which calculated for the relationship between the stream number and the stream count and lengths showed strong inverse relation. Moreover, observed bifurcation ratio for the watersheds considered as low with exception of the seventh order in some watersheds, where the streams tend to be braided due to the stream runoff through the depositional zone that consisting of recent uncompact fluvial deposits. Drainage densities in the study area are coarse which indicated the much susceptibility to flooding and soil erosion. Where the drainage texture in the study area mostly is very coarse with the exception of some watersheds those are considered as coarse texture. Stream frequencies show very low values. Furthermore, the length of overland flow classified as moderate. The results of relief aspects computation show variation among the watersheds from high to low values. For the ruggedness number values, all watersheds show sharp morphology. Finally, The morphometric characteristics of the watersheds show moderate geomorphologic characteristics, stability in tectonic geology, and homogenous lithology, also the watersheds have intermediate to low flooding susceptibility but in case of heavy rainstorms a very strong flash flood may occur, as the upper stream areas of the watersheds prevail high risk of soil erosion, therefore flood protection, and soil conservation measures are crucially demanded in the study area especially in the northern parts.

Key Words: Green Mountain, Morphometry, GIS, Hydrology, Water harvesting.

1. INTRODUCTION

Morphometric analysis plays a significant role in understanding the geohydrological characteristics of the drainage basin in relation to the terrain feature and its flow patterns. It also helps to estimate the incidence of infiltration and runoff and another related hydrological character of a watershed like erosion and sediment transport which has a strong implication for natural resource conservation [1]. Moreover Drainage basin watershed analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics regarding slope, topography, soil condition, runoff characteristics, surface water potential, etc. [2]. The study area is shown in figure (1) located on the southern Al Jabal Al Akhdar area (Green Mountain), which is a mountain range along the northern coast of north eastern Libya, located approximately 31° N, and 23° E. The areal extent of the study area about 17721 km² extending from Wadi Al Bab in the west to Wadi Tamimi in the east, and from Taknis and Sidi Al Humree villages in the north to the temporary lakes areas in the south. Altitude of the watershed ranges from -2 m in the southern eastern parts to 880 m in the northern part. Moreover the study area comes under the agro-climatic zone of Al Jabal Al Akhdar which is a hot arid ecological region that characterized by a hot summer and dry winter in the south, and semi-arid in the north. The dominant land cover in the study area consists alluvial plains composed of ancient sediments of the fluvial activities and spreading zones composed of recent fluvial deposits, and both are consist of deposits range

from coarse desert alluvium with a pavement of gravel on the surface to silty alluvium with a finely textured surface. Vegetation land cover that consists of the forest land distributed only in northern parts of the study area consists of some species like cypress (*Cupressus spp.*) pinus (*halepensis spp.*) , ilex (*Ilex spp.*), juniper (*Juniperus spp.*) and other trees. Grassland and steppes landcover consists of plant communities of dwarf shrubs or grasses and annual herbs distributed sparsely in all the study area. The bare rock landcover which is consolidated and non-consolidated consisting mainly of marine carbonate rocks ranging in age from late Cretaceous to Quaternary.

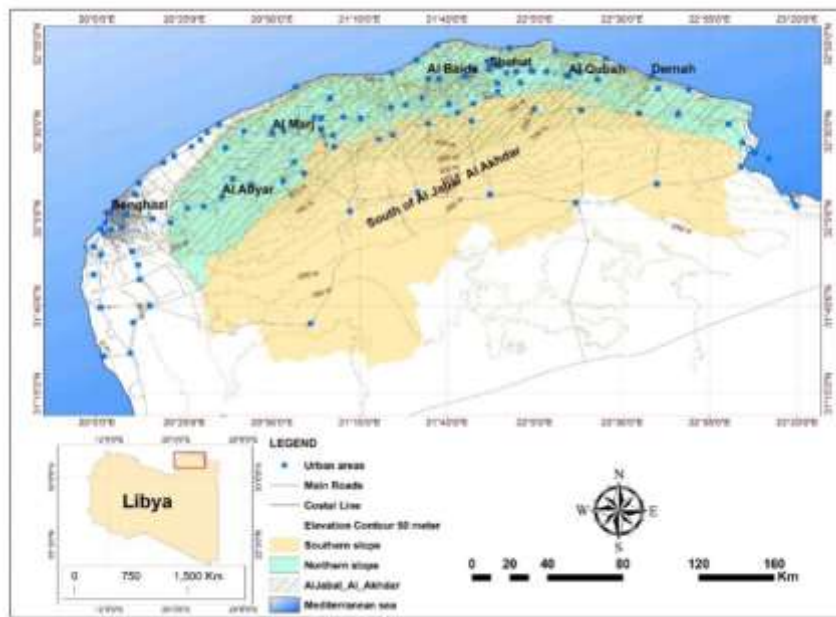


Figure 1. Location map of the study area

The watersheds are large and have a moderate slope receive a considerable amount of precipitation especially in the northern parts which reach 300 mm per year ,but unfortunately not utilized in a proper way, where most of the precipitated rain is lost in the evaporation and the remain goes for sudden floods that occur annually leading to natural disasters that result in heavy human and economic losses, in addition to the problems caused by soil erosion and transport from the north to the south leading to the loss of vegetation cover. Since soil and water resource are main resources in semi-arid and arid regions, therefore the aim of this work is to quantify the morphometric characteristics by conducting an automatic extraction of streams and morphometric parameters and indices using GIS techniques and remote sensing data for the southern Al Jabal Al Akhadar watersheds to provide reconnaissance data to help water and soil conservation issues.

2. RESESRCH METHODOLOGY

Digital Elevation Model (DEM) data of 1 arcsec resolution for the study area downloaded from USGS Earth explorer and processed according to the steps in figure (3) using ArcGIS software hydrology toolset , which is a tool in ESRI ArcGIS Spatial Analyst extension for processing topographic data to identify sinks, determine flow direction, calculate flow accumulation, delineate watersheds, create stream networks, and perform morphometric and hydrologic analysis[3]. Stream order was made according to Strahler’s law, and the morphometric parameters and indices were calculated according to the formulas in table (1).

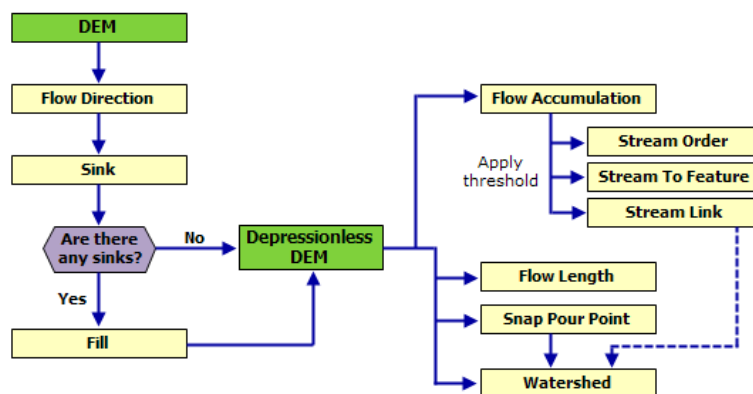


Figure 2. Watershed attribute extraction steps (ESRI,2018)

Table 1 . Methods for Calculation of Morphometric Parameters

Parameter	Symbo	Unit	Formulas	Citation
Linear Aspects				
Stream Order	u	-	Hierarchical rank	[4]
No.of stream	Nu	-		[5]
Stream Length	Lu	km	$L_u=L_1+L_2.....L_n$	[6]
Mean Stream Length	Lsm	km	$L_{sm}= L_u/N_u$	[6]
Stream length ratio	R _L	-	Where L_u = The mean length of all stream segments of a given order(u) $L_{(u-1)}$ = The mean length of all stream segments of one order less to given order(u)	[5]
Bifurcation ratio	R _b	-	$R_b= Nu/Nu+1$ $R_b = Nu/Nu + 1$; Where, Nu = Total no. of stream segments of order “u”; $Nu + 1$ = Number of stream segments of the next higher order	[7]
Mean Bifurcation ratio	R _{bm}	-	average of bifurcation ratio of all orders	[4]
Areal Aspects				
Basin length	L _b	km	Calculated by ArcGIS software	[5]
Basin area	A	km ²	Calculated by ArcGIS software	[5]
Basin Perimeter	P	km	Calculated by ArcGIS software	[5]
Drainage Density	Dd	Km/ km ²	$Dd= Lu/A$	[5]
Drainage texture	Dt	1/km	$Dt= Nu/P$, Where P= Perimeter (km)	[5]
Stream Frequency	Fs	1/ km ²	$Fs= Nu/A$	[5]
Form Factor	Rf	-	$Rf= A/L_b^2$ Where, L_b^2 = Square of the basin length	[5]
Elongation Ratio	Re	-	$Rc= 4\pi A/P^2$	[6]
Circulatory Ratio	Rc	-	$Re= (2/L_b)*(A/\pi)^{0.5}$	[8]+[4]
Length of Overland flow	Lof	Km ² / km	$Lof = 1/ 2Dd$,	[5]
Relief Aspects				
Basin Relief	Bh	m	$Bh = \text{Max.} - \text{Min. elevation of watershed}$	[9]
Relief ratio	Rh	m/km	$Rh= Bh/ L_b$	[6]
Ruggedness number	Rn	m*Km/ km ²	$Rn= Bh* Dd$	[6]

2. RESULT AND DISCUSSION

2.1 Spatial characteristics

Digital Elevation Model (DEM) processed and the results area illustrated in figure (3) and the geometric variables in the table (2), where the overall areas of southern watersheds of Al Jabal Al Akhdar 17721 a square kilometer, these watersheds bounded in the north by the hydrologic divide that extends from the southwest to the east with the length of 470,75 km.

2.2 Linear Aspects

The stream number or stream ordering (u) refers to the categorized position of the stream in a drainage basin. The value of stream order is dimensionless and it has a direct relation with the area of the subsidizing watershed, channel dimension as well as the stream discharges [10]. In the study area the streams orders and their numbers were extracted using ArcGIS hydrology toolset as in table (3), and the linear aspects were computed according to the formulas in table (1), The result of linear aspects computation are shown in the tables (4),(5), (6), and (7). The stream order (Nu) of the watersheds varies from first orders to seventh orders, where the total number of streams (Nu) for the watersheds is 53562. Where large numbers of streams were found in the first, second, and third orders, furthermore the first order streams account for 50 % of the total number of streams in all watersheds. moreover, it is observed the stream order increases as the count of streams decrease with exception of Al Bab watershed that shows low stream segments in the second order, which may due to the effect of local tectonic control. The drainage maps of each watershed with a stream order for the study area are shown in the figures (4) and (5), where the drainage networks of the watersheds are a dendritic pattern reflects the homogeneity in the subsurface lithology.



Figure 3. Spatial characteristics of the study area

Table 2. Geometric variables of the southern Al Jabal Al Akhadar Watersheds

Watershed	Area Sq. km	Length Km	Perimeter Km	MIN Elevation M	MAX Elevation M	Average Elevation M	Average SLOPE DEG	Average ASPECT
Al Bab	1082	74.1	332.3	98	603	276	3.41	SE (157)
Msus	2039	90.9	416.3	44	644	212	2.53	SE (134)
Al Khrubah	3928	105.8	599.8	63	670	222	2.36	SE (124)
Samalus	1511	87.7	512.7	139	775	419	3.61	SE (149)
Qlulud	569	45.8	216.9	140	303	188	2.21	SE (119)
Therwa	1484	67.5	309.9	141	736	364	3.72	SE (151)
Al Hamamah	1522	78.9	354.9	124	832	364	3.69	SE (149)
Tanmlou	301	65.8	251.3	125	762	382	3.86	SE (148)
Ar Ramlah	1559	81.7	364.9	131	880	427	3.16	SE (140)
Muallq	869	109.1	426.8	-6	852	417	3.34	E (106)
Tamimi	2857	79.9	491.3	-2	464	220	2.25	E (112)

Stream length (L_u) which is a characteristic property related to drainage network [6], in the study area the highest lengths observed in the first orders and decreases as the stream order increases, where the total lengths of streams in the study area are 35757.8 km. Also, the first order streams account for 50 % of the stream length in all watersheds, where Al Kharubah and Msus watersheds are the highest in stream lengths, and the lowest in stream lengths in Qlulud and Thuban watersheds. Furthermore, the correlation coefficients calculated for the relation between the stream order versus the stream count and stream lengths showed strong inverse relation. Stream length (L_u) which is a characteristic property related to drainage network [6], in the study area the highest lengths observed in the first orders and decreases as the stream order increases, where the total lengths of streams in the study area are 35757.8 km. Also, the first order streams account for 50 % of the stream length in all watersheds, where Al Kharubah and Msus watersheds are the highest stream lengths and the lowest in stream lengths in Qlulud and Thuban watersheds. Furthermore, the correlation coefficients calculated for the relation between the stream order versus the stream count and stream lengths showed strong inverse relation. Stream length ratio (R_L) which is defined as the ratio between the mean stream lengths of one order with that of the next lower order of the stream segments [11]. The maximum value of R_L in Tamimi watershed 6.714 watershed and minimum value also observed in Tamimi watershed, where the value of R_L will have close resemblance with the

comparative permeability of the underlying rock structures of the watershed. The R_L values show significant interrelationship towards the discharge of streamflow on the surface and the stage of erosion of the watershed [12], moreover, the variation in the R_L values from one order to the successive order reveals their delayed youthful stage in the development of geomorphic structures [13]. In the other hand, an increasing trend in the stream length ratio from lower order to higher order indicates their mature geomorphic stage[14].

Table 3. Total Number of stream segments

Watershed	Orders							Total (Nu)	Correlation coefficient
	I	II	III	IV	V	VI	VII		
Al Bab	1622	731	449	174	176	67	0	3219	-0.874
Msus	3182	1358	848	547	246	126	14	6321	-0.875
AlKhrubah	6088	2760	1481	1010	491	145	144	12119	-0.871
Samalus	2370	1087	633	345	123	159	0	4717	-0.875
Qlulud	889	421	205	130	82	27	0	1754	-0.877
Therwa	2281	1048	511	305	216	154	24	4539	-0.860
Al Hamamah	2385	1031	544	399	252	128	9	4748	-0.864
Thuban	457	199	127	31	88	0	0	902	-0.862
Ar Ramlah	2406	1018	679	274	173	264	110	4924	-0.840
Muallq	1334	587	284	217	62	161	0	2645	-0.847
Tamimi	3262	1993	1122	755	214	255	73	7674	-0.923

Table 4. Stream Length(Lu) km

Watershed	Orders							Total	Correlation coefficient
	I	II	III	IV	V	VI	VII		
Al Bab	993.3	47.0	271.1	102.2	92.3	32.0	0.0	1537.9	-0.697
Msus	2032.9	956.0	552.3	312.0	144.0	77.0	9.5	4083.7	-0.905
AlKhrubah	3836.8	1991.0	1017.0	653.0	312.0	86.0	87.0	7982.8	-0.919
Samalus	1398.0	682.8	362.5	180.5	54.0	86.0	0.0	2763.8	-0.897
Qlulud	553.0	292.0	147.0	87.0	47.0	24.0	0.0	1150.0	-0.913
Therwa	1437.0	729.0	335.0	161.0	120.0	96.0	13.0	2891.0	-0.887
Al Hamamah	1425.0	689.0	340.0	220.0	156.0	74.0	10.0	2914.0	-0.891
Thuban	278	140	85	18.6	51	0	0	572.6	-0.900
Ar Ramlah	1530	686	383	167	95	118	11	2990.0	-0.874
Muallq	801	409	170	130	34	87	0	1631.0	-0.873
Tamimi	4475	1493	699	441	10	80	43	7241.0	-0.843

Table 5. Mean Stream Length

Watershed	Orders						
	I	II	III	IV	V	VI	VII
Al Bab	0.612	0.064	0.604	0.588	0.525	0.478	0.000
Msus	0.639	0.704	0.651	0.570	0.585	0.611	0.679
AlKhrubah	0.630	0.721	0.687	0.647	0.635	0.593	0.604
Samalus	0.590	0.628	0.573	0.523	0.439	0.541	0.000
Qlulud	0.622	0.694	0.717	0.669	0.573	0.889	0.000
Therwa	0.630	0.696	0.656	0.528	0.556	0.623	0.542
Al Hamamah	0.597	0.668	0.625	0.551	0.619	0.578	9.000
Thuban	0.608	0.704	0.669	0.601	0.580	0.000	0.000
Ar Ramlah	0.636	0.674	0.564	0.609	0.549	0.447	0.100
Muallq	0.600	0.697	0.599	0.599	0.548	0.540	0.000
Tamimi	1.372	0.749	0.623	0.584	0.047	0.314	0.589

Table 6. Stream length ratio

	I/II	III/II	IV/III	V/IV	VI/V	VII/VI
Al Bab	0.105	9.389	0.973	0.893	0.910	-
Msus	1.102	0.925	0.876	1.026	1.044	1.110
AlKhrubah	1.145	0.952	0.942	0.983	0.933	1.019
Samalus	1.065	0.912	0.913	0.839	1.232	-
Qlulud	1.115	1.034	0.933	0.856	1.551	-
Therwa	1.104	0.942	0.805	1.052	1.122	0.869
Al Hamamah	1.118	0.935	0.882	1.123	0.934	1.922
Tanmlou	1.157	0.951	0.898	0.964	-	-
Ar Ramlah	1.060	0.837	1.081	0.901	0.814	0.224
Muallq	1.160	0.859	1.001	0.915	0.985	-
Tamimi	0.546	0.832	0.938	0.080	6.714	1.878

Bifurcation ratio R_b has a close relationship with the drainage network branching pattern as greater R_b , the lower the branching pattern in the drainage network and vice versa [15]. The higher value of R_b shows the extreme overland flow and high tectonic activity. The lower value of R_b shows very less distort of geological structure in the drainage pattern that evidently reflects the very partially disturbed watershed [16]. In addition, R_b has a direct relationship with erodibility which makes the sub-watersheds having higher R_b highly vulnerable for soil erosion. Various morphological parameters such as basin shape, drainage density, stream entrance angles, geological characteristics, and basin area also control R_b [17],[18],[19] and [10]. Also, the classifications of range value for the R_b varies among the researchers and there is no statement for it, therefore based on some researches, it can be concluded that less than five (5) may be classified into low, and more than five (5) into high [2]. In the study area the bifurcation ratio is considered as low with the exception of the seventh order in Msus, Therwa, and Al Hamamah watersheds, where the R_b values are high, which can be interpreted as the behavior of the streams tends to be braided due to the runoff through the depositional zone consist of a recent uncompact fluvial sediments.

Table 7. Bifurcation ratio

Watershed	Orders						Mean
	I	II	III	IV	V	VI	
Al Bab	2.22	1.63	3.1	0.99	2.63	-	2.01
Msus	2.34	1.60	3.1	2.22	1.95	9.00	3.11
AlKhrubah	2.21	1.86	3.1	2.06	3.39	1.01	2.00
Samalus	2.18	1.72	3.1	2.80	0.77	-	1.86
Qlulud	2.11	2.05	3.1	1.59	3.04	-	2.07
Therwa	2.18	2.05	3.1	1.41	1.40	6.42	2.52
Al Hamamah	2.31	1.90	3.0	1.58	1.97	14.22	3.89
Tanmlou	2.30	1.57	3.2	0.35	-	-	2.08
Ar Ramlah	2.36	1.50	3.0	1.58	0.66	2.40	1.83
Muallq	2.27	2.07	3.0	3.50	0.39	-	1.91

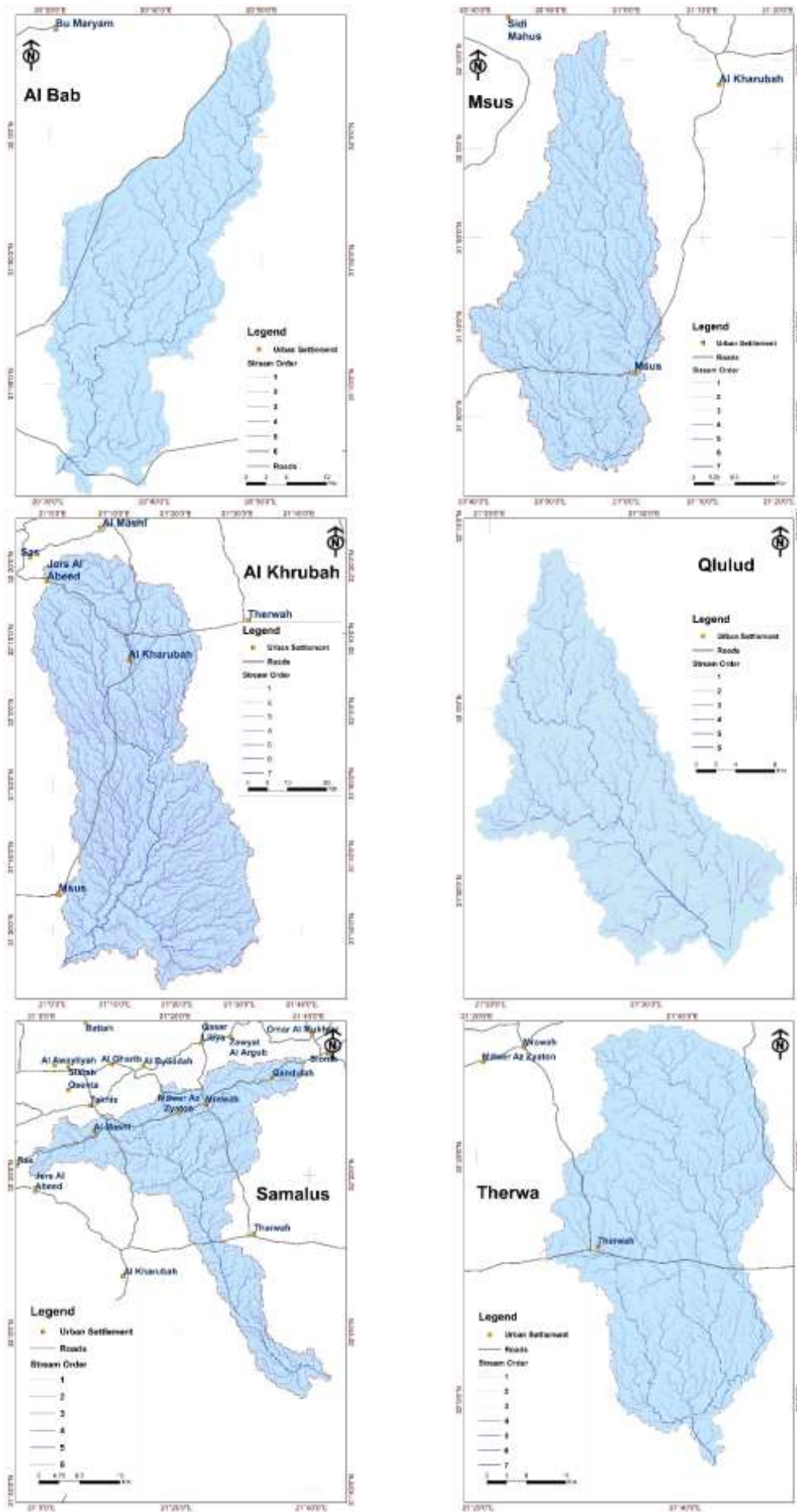


Figure 4. Watersheds stream orders

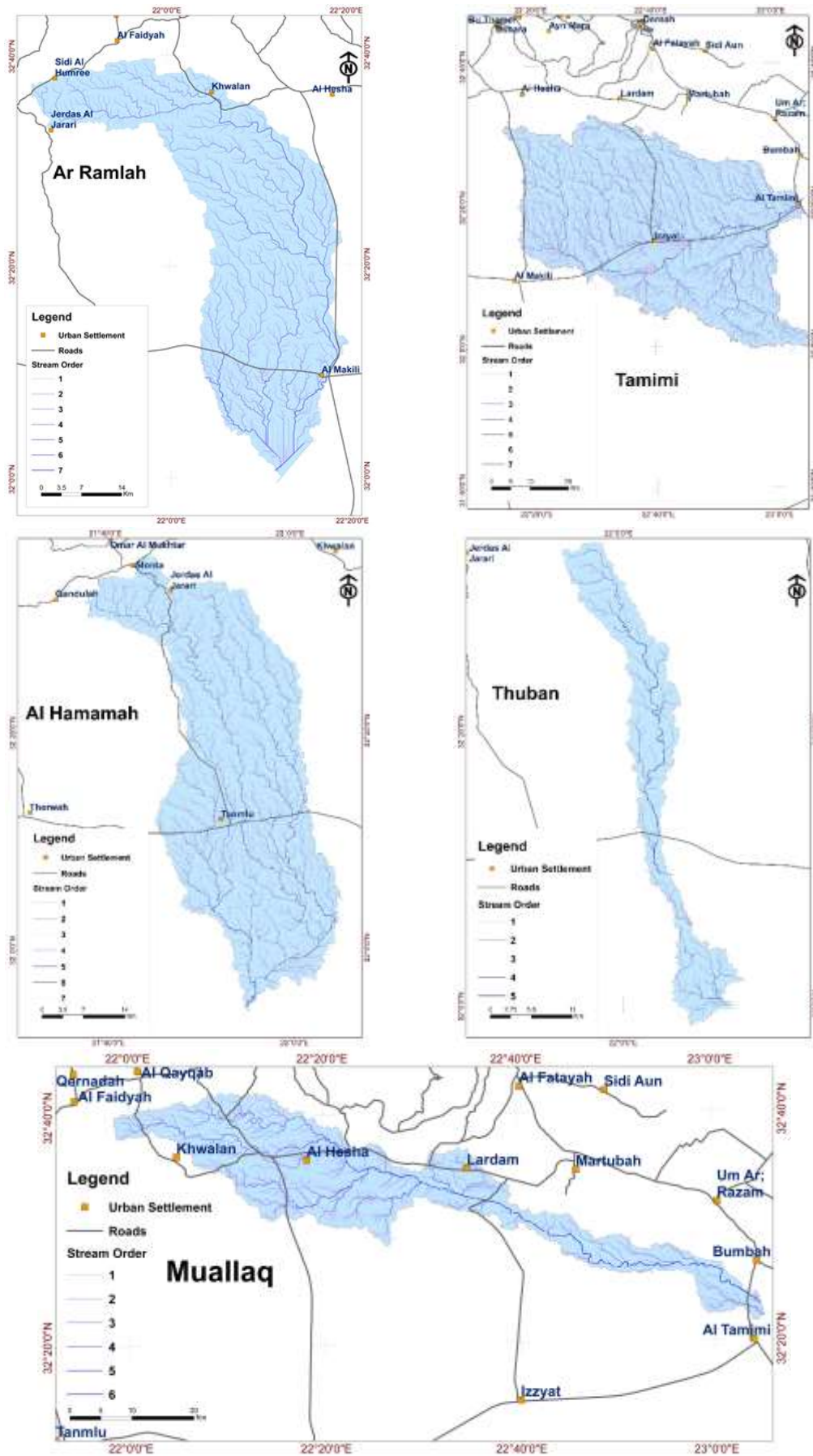


Figure 5. Watersheds stream orders

2.3 Areal aspect

The result of areal aspect computation is shown in table (8) and illustrated in figure (6). Drainage density (Dd) which is total length of streams of all orders per drainage area, also it is important factor for indication of landscape dissection and peak runoff potential of basin [20], where the higher drainage density of the watershed shows poor vegetation cover and impermeable underlying materials and vice versa [21]. The drainage density can be classified according to [20] into; coarse ≤ 5 , medium 5-10, and fine ≥ 10 . In the study area the drainage density is coarse which indicated the high susceptibility to flooding and soil erosion. The drainage texture (Dt) which is classified into five classes with the following value ranges; very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8) [22]. In the study area most the drainage texture of the watersheds are very coarse with exception of Tamimi, Msus, Al Khrubah, and Qlulud watersheds those are considered as coarse, where hydrologically the very coarse texture watersheds have large basin lag time periods [23]. Stream frequency (Fs) is the total number of channel segments of all stream orders per unit area, and the total number of channel segments are dimension-less [20]. Generally, the value of stream frequency ranges from 3.91 to 9.99. Also, Fs values depend on the lithology of the catchment and reflect the texture of the drainage network. The Fs values are positively correlated with Dd values of the watershed, which means that the increase in stream population is connected to drainage density [24]. High stream frequency means more percolation with respect to drainage density and thus more groundwater potential [12]. In the study area, Fs ranges from 2.98 to 3.12 indicating low stream frequency, which can be interpreted as a result of the homogeneity of the underlain strata and low climatic impact. Form factor (Rf) which is the ratio of watershed area to the square of the length of the watershed. Flood hydrograph always affected by the basin form [25]. There are some different value ranges for form factor, as the range values for form factor are <0.78 (elongated) and >0.78 (circular) [26], also the catchments with high Rf, have peak flows of shorter duration, whereas elongated watersheds with low form factors have lower peak flow of longer duration [27] and [28]. According to the result, the study area watersheds are elongated as its also observed from the values of elongation ratio (Re) and circularity ratio (Rc). Length of Overland (Lof) flow relates to the length of water over the ground before it becomes concentrated into definite stream channels. It is considered the most crucial independent variable affecting hydrological and geomorphological development of drainage basins [29]. The average length of overland flow is relatively half the average distance between stream channels, and thus, is approximately equal to half of the drainage density [5]. Length of overland flow relates inversely to the average channel slope [30]. There are three classes of Lof i.e., low value (< 0.2), moderate value (0.2 – 0.3), and high value (>0.3) [31]. where the low value of Lof indicates high relief [26], short flow paths, more runoff, and less infiltration [31], which leads to more vulnerable to the flash flooding. Meanwhile, a high value of Lof means gentle slopes and long flow paths [32] more infiltration, and reduced runoff [31], in the study area Al Bab watershed has the high value and Tamimi has the low value of Lof, other watersheds can be classified as moderate Lof.

Table 8. Areal aspects

Watershed	Drainage Density km/ km ²	Drainage Texture km/ km ²	Stream Frequency 1/SQ km	Basin length km	Form Factor	Circularity Ratio	Elongation Ratio	Length of overland flow
Al Bab	1.420	9.690	2.980	74.100	0.197	0.123	0.501	0.352
Msus	2.000	15.180	3.100	90.900	0.247	0.148	0.561	0.250
Al Khrubah	2.030	20.210	3.090	105.800	0.351	0.137	0.669	0.246
Samalus	1.830	9.200	3.120	87.700	0.196	0.072	0.500	0.273
Qlulud	2.020	8.090	3.080	45.800	0.271	0.152	0.588	0.247
Therwa	1.950	14.650	3.060	67.500	0.326	0.194	0.644	0.257
Al Hamamah	1.910	13.380	3.120	78.900	0.244	0.152	0.558	0.261
Thuban	1.900	3.590	3.000	65.800	0.070	0.060	0.298	0.263
Ar Ramlah	1.920	13.490	3.160	81.700	0.234	0.147	0.545	0.261
Muallq	1.880	6.200	3.040	109.100	0.073	0.060	0.305	0.266
Tamimi	2.530	9.690	2.980	79.900	0.448	0.149	0.755	0.197

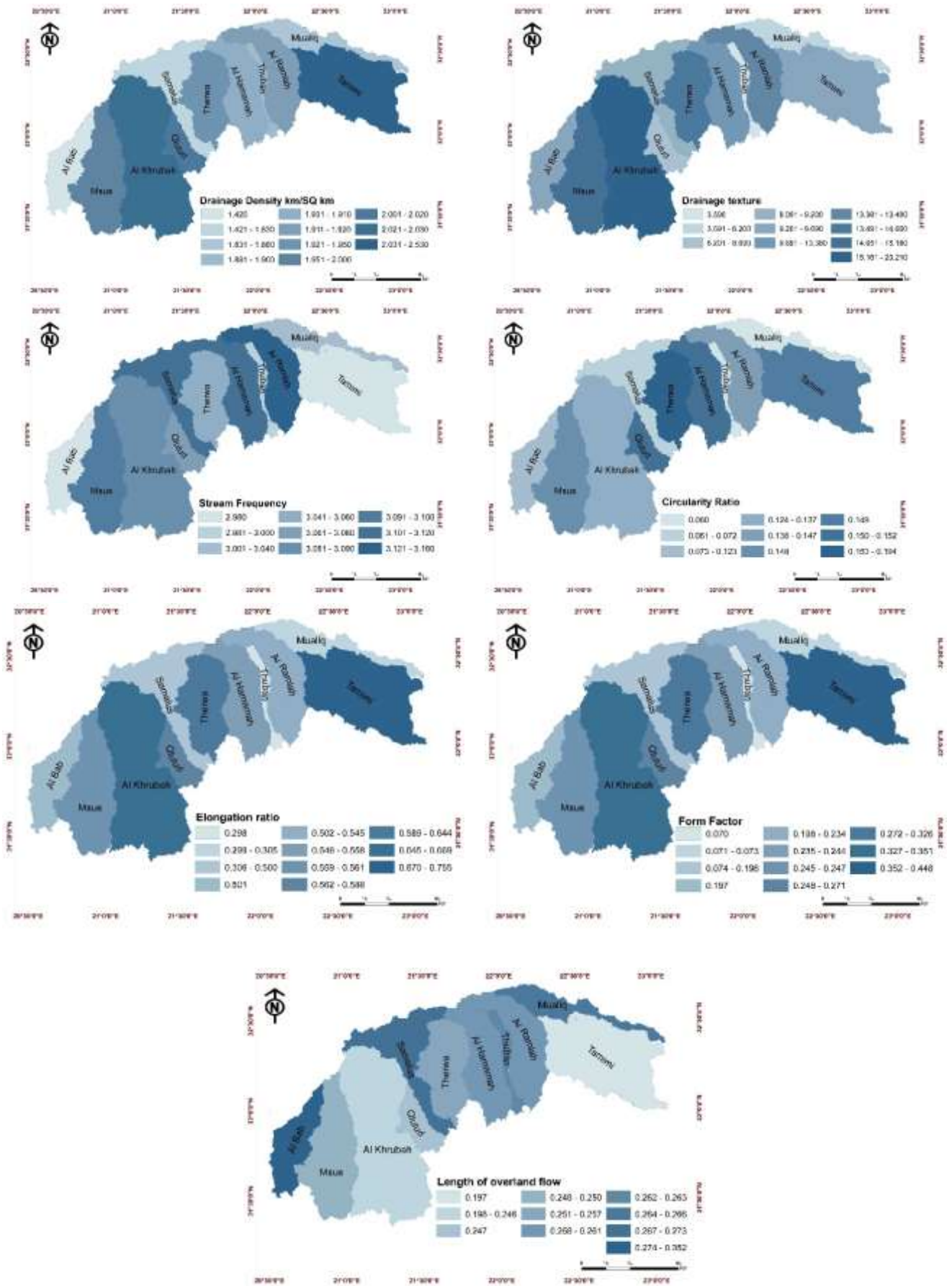


Figure 6. Areal aspect maps

2.4 Relief aspect

The result of relief aspects computation is shown on table (9) and figure (7). Basin relief (Bh) or “total relief” of a watershed is defined as the difference in elevation between the highest and lowest points on the basin [7]. The total relief in the study area varies from 163 m in Qlulud watershed and to 858 m in Muallq, while other watershed basin relief (Bh) shows close values . Relief ratio which is the ratio of the total relief of the basin to it the longest basin length measured along the main drainage line [7]. Where the low value of relief is due to hard rock and low degree of slope. The highest value indicates steep slope and high relief [20]. Moreover Relief ratio (Rr) is considered a reasonable mean to measure the overall steepness of a drainage basin. Also, it is an indicator of the intensity of erosion processes operating on the watershed slopes [33], highest relief ration is observed in Muallaq watershed indicating the steep slope, while the low values observed in Qlulud ,Tamimi, and Al Khrubah indicating low slope ,other watersheds observations of (Rh) indicates moderate to low relief. The ruggedness number (Rn) is defined as the product of drainage density (Dd) and basin relief (Bh) divided by 1000 [4] and [6]. Observed values of ruggedness number range from low (i.e. 0.06) for smooth and subdued morphology to over 1.0 for sharp morphology, and very high, extreme values (>2) characterizing bad lands topography where the watersheds having high Rn values can be described by high susceptibility to soil erosion, land sliding, and a high response to an increase in peak discharge[29]. I Ruggedness number values in the study area indicates sharp morphology for all the watersheds.

Table 9. Relief aspect

Watershed	Basin Relief	Relief ratio	Ruggedness number
Al Bab	505	7.28	0.72
Msus	600	6.03	1.20
Al Khrubah	607	4.22	1.23
Samalus	636	7.57	1.16
Qlulud	163	3.4	0.33
Therwa	595	7.17	1.16
Al Hamamah	708	8.43	1.36
Thuban	637	19.01	1.21
Ar Ramlah	749	8.76	1.44
Muallq	858	13.84	1.61
Tamimi	466	3.87	1.18

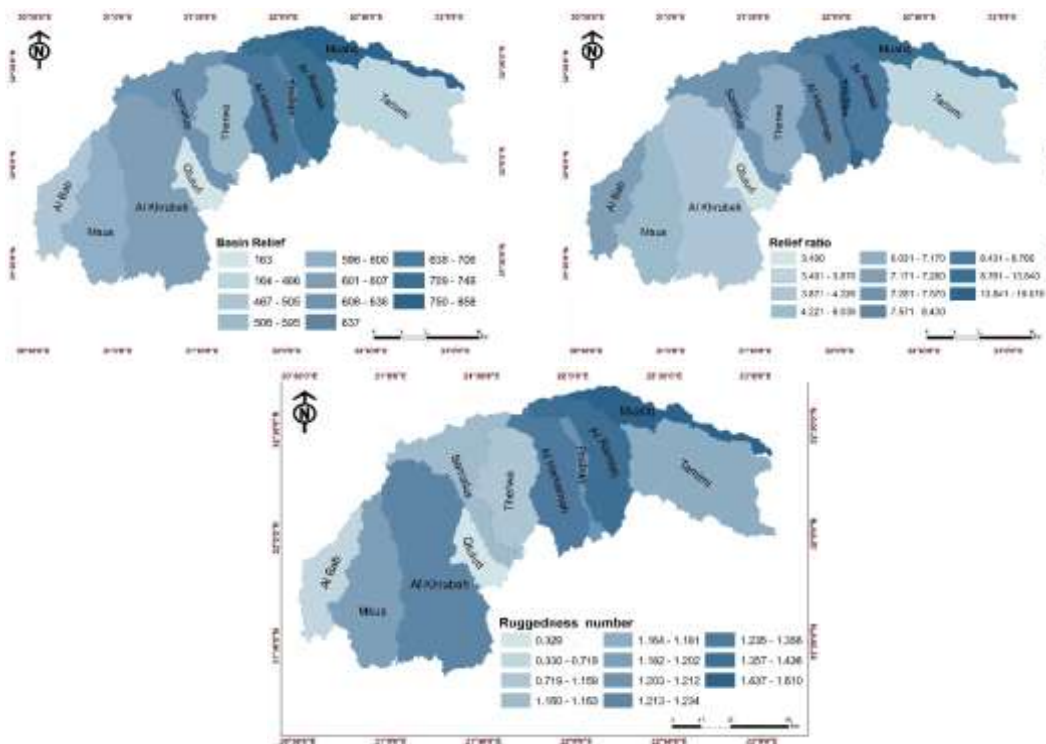


Figure 7. Relief aspect maps

3 CONCLUSION

From the result of morphometric analysis for the 11 watersheds, it is concluded that the whole watersheds area has uniformity in underlying lithology, and there is similarity in the observed morphometric characteristics with some exceptions due to the local geologic structure in some watersheds. Moreover, the watersheds have intermediate to low flooding susceptibility but in case of heavy rainstorms a very strong flash flood may occur, as the drainage networks are coarse with sharp morphology and poor land cover. Also, the watersheds are vital areas for pastoral activities, rainfed crops and considered as promising areas for investment in water harvesting, which in turn covers some of the water demands for different purposes, as well as an important technique in protecting soil from erosion. Moreover, the hydrological investigation is crucially required to quantify the surface runoff of these watersheds which will give more insight for the surface water potential, flood protection procedures, and soil conservations measures.

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