MORPHOMETRIC ANALYSIS OF WADI DARNAH WATERSHED NE LIBYA, USING GIS TECHNIQUES

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Abstract

Wadi Darnah is about 586 km^2 and lies in the northern portion of the Al Jabil AL Akhdar. The Wadi drains into the Mediterranean Sea. The present study incorporates a morphometric analysis of Wadi Darnah by using remote sensing and GIS techniques. Digital Elevation Model (DEM) and topographic sheets were processed in ArcGIS software. The study revealed that the drainage patterns of stream network from the basin are mainly of dendritic type which indicates homogeneity in texture and lack of structural control. The bifurcation ratio value of 4.53 indicates that the area is not much influenced by the geological structure and undisturbed drainage pattern. The study area is of the low density group basins (2.09 km^{-1}). The elongation ratio (0.36), circularity ratio (0.14) and form factor (0.10) show elongated basin with steep relief, moderate discharge, and a long main channel. The basin has a high relief up to 850 m, which leads to a high rate of runoff but the effect of this water flow is reduced by the high infiltration capacity due to the high rate of karstification and karst features in the basin area.

Keywords: Morphometric parameters; GIS; Watershed; Ordering and Wadi Darnah.

Introduction

A drainage basin is the part of the earth's surface that is drained by the main stream and its tributaries. The drainage basin is a fundamental geomorphic unit of land and the flow of surface is governed by its properties. It is an open system into which and from which energy flows. Drainage basin is a fundamental, precise and usually ambiguous unit that is recognized as a reliable and useful planning unit. It has now formed a framework for human activities like agriculture and has guided river navigation towards sustainable agriculture (Ofomata and Umeuduji, 2000).

Horton (1945) initiated a scientific approach to the hierarchical classification of streams and basin area through defining and measuring several drainage basin characteristics on topographic maps. Today, these characteristics can be measured on satellite imageries. These characteristics include stream order, stream length, bifurcation ratio, basin area and length, perimeter, drainage density, stream frequency, elongation ratio, circularity ratio, texture ratio and form factor ratio (Shreve, 1966).

The analysis of branching drainage network an ingenious numbering system derived by Horton (1945) and modified by Strahler (1952) is one of the early accomplishments of fluvial morphometry. The fingertip tributaries of streams originate from overland or ground water flow and they are designated as first order stream. The second order stream begins at the junction where two first order streams meet; it may receive additional first order tributaries but there is no increase in the second order stream. Where two order streams meet a third order stream is formed. It continues like that till the last order is reached.

Today, a more efficient technique of Geographical Information System, to measure drainage basin characteristics, boosts the work of Horton, (1945). This technique is used for spatial analysis of spatially referenced data. Previously, the application of GIS environment has not been widely used in drainage basin analysis. This technique would be used to measure the morphometric characteristic of the watershed (Wadi Darnah Basin).

The study area encompasses about 586 km^2 in the northern part of the Al Jabil AL Akhdar andit includes cities of Darnah and Al Qubah. Geographically. It lies between longitudes 21°57' 00" and 22°44' 00" East and latitudes 32°35'00" and 32°50' 00" North, see Figure (1). Wadi Darnah represents one of the important Wadis in AL Jabil Al Akhdar system. It runs from the outskirts of the AL Qayqab, a city southwest of Darnah, to northward, and drains into the Mediterranean Sea. In Wadi Darnah there are two abundant natural springs (fresh water), Ain al-Bilad and Ain Abu Mansur, and the latter one is pouring from a high hill to the main trunk of the wadi, forming the famous Abu Mansur waterfall. Two dams were constructed in this wadi; the first one is Darnah dam with total capacity of about 1MCM (Million Cubic Meters) and Abu Mansur dam with storage capacity of 22.3 MCM (Arghin and Hamad, 2003). Wadi Darnah basin can be divided into three sub basins as follows:

1- The upper sub basin is occupying southwest portion of the studied Wadi with an area about 345km^2. This sub basin is characterized by high amounts of annual rainfall which reach about 400mm/cm^2.

2- The middle sub basin is located between the Seyrt El Washka area and Abu Mansur dam. This part is about 140 km^2 and its average annual rainfall is 150 mm/cm^2.

3- The lower sub basin is located between Abu Mansur dam and the Mediterranean Sea. This part of Wadi Darnah receives an average rainfall of about 250 mm/cm^2 .Rainfalls caused flash floods that collected in the Lake of Darnah dam.

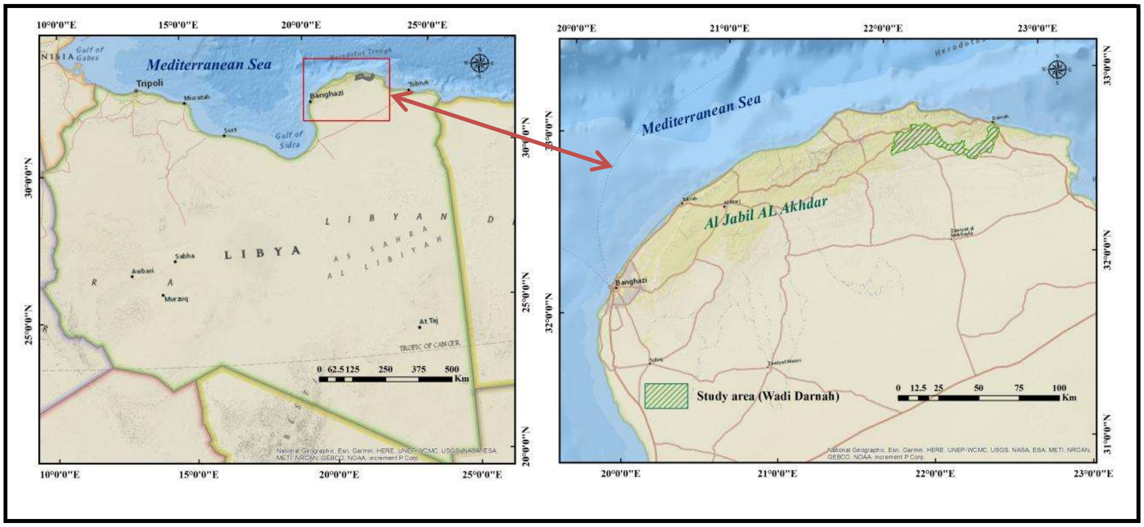

Figure (1): Location Map of Al Jabil AL Akhdar, Showing Wadi Darnah.

Climatologically: the studied area is classified as of mediterranean to semi-arid, with a hot and dry summer to a cold and rainy winter. June has the highest temperature during the year; the average maximum temperature is 44.8°C, while January and February months have the lowest temperature; the average minimum temperature is 4.4°C. The level of humidity is relatively high due to being close to the sea; it ranges from 78% in the summer to 75.3% in the winter. The study area usually receives rainfall from September to June with a maximum value of 60 mm in January and a minimum value of 2 mm in June. Generally, the total annual rainfall is about 274 mm (DWD, 2013). The rainfall is noticed in the form of flash flood with heavy rainfall within short time and high intensity, which may cause disasters. This area received several high flash floods as in 1941, 1956, 1959, 1968, 1986 and 2011.

Geological and Geomorphological Settings

Stratigraphy: the stratigraphic sequence of Wadi Darnah basin is represented mainly by carbonate rocks, ranging in age from Eocene to early Miocene. Five formations have been recognized namely; Apollonia, Darnah, al-Bayda, al-Abraq and al-Faidiyah; they are arranged from the oldest to the youngest following Rohlich, 1974 – Figure (2).

Eocene deposits: the Eocene sequence in the study area is represented by two formations. The **first is** *Apollonia Formation*, which consists of light coloured, massive, fine-grained, siliceous limestones with chert nodules. The limestones are chalky and sometime marly. A characteristic feature of the limestone is the bituminous smell it produces when being struck (El Hawat and Thomas, 2005). The second is *Darnah Formation*, which consists of a basal bed of hard, massive, fine-grained, creamy grey limestone, which contains *Nummulites gizhensis*, followed upward by light grey, medium-grained, nummulitic limestones with intercalations of dolomitic limestone (El Hawat and Abdulsamad, 2004).

Oligocene deposits: the Oligocene sequence in the study area is represented by the Al Bayda Formation followed by Al-Abraq Formation. The *Al Bayda Formation* consists of two members: (a) the first is Shahht Marl member, which consists of grey to yellow marl together with marly limestone (wackestone-packstone) and gluconitic fossiliferous limestone and (b) the second is Algal limestone member, which consists of yellowish limestone, soft marl and argillaceous limestone interbeds (Abdulsamad et al., 2009) .*Al-Abraq Formation* consists of yellowish white, soft to medium hard limestone or grainstone (Muftah and Erhoma, 2002).

Miocene deposits: represented mainly by *Al-Faidiyah Formation* consists of basal gluconitic marl and argillaceous microcrystalline limestone grading upward into yellowish, fossiliferous, massive and cross-bedded packstone and wackestone (El Hawat and Abdulsamad, 2004).

It is obvious that the areal distribution of the aforementioned formations are arranged regionally from the youngest one in the upstream part to the oldest in the downstream part Figure (2).

Structure: Al Jabil Al Akhdar defines a gentle doubly plunging anticlinorium with axis trends roughly N50°E and plunges gently to the northeast and southwest. Abd El-Wahed and Kamh (2013) recorded in Wadi Darnah region two main fault systems, the first is a set of E-W striking faults, and the second is a system of normal NW-SE striking faults Figure (2). These structural elements play an important role in the development of the drainage pattern of Wadi Darnah basin.

Geomorphologic Setting: *Regional Geomorphology;* The geomorphologic features in Al Jabal Al AKhdar are largely related to tectonic events, which dominated the area from the Upper Cretaceous to the Tertiary, and also to the prevailing climatic conditions, weathering and erosion processes of the existing extensive carbonate rocks in the region. In a geomorphologic expression, Al Jabal Al Akhdar represents a rising hill, which its northern sides slope steeply towards the coast forming steep cliffs separated from the sea by a coastal band, which differs in width from one place to the other, and which its southern sides lopes gradually until it merges with the southern physiographic zone. In the northern side, Al Jabal al Akhdar appears as elongated ridges extending from west to east, and it is almost parallel to the Mediterranean Sea. Two main steps bounded by escarpment and differ in their width and steepness of the slope can be distinguished. The first escarpment is the longest and highest one about 300 meter, a.m.s.l. .Detailed geomorphologic studies show that the escarpment consists of steps that are of a limited extension and width formed by marine erosion, and extend along those steps alluvial fans that are crossed by short wadies. The width differs also from one place to the other; about 20 km^2 in Al Marj area and it gets narrower to the east. (Arghinand Hamad, 2003).

***Local Geomorphology*:** the Wadi Darnah basin is located in the northern flank of Al Jabil Al akhdar, which consists of steep plateaus bordered by escarpment. The study area is characterized by a wide range of elevation of land surface from (+856 ma.m.s.l) at the upstream to (+6 m a.m.s.l) at the downstream, and generally it slopes towards the north. This Wadi drains its flash flood water into the Mediterranean Sea as shown in the Digital Elevation Model Figure (3). The landscape of Wadi Darnah basin can be regarded as a result of interactions between the geological and structural characteristics such as; types of rocks ,faults ,strata thickness ,dipping etc. and external factors such as wind and torrential action.

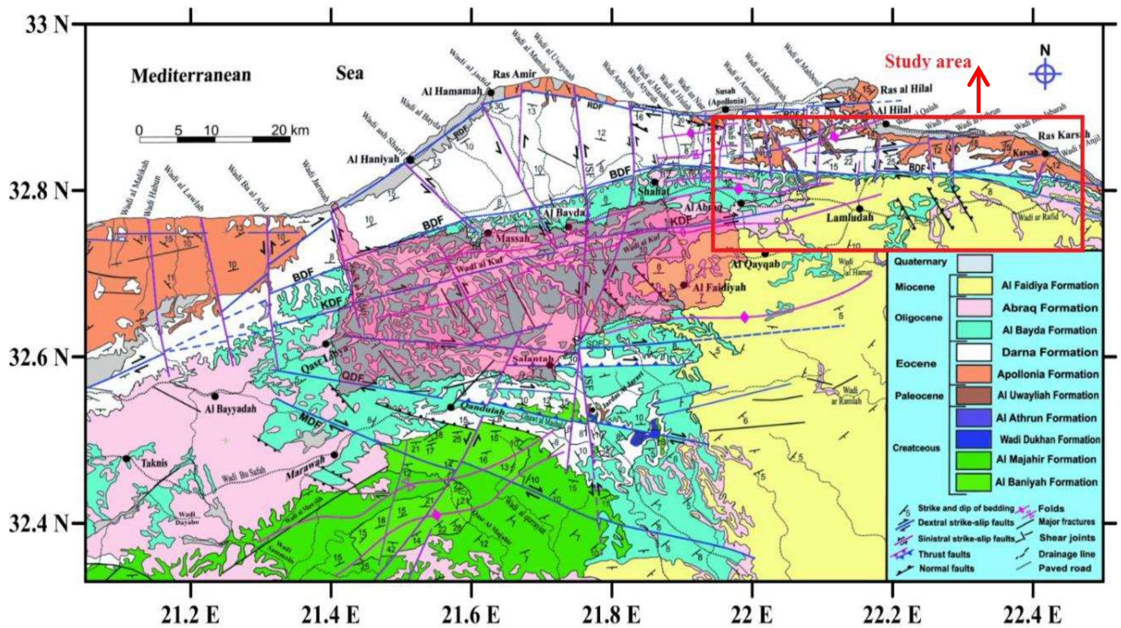

Figure (2): Geologic Map of w. al-Kouf Watershed (After Rolich, 1974 and Modified by Abd El-Wahed and Kamh, 2013).

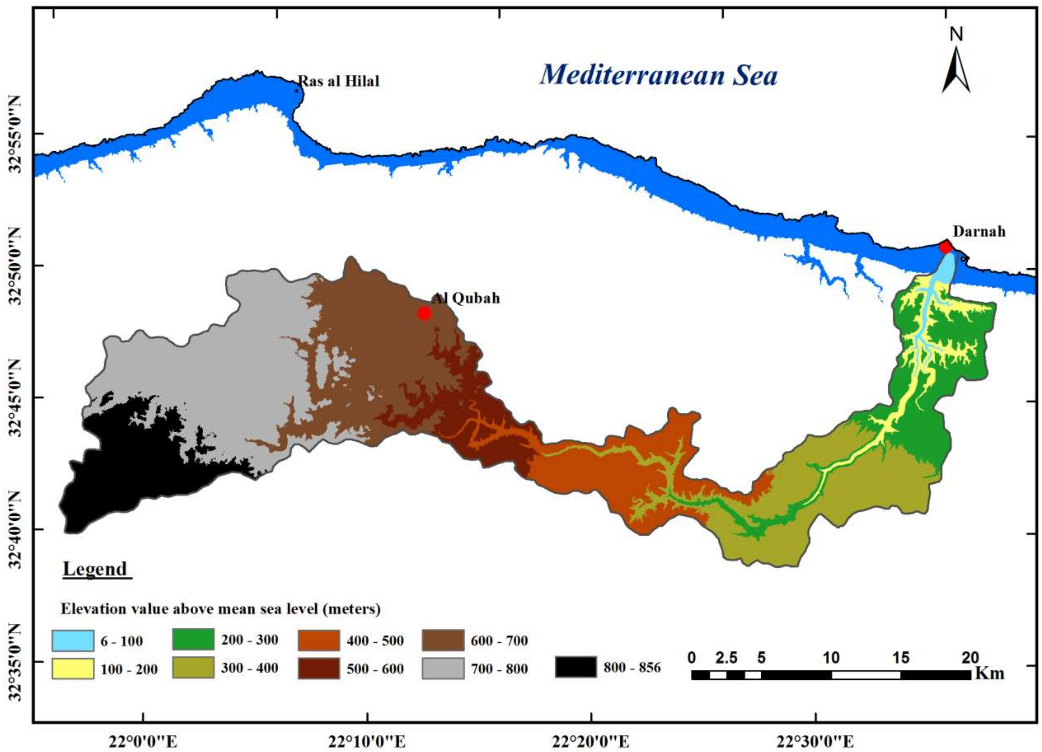

Figure (3): Digital Elevation Model (DEM) of Wadi Darnah.

Materials and Methods

- Several previous studies and reports about climate, lithology, structure and stratigraphy of the Al Jabil Al Akhdar have been collected.
- Shuttle Radar Topography Mission (SRTM) images which were produced in September 23, 2014provide details down to 30m lengths (available at https://dwtkns.com/srtm30m/). ArcGIS (v. 10.3) software have been used to delineate W. Darnah basin from SRTM data and to extract the surface derivatives such as relief map, Digital Elevation Model (DEM), contour, drainage network maps.
- A Topographical Map (scale 1:50.000), was scanned and imported to ArcGIS (v. 10.3) where it was georeferenced. After georeferencing, onscreen **a** digitization process was carried out to determined catchment boundary and drainage networks for W. Darnah.
- The various morphometric parameters of Wadi Darnah were computed and the results were graphically represented using Microsoft Excel 2010.

Morphometric Characteristics

The morphometric analysis in this study is mainly based on the physiographic features of the basin through tracing the drainage network by using a digital elevation model (DEM) of 30-m resolution. Depending on Strahler method (Strahler, 1957), the streams were ordered, and the different parameters were measured and calculated according to Horton (1932 and 1945) as shown in Tables (1) and (2). In this modal, such parameters can be grouped into four categories: linear aspect, areal aspect, drainage texture analysis and relief aspect.

Linear Aspects of the Drainage Network: The linear aspects of drainage network are represented by stream order (u), stream number (Nu), stream length (L_u), bifurcation ratio (Rb) and Weighted Mean Bifurcation Ratio (WMRb).

Stream Order (u) and Stream Number (Nu)

Stream Order (u): the first step in drainage-basin analysis was the designation of stream orders, following a system introduced by Horton (1945) and slightly modified by Strahler (1952). The stream order (u) is a measure of the position of the stream in the basin and is directly proportional to the size of contributing watershed, to the channel dimensions and to the stream discharge. It means that the streams of first order are the streams, which have no tributaries. The second order streams are created from the joining of two streams of first order and so on. So the highest steam order of the basin reflects large contributing watersheds and large stream discharge. The order of the main trunk (wadi) is the highest order.

The results of the studied basin are shown in Table (1) and Figure (4).

Stream Number (Nu): The total order stream segments are known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number.

According to Strahler's classification and to the drainage network map of this basin Table (1) and Figures (4, 5 and 6), it can be seen that the main trunk streams in Wadi Darnah streams of sixth order. They exhibit a direct relation with the surface area and stream number. The numbers of streams of the first order represent 77.78% of the total streams. The second order streams represent about 17.52% of the total streams, while the third order streams represent only 3.85% of the total streams of the basin. The relationship between stream orders and stream numbers is shown in Figure (5), which shows a strongly inversely proportion (Negative regression relation).

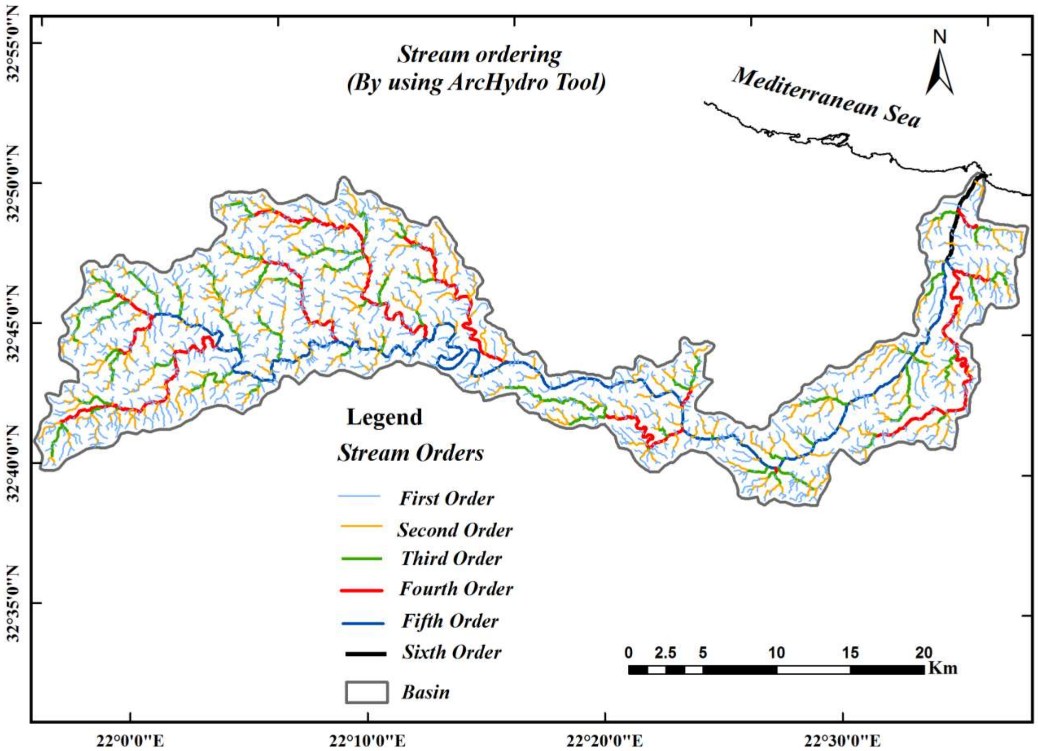

Figure (4): Drainage Map of Darnah Basin (by Using ArcHydro Tool).

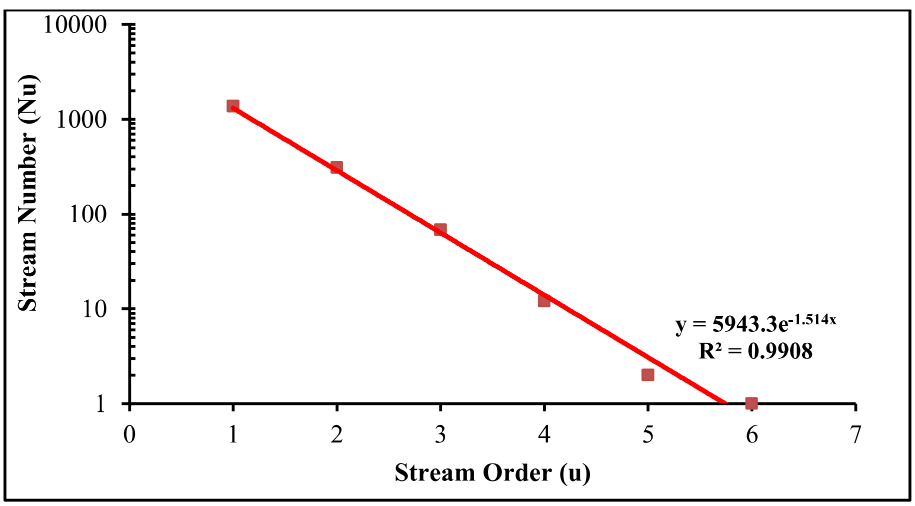

Figure (5): The Relationship Between Stream Numbers (Nu) and Stream Orders (U) in the Study Area.

Stream Length (Lu): The stream length means length of stream-channel segment of U order; the dimensional property reveals the characteristic size of components of a drainage network and its contributing basin surface (Strahler, 1964).

The stream lengths of the studied basin were measured using Arc GIS-10.3 software. The total stream length of the basinis1183.53 Km. The stream length revealed a direct relationship with the number of the stream, the area, the perimeter, and the length of the basin .Table (1) shows that the streams of the first order occupy 49.44% of the basin, the second order streams 22.16%, the third order ones occupy 11.36%, and the fourth order occupy 8.93%.There is an obvious increase in the total length of the high tributary streams (1st, 2nd and 3rd 82.96%) and an obvious decrease in the total length of the higher order streams. Due to the increment in the number of the first, second and third order streams, the relationship between the total stream lengths and the stream orders is an inversely proportion Figure (6).

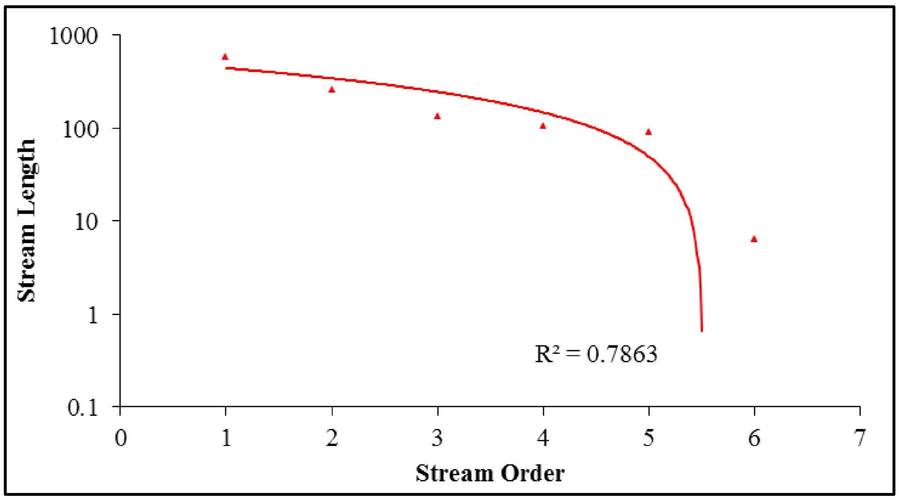

Figure (6): The Relationship Between the Total Stream Length (Lu) and Stream Orders (U) in the Study Area.

Bifurcation Ratio (Rb): The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order as represented by the following relation (Schumm, 1956).

$$Rb = \frac{Nu}{Nu + 1}$$

Where ***Rb*** is the bifurcation ratio, ***Nu*** is the number of stream order, and ***Nu+1*** is the number of streams of the next higher order.

The bifurcation ratio (Rb) is considered as one of the most important morphometric scales, which control the rate of discharge. The bifurcation ratio (Rb) tends to have relatively narrow ranges between 3 and 5 (Smart, 1972 and Kirchner, 1983) except for conditions of strong geologic control. Basins with Rb values greater than 3 reflect high mountainous dissected area (Horton, 1945). The bifurcation ratio shows a relationship with the geometric shape of the basin (elongated and circularity) which is reflected on the rate of discharge and time of concentration.

Basins of high bifurcation ratios are elongated in shape that permits passages of runoff over an extended period of time (long concentration times) thus, results in a higher chance of recharging the shallow aquifers. On the other hand, basins of low bifurcation ratios are circular in shape and allow the runoff to pass in a short time (low time of concentration) forming a sharp peak. In the latter case, dams should be constructed to control the runoff. The results show that the bifurcation ratio of the studied basin reaches 4.53 Table (1). Such a value expresses an index of relief and dissection (Horton, 1945) and provides a geological control (Strahler, 1958). In another words this value indicates that the area is not much influenced by the geological structure and is of an undisturbed drainage pattern.

Weighted Mean Bifurcation Ratio (WMRb): To arrive at a more representative bifurcation number Strahler (1952) used a weighted mean bifurcation ratio which is obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values.

$$\mathbf{WMRb} = \frac{\Sigma(\boldsymbol{Rb_u}/\boldsymbol{Rb_{u+1}})(\boldsymbol{N_u} + \boldsymbol{N_{u+1}})}{\Sigma \boldsymbol{N_u}}$$

Where ***WMRb*** is Weighted Mean Bifurcation Ratio, $\boldsymbol{Rb_u}$ is bifurcation ratio of stream order, $\boldsymbol{Rb_{u+1}}$ is bifurcation ratio of next stream order; $\boldsymbol{N_u}$ is the number of stream order, Nu+1 is the number of streams of the next higher order.

The value of the weighted mean bifurcation ratio calculated for this Wadi is 5.5 Table (1).

Table (1): Drainage Network (Stream Order, Streams Number, Stream Length and Bifurcation Ratios) in the Studied Basin (by Using ArcHydro Tool).

U	*Nu*	*%*	*Lu (Km.)*	*%*	*Rb*	*WMRb*
Frist	1372	77.78	585.18	49.44		
Second	309	17.52	262.23	22.16	4.44	
Third	68	3.85	134.44	11.36	4.54	
Fourth	12	0.68	105.64	8.93	5.67	5.51
Fifth	2	0.11	89.62	7.57	6	
Sixth	1	0.06	6.42	0.54	2	
Total	***1764***	100	***1183.53***	***100***		
Mean					***4.53***	

Where: U:Stream order, Nu: Number of streams, Lu: Stream length, Rb: Bifurcation ratios and Rbwm: Weighted mean bifurcation ratios

Areal Aspects of the Drainage Basin: The aerial aspects of the drainage basin are represented by Basin Length (L_b), Valley Length (L_v), Basin width (W), Basin Area

(A), Basin Perimeter (P), Elongation ratio (Re), Circularity ratio (Rc), form factor ratio (Fr) and Sinuosity Index (Si), Table (2).

Basin Length (L_b): Schumm (1956) defined basin length as the longest dimension of the basin parallel to the principal drainage line. According to this, the length of the studied basin watershed is75 Km.

Valley length (L_v): The valley length is the path length of the main stream from the source to the mouth. The valley length of Darnah basin was measured by using ArcGIS-10.3 software, and it was about 111 km.

Basin width (W): The main limitation of the width of a basin is the surface slope. If it is steep, the basin should be narrow; otherwise too much sediment movement will be needed to obtain level basins. Basin width is an important element to study the shape of basins (Sherief, 2008). There are two methods used to measure the width of a basin; the first is the average of some measurements of basin width, the second is the result of division of basin area (***A***) with basin length (***L_b***). By applying the first method, Wadi Darnah basin is considered narrow basin because its width is only 8.35 km, Table (2).

Basin Area (A): Area of a basin is one of the parameter in a morphometric study. It is defined as the total area projected upon a horizontal plane contributing to cumulate of all order of basins. According to Strahler (1952) the basins which have similar area and form characteristics are expected to be similar in their geomorphological characteristics too. Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitudes of the peak and mean runoff. According to Horton (1945) basins size are classified into large (more than 100 Km^2) medium (50-100 km^2) and small (less than 50 Km^2). The area of studied basin was determined by using ArcGIS 10.3 software and it was classified by size into large basins' category it was about 580 km^2 Table (2).

Basin Perimeter (P): Perimeter is considered as the main element of basin dimensions because it is used to compute many elements within a morphometric analysis such as basin shape, circulation ratio, and relief ratio. Moreover, it is the total length of the drainage basin boundary which reflects the geomorphological stage of basins. Wadi Darnah basin perimeter was determined by using ArcGIS-10.3 software, and it was 224.71 km Table (2).

Elongation ratio (Re): According to Schumm (1956), elongation ratio is defined as the ratio of diameter of a circle of the same area of the basin to the maximum basin length. Strahler (1964) states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The basin is considered circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<

0.5). The elongation ration of Darnah basin is 0.36 Table (2), which indicates that the watershed is more elongated.

Circularity ratio (Rc): For the out-line form of basin Strahler, 1964; Miller and Summerson, 1960 used dimensionless circularity ratio as a quantitative method. Circularity ratio is defined as the ratio of basin area to the area of a circle of the same perimeter as the basin.

Miller and Summerson, (1960) described the basins of circularity ratios that range from 0.4 to 0.7 as having strongly elongated and highly permeable homogenous geologic materials. Darnah basin circularity ratio reaches 0.14 Table (2). Morphometrically, the circularity ratio approaches 1if the shape of the basin is circular, and it tends to 0 if the basin is rectangular. This means that the studied basin has elongation shape.

Form Factor Ratio (Fr): According to Horton (1932), form factor is the ratio of a basin's area to the square of basin's length. The value of form factor would always be less than 0.44 (for a perfectly circular basin). The smaller the value of form factor, the more elongated it will be. Basins with high form factors have high peak flows of shorter duration (square or circular shape). Wadi Darnah basin form factor is 0.1, Table (2). It is a small value of form factor and it represents an oval shape that tends towards elongation. In general, for the basin being oval, and tending towards elongation with low form factor indicate that this basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin.

Sinuosity Index (Si): The valley length (L_v) is the total length of the main trunk, while the basin length (L_b) is the distance between the mouth and the source of stream (Mueller, 1968). The sinuosity ratio is the ratio between valley length and basin length. Sinuosity ratio represents the degree of meandering. Straight valleys are more effective in flooding than the meandering ones. The Si value of the studied basin is 1.48 Table (2). Thus, those streams can be classified as transitional to regular streams, which is due to the steep slopes in the topography of the study area.

Table (2): Morphometric Parameters for Basin Geometry.

Morphometric Parameters	*Formula*	*Reference*	*Results*	*Unit*
Basin length (L_b)	GIS software Analysis	Schumm (1956)	75	Km
Valley length (Lv)	GIS software Analysis		111	Km
Basin width (W)	W=A/Lb		8.35	Km
Basin Area (A)	GIS software Analysis		580.12	Km^2
Basin Perimeter (P)	GIS software Analysis		224.71	Km

Elongation ratio (Re)	$Re = 2 / Lb *(A/\pi)^{0.5}$	Schumm (1956)	0.36	-
Circularity Ratio (Rc)	$Rc= 4\pi A/(P^2)$	Miller (1953)	0.14	-
Form Factor Ratio (Fr)	$Fr = A / Lb^2$	Horton (1932)	0.10	-
Sinuosity Index (Si)	Si=Lv/Lb	Mueller (1968)	1.48	-

Drainage Texture Analysis: The aerial aspects of the drainage basin such as Stream Frequency (Fs), Drainage Density (D), Length of Overland Flow (Lo), Infiltration Number (FN), Drainage Pattern (Dp), are discussed in the following paragraphs.

Stream Frequency (Fs): Stream frequency or channel frequency (Fs) is the total number of stream segments of all orders per a unit of area (Horton, 1932). High values of stream frequency tend to provide more possibilities for the collection of runoff water. Quantitatively, the stream frequency is one of the main effective parameters in the flood hazard assessment. In the present study, the stream frequency of the Darna watershed is 3.04 km^{-2} Table (3).

Drainage Density (D): Experimental relationship between drainage density and drainage frequency that has been tested and found valid for several basins was expressed by (Melton, 1957). Drainage density reflects the type of the surface layer, its permeability and roughness. It is an inverse function of permeability. Table (3), shows that the drainage density value of Darna basin reaches up to 2.09km^{-1}. This value indicates that for every square kilometer of the basin, there is 2.09 kilometer of stream channel, which is considered low. Since basins of high drainage density are characterized by areas of low permeability and/or steep surface less density of plant cover (Abdel-Mogheeth et al., 1985), Darnah basin permeability is high.

Length of Overland Flow (Lo): The length of overland flow (Lo) is the length of water over the ground surface before it gets concentrated into a definite stream channel (Horton, 1945). (Lo) is one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. In this study, the length of overland flow of Darna watershed is 0.24 Km Table (3), which shows high surface runoff of the study area.

Infiltration Number (FN): According to Faniran (1968), the infiltration number is defined as the product of drainage density and stream frequency. It gives an idea about the infiltration characteristics of the basin that reveals the impermeable lithology and the high relief. The higher the infiltration number the lower will be the infiltration and consequently the higher will be surface runoff. This leads to the development of higher drainage density. The calculated value of infiltration number of Wadi Darna basin reaches 6.36 Table (3). This high infiltration number (6.36) implies the high run-off this watershed.

Drainage pattern (Dp): Basin drainage pattern helps identify the stage of the cycle of erosion and reflects the influence of slope, lithology, and structure (Howard, 1967). Dendritic pattern is the main pattern of the study basin and, as shown in Figure (3). This formation in the drainage basin reflects the homogeneity of the underlying lithology.

Table (3): Morphometric Parameter for Drainage Texture Analysis.

Morphometric Parameters	*Formula*	*Reference*	*Results*	*Unit*
Stream Frequency (Fs)	$Fs=\Sigma N_u/A$	Horton (1932)	3.04	Km^{-2}
Drainage Density (D)	$D= (fs/0.694)^{\wedge 0.5}$	Melton (1957)	2.09	Km^{-1}
Length of overland Flow (Lo)	$Lo=1/2D$	Horton (1945)	0.24	Km
Infiltration number(FN)	$FN = (F)(D)$	Faniran (1968)	6.36	
Drainage Pattern (Dp)			dendritic	-

Relief Aspects: The relief aspects determined include Basin relief (R), Relief ratio (Rf), Relative relief (Ri), Ruggedness Number (Rn), Slope Index (SI) and Mean basin slope (Sm). The results of the analysis are given in Table (4).

Basin relief (R): Basin relief is the elevation difference of the highest and lowest point of the valley floor. Wadi Darna is moderately elevated basin, where the elevation ranges from + 6m at the Mediterranean Sea Coast to + 856m above sea level at the water divisions of the basin. The calculated basin relief value of the Wadi is 850m, which represents high relief Table (4). This high relief value leads to a high rate of runoff, but the effect of this water flow is minimized by the high infiltration capacity resulting from the high rate of karstification and karst features of the basin area.

Relief ratio (R_f): Relief ratio is defined as the ratio between the basin relief and the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). Relief ratio normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). Table (4) shows that Wadi Darna basin relief ratio is 11.33m/km. Hence, this catchment can be considered as the most topographical-complex basin in the study area (Gottschalk, 1964).

Relative relief (Ri): Relative relief is defined as the ratio between total basin relief (R), and basin perimeter (P). Relative relief is the difference between summit level, (the highest altitude for a given area), and base level (lowest altitude for a given area) divided by perimeter. Relative relief can be used as an index of the relative velocity of vertical tectonic movements. It can be computed by Melton's formula (1957)

Table (4). The low values are characteristic features of less resistant rocks (Sreedevi, 1999).

The result in Table (4) showed that the value of relative relief of Darnah basin equals 3.78 m/km, which represented a high value.

Ruggedness Number (Rn): Strahler (1968) describes ruggedness number (Rn) as the product of the maximum basin relief and drainage density and it usually combines slope steepness with its length. The high value of ruggedness number reflects a greater runoff. Darnah watershed has a ruggedness number 1.78 Table (4). This low ruggedness value of watershed implies that the area is less prone to soil erosion and has an intrinsic structural complexity in association with relief and drainage density.

Slope Index (SI%): The slope index (SI) is defined as the relationship between the difference in the internal relief (the difference in elevation in meter of points at 85% and 10% of length of the main channel from its mouth) and 0.75 of the valley length (Majure and Soenksen, 1991). Generally, Wadi Darnah is characterized by high relief and high topography and high slope index 5.5% Table (4).

Mean basin slope (Sm): Slope is the most important and specific feature of the drainage basin form. Maximum slope line is well marked in the direction of a channel reaching downwards on the basin. Slope map of the study basin Figure (7) has created by using Surface Analysis Tool in ArcGIS-10.3. The slope ranges from 0° (flat) to 52.47°, with a mean value of 4.9° and the high degree of slopes is noticed at the Northeastern part of the Wadi. The dominant slope ranges between 0° and 7° (36%) which means that the Wadi is almost of a medium slope. The wide variations between the values of mean slope are due to the variation of the topography and lithology of basin parts. Generally, the slope of the terrain affects the total runoff volume and time of concentration to the peak of hydrograph. Basins of gentle slope produce less runoff volume and smaller peaks of the runoff hydrograph. In gentle slope basins, the velocity of overland flow will be low and there will be more time for water to infiltrate thereby reducing the amount of surface runoff reaching the stream. A steep slope produces greater velocities and allows faster removal of the runoff from the watershed; therefore, shorter concentration times to peak of hydrograph.

Table (4): Morphometric Parameter for Relief Aspects.

Morphometric Parameters	*Formula*	*Reference*	*Results*	*Unit*
Downstream Elevation (z)	GIS software Analysis		6	M
Upstream Elevation (Z)	GIS software Analysis		856	M

Basin Relief (R)	*R = Z-z*	Strahler (1952)	850	M
Relief Ratio (R_f)	*(R_f=R/L_b)*	Schumm (1956)	11.33	m/km
Relative relief (Ri)	*Ri= R/P*	Melton (1957)	3.78	m/km
Ruggedness No.(Rn)	*Rn=D*(R/1000)*	Strahler (1968)	1.78	m/km
Slope Index (SI%)	*SI=E85%-E10%/(0.75Lv)*	Majure & Soenksen (1991)	5.1	-
Mean basin slope (Sm)	GIS software Analysis		0 – 52.47	Degree

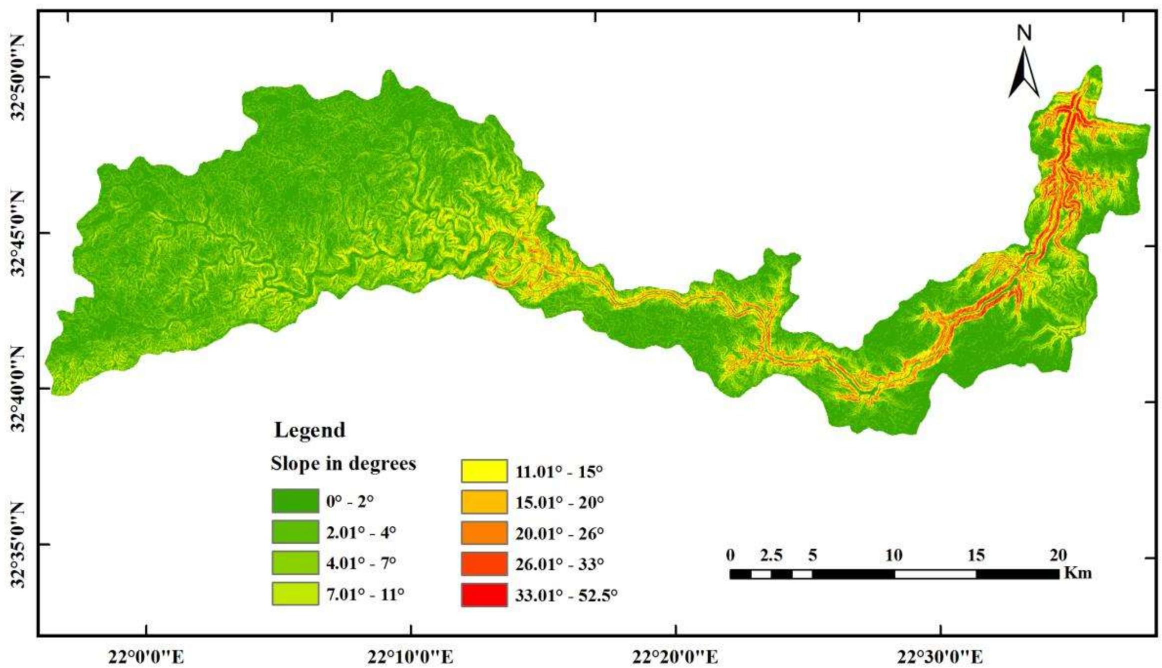

Figure (7): Slope Maps of the Study Basin.

Conclusion

The present study indicates that systematic analysis of morphometric parameters within drainage networks using GIS can provide significant value in understanding drainage characteristics with respect to runoff. The uniform geology, structural style and steep slopes played an important role in the development and integration of the drainage network of Wadi Darnah basin. The studied basin occupies more than 100 Km^2, which means that it is a large size basin. The total number of 1764 streams were identified of which 1372 are of the 1^{st} order streams, 309 are of the 2^{nd} order, 68 are of the 3^{rd} order, 12 are of the 4^{th} order, 2 are of the 5^{th}, and one is a 6^{th} order stream. Drainage patterns of stream network from the basin were mainly of dendritic type, which indicates the homogeneity in texture and lack of structural control. The circularity, elongation ratios and form factor showed an elongated basin with steep relief, moderate discharge, and a long main channel. The drainage density indicated structural control, high infiltration capacity and high water flow speed. The permeability of Darnah basin rocks is high. Relief aspects and the visual interpretation of DEM of the basin indicated that the basin has high relief up to 850 m. It also showed that it is of a steep to moderate slope (0° – 52.47°) which leads to a high rate of runoff but the effect of water flow is minimized by the high infiltration capacity due to the high rate of karstification and karst features in the basin area. In short, Darnah can be considered as an area with good groundwater prospect as it has a permeable subsurface and condition favourable for infiltration of surface water.

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References

- Abd El-Wahed, M. and Kamh, S., (2013). “Evolution of strike slip duplexes and wrench-related folding in the central part of Al Jabal Al Akhdar, NE, Libya”. The Jour. of Geology, 121, pp. 173-195.

- Abdel-Mogheeth, S.M., Hammad, F.A. and Abdel-Daiem, A.A., (1985). “Hydrogeological remarks on Gharandal Basin, southwest Sinai Peninsula”. Desert Inst. Bull., Egypt, 5 (2): pp. 309-329.

- Abdulsamad, E.O., Bu-Argoub, F.M, and Tmalla A.F., (2009). “A stratigraphic review of the Eocene to Miocene rock units in the al Jabal al Akhdar, NE Libya”. Marine and Petroleum Geology 26, pp. 1228–1239.

- Arghin S.S. & Hamad S. M., (2003). ”Water Resource of Cyrenaica:Part I Al Jabal Al Akhdar”. National Water Resource Management Work shop. 14-15 November 2003 Benghazi, Libya. 11p.

- El Hawat, A. S. and Abdulsamad, E.O., (2004). “The geology of Cyrenaica: A Field Seminar. 3rd Symposium on the Sedimentary basins of Libya, Geology of East Libya”. Earth Science Society of Libya (ESSL), 130 p.

- El Hawat, A. S. and Thomas, P., (2005). “A Field Guidebook to the Geology of Cyrenaica, Libya”. See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/271503643.

- Faniran, A., (1968). “The index of drainage intensity-a provisional new drainage factor”. Aust J Sci 31:pp. 328–330.

- Gottschalk, L.C., (1964). "Reservoir Sedimentation in Handbook of Applied Hydrology". (New York, Mc. Graw Hill Book Company 1964).Section 7-1.

- Horton, R. E., (1932). "Drainage basin characteristics". Am. Geophysics. Union, Trans. 13,pp. 348–352.

- Horton, R. E., (1945). "Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology". Geol. Soc. Am. Bull.56: pp. 275-370.

- Kirchner, J., W. (1983). "Statistical inevitability of Horton's law and apparent randomness of stream channel network, Geology". Vol. 21. pp. 591-594.

- Majure J.J., Soenksen P.J., (1991). "Using a geographic information system to determine physical basin characteristics for use in flood-frequency equations". In: Balthrop BH, Terry JE (eds) U.S. geological survey national computer technology meeting-proceedings, Phoenix, Arizona, p 14–18, 1998: U.S. Geological Survey Water Resources.

- Melton, M. N., (1957). "An analysis of the relations among elements of climates, surface properties and geomorphology". Project NR 389-042 Tech. Report II, Columbia University, Department of Geology, New York, 34p.

- Miller, O.M., and Summerson, C.H., (1960). "Slope zone maps, Geographical Review", 50,pp. 194-202.

- Mueller, J.E., (1968). "An introduction to the hydraulic and topographic sinuosity indexes, Annals of the Association of American Geographers", 58, 371-385.

- Ofomata, M. and J.E. Umeuduji, (2000). "Topological Indices of Morphological Transformation in the Aboine Basin. Nigeria Environ". Revolution J., Vol. 1.

- Rohlich, P., (1974). "Geological map of Libya". 1:250.000, Sheet: Al Bayda, NI 34-15, explanatory booklet. Ind. Res. Cent., Tripoli, 70 p.

- Schumm, S. A., (1956). "Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey". Geol. Soc. Am. Bull. 67: pp. 597-646.

- Shaltami, O.R., Fares, F.F., Errishi, H., EL Oshebi, F.M. and Souza, R., (2018). "Chemostratigraphy of the Al Abraq Group, Cyrenaica Basin, NE Libya". 4^{th} International Conference on Applied Science and Engineering (ICASE), Bhubaneswar, Odisha, Proceeding Book; pp. 30-39.

- Sherief, Y. S., (2008). "Flashfloods and their effects on the development in EL-Qaà Plain area in South Sinai, Egypt, a study in applied geomorphology using GIS and remote sensing". Ph. D. Thesis in Geography the Department of Chemistry, Pharmacy, Geosciences the Johannes Gutenberg University Mainz.

- Shreve, R.L., (1966). "Statistical Law of Stream Numbers", J. Geol., 74: pp. 19-38.

- Smart, J., S., (1972). "Channel network advances in hydro sciences". Vol. 8. pp.305-346.

- Sreedevi, P.D., (1999). "Assessment and management of groundwater resources of Pageru River basin, Cuddapah District, Andhra Pradesh, India". Unpublished Ph.D. Thesis, Sri Venkateswara Univ., Tirupati.

- Strahler, A., (1964). "Quantitative geomorphology of drainage basins and channel networks". In: Chow VT (ed) Handbook of applied hydrology. McGraw-Hill, New York.

- Strahler, A. N., (1952). "Hypsometric analysis of erosional topography". Bulletin of the Geological Society of America, 63, pp. 1117-42.

- Strahler, A. N., (1957). "Quantitative analysis of watershed geomorphology". Transactions of the American Geophysical Union No. 38. pp.913-920.

- Strahler, A. N., (1968). "Quantitative geomorphology". In: Fairbridge, R.W. (Ed.), Encyclopaedia of Geomorphology. Reinhold, New York, pp. 898–912.

- SRTM images (Shuttle Radar Topography Mission) are produced in September 23, 2014 and give details until 30m lengths (available at https://dwtkns.com/srtm30m/).

- DWD, (2013) Germany's national meteorological service (DeutscherWetterdienst):https://www.dwd.de/DWD/klima/beratung/ak/ak_620590_kt.pdfKlimatafel von Derna / Libyen" (PDF).Baseline climate means (1961-1990) from stations all over the World.