Evaluation of Morphometric Parameters of Paleo-river by GIS application in Kufrah basin SE Libya

Jamal Zamot (jamal.zamot@uob.edu.ly)
University of Benghazi Faculty of Science https://orcid.org/0000-0003-4558-1657
Mohammed Afkareen
University of Garyounis: University of Benghazi

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Jamal Zamot (1)

Mohammed Afkareen (2)

1- Benghazi University, Earth sciences Department, Benghazi-Libya.

e-mail: Jamal.Zamot@uob.edu.ly.

2- Sirte Oil Company (SOC), Marsa El-Brega, Libya.

e-mail: Mohammed_eff2010@yahoo.com.

Abstract

A great buried paleo-river in SE Libya have been discovered by various approaches of remote sensing and GIS techniques. The buried river was running through the Kufrah basin and drained eastern part of Libya externally to the Mediterranean Sea via Sahabi Valley and lately has changed to be drained internally into the inland delta of the Al-Jaghbub depression. In the current study a DEM with 30m spatial resolution is used to delineate and morphometrically analyse the network streams of the Kufrah paleo-river. The results show that the study area is a flat area with low relief topography, low moisture content and high evaporation rate. The drainage pattern of the Kufrah paleo-river is a dendritic pattern with the 7th order of streams. The network streams over a permeable sub-surface material, high infiltration capacity with very coarse texture, and low run-off. The Kufrah river can be described as an "Old age" river, and it's highly eroded and dissected drainage basin.

Keywords: remote sensing, GIS techniques, morphometric analysis, Kufrah paleo-river, hypsometric curve.

Statements and Declarations

"The Authors declare that there is no conflict of interest."

Introduction.

Recently, many studies have been published about a controversial thought, which is a preserved, buried river under a massive sheet of sand in the SE of Libya, (Ghoneim et al., 2012). It is believed that this river was running from the south specifically from the Chad mega lake across the Sahara to the Mediterranean Sea to the north (Coulthard et al., 2013; Paillou et al., **2012**; Ghoneim et al., 2012). This river was recharged by rainfall during wet phases in Pliocene and Pleistocene time, (De Menocal et al., 2000). The existence of freshwater fauna that found in the Sahabi's paleochannel besides to the width and depth of the Sahabi Canyon are strongly confirmed that the paleo-river was drained to the Mediterranean Sea via Sahabi paleochannel, (Boaz, 1987). Furthermore, as consequences of a tectonic event that had occurred lately in the area, the river drainage had been affected to be drained internally into the inland delta of the Al-Jaghbub depression, (Hecht, 1987; Boaz, 1987).

However, remote sensing and GIS applications are considered as a successful approach for hydrologic network delineation, and morphometric analysis of network stream. Moreover, remote sensing and GIS techniques have proofed their abilities in penetrating the ground surface and distinguishing the buried features such as channel system, drainage network system (e.g., Roth and Elachi, 1975; McCauley et al., 1982; El-Baz et al., 2000; Robinson et al., 2006; Ghoneim et al., 2007; Paillou et al., 2009).

Objective of the study

The main objective of the current study is a morphometry studying and basin delineation of the Kufrah Paleo-river utilizing GIS applications with conventional widespread mathematical equations.

A hypsometric curve was also produced to characterize the distribution of heights across the river's catchment region in order to speculate on the development stage of the Kufrah basin drainage network.

Location of the study area

The study area is located in the Kufrah basin south-eastern part of Libya and cover area 174591.18 km^2. It is bordered by Egypt to the east, Sudan and Chad to the south, high Tibesti Volcanic Province to the west and from the north by the Al-Jaghbub depression and Mediterranean Sea (Fig, 1).

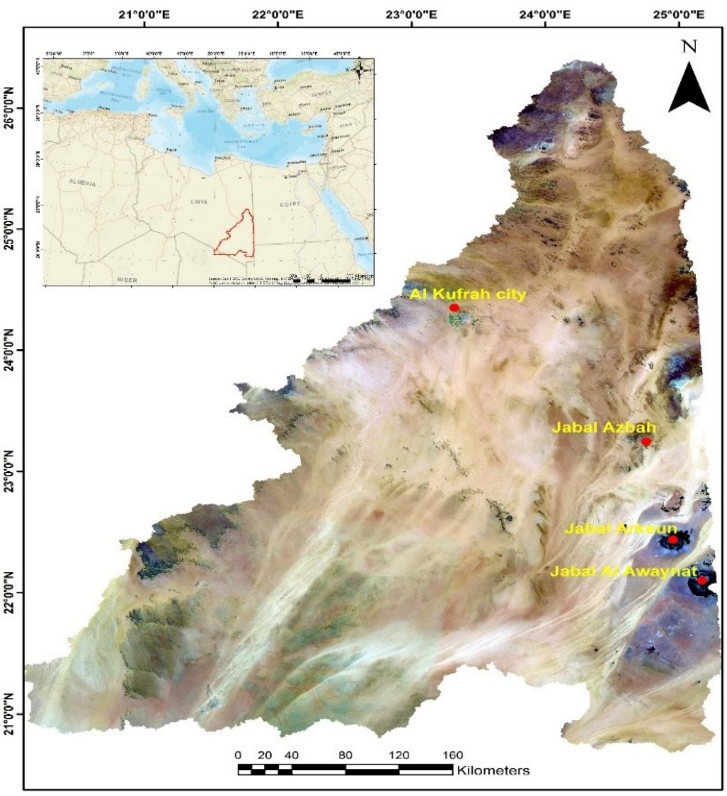

Figure (1). Shows the location map of the study area, SE Libya.

Data and methodology

The accuracy of the generated drainage networks is influenced by the DEM precision. The main used data is a Digital Elevation Model (DEM) over the study area that was taken from Shuttle Radar Topography Mission (SRTM), Open-source data at (https://srtm.csi.cgiar.org/); with a spatial resolution equal to 30 meters, which achieved excellent results. Errors such as sinks and peaks were eliminated from the DEM after it was created to eliminate drainage network discontinuities. In addition, a geological map of Kufrah basin from Industrial Research Centre with 1:250,000 scale is used. The morphometric analysis, hydrology drainage network and basin delineation have been obtained from DEM by using ArcGIS hydrology tools (10.5), besides to a manually mathematical analysis by using equations as shown in the Table, (1).

Table (1). List of the morphometric parameters and the formulas used in Kufrah Paleo-river analysis.

MORPHOMETRIC PARAMETERS	**FORMULA**	**REFERNCE**
Basin length (Lb)	*GIS Software*	*Schumm (1956)*
Basin perimeter (P)	*GIS Software*	*Schumm (1956)*
Basin area (A)	*GIS Software*	*Schumm (1956)*
Mean Basin width (Wb)	*Wb = A / Lb; where A area of watershed; Lb basin length.*	*Horton (1932)*
Drainage density (Dd)	*Dd = Lu / A; where Lu total length of streams; A area of watershed*	*Horton (1932)*
Drainage intensity (Di)	*Di = Fs / Dd; where Fs Stream frequency; Dd Drainage density*	*Faniran (1968)*
Drainage texture (Dt)	*Dt =Nu / P; where Nu total number of streams; P Basin perimeter.*	*Horton (1945)*
Stream frequency (Sf)	*Sf = Nu / A; where Nu total number of streams; A area of watershed*	*Horton (1932)*
Texture ratio (Rt)	*Rt = ΣN1/P, where N1 the total number of streams of* 1^{st} *order, P perimeter of watershed.*	*Schumm (1956)*
Form factor (Rf)	*Rf =* $A/(L)^2$*; Where A area of watershed; L basin length.*	*Horton (1932)*
Circularity ratio (Rc)	*Rc =* $4\pi A/P^2$*;* π*=3.14, A area of watershed, P perimeter of watershed.*	*Miller (1953)*
Elongation ratio (Re)	*Re =* $2\sqrt{(A/\pi)}/L$*; where* π *= 3.14, A area of watershed, L length of watershed.*	*Schumm (1956)*
length of overland flow (Lof)	*Lof = 1/2Dd; Dd Drainage density*	*Horton (1945)*
Infiltration number (In)	*In=Dd * Sf; Sf Stream frequency, Dd Drainage density.*	*Faniran (1968)*
Constant channel maintenance (Ccm)	*Ccm = 1 / Dd; where Dd Drainage density*	*Schumm (1956)*

The geology of the area

The interested river is located within Kufrah basin, which is an intracratonic sag basin that located in the SE of Libya (Lu¨ning et al., 1999; Hallett, 2002). The basin flanks are bordered by highs that made up of the basement, where a succession of Proterozoic and Palaeozoic strata crop out, Tibesti Massif in the west, Jebel Uweinat in the east, the Ennedi and Borkou in the south, and Jebel Dalma in the north (Fig, 2) (Lu¨ning et al., 1999; Hallett, 2002).

The Kufrah basin is generally filled with Palaeozoic and Mesozoic sedimentary strata. Fluvial, shallow marine sandstones, and shales are the most characterization of the deposition in Cambrian-Ordovician time. The strata of Triassic to Early Cretaceous made of continental sandstones (Nubian Sandstone) that rest uncomfortably over Palaeozoic rocks. The Mesozoic sediments overlain by fluvial deposits of Messinian to Pliocene and Quaternary aeolian deposits, (Fig, 2), (Bellini and Massa, 1980; Bellini et al., 1991; Lu¨ ning et al., 1999; Gindre, et al., 2012.)

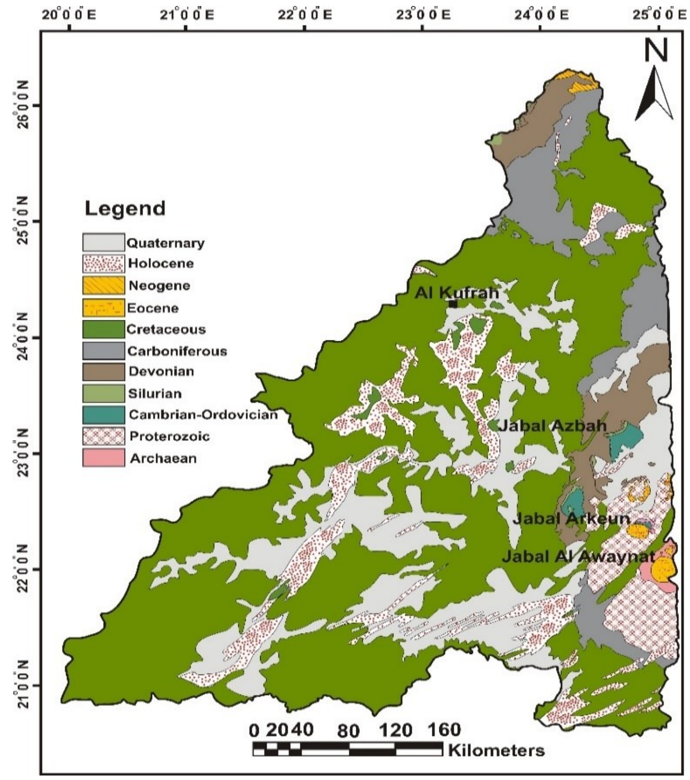

Figure (2). The geological map of the Kufrah basin.

Results and discussion

The results of morphometric analysis of the Kufrah paleo-river are listed in tables (2 & 3) respectively and they are under major heads of slope, areal and relief aspects.

Table (2). The results of morphometric parameters analysis of the Kufrah Paleo-river.

MORPHOMETRIC PARAMETERS	FORMULA	RESULTS	REFERNCE
Basin length (Lb)	*GIS Software*	*733 km*	*Schumm (1956)*
Basin perimeter (P)	*GIS Software*	*3332.044 Km*	*Schumm (1956)*
Basin area (A)	*GIS Software*	*174591.18 Km^2*	*Schumm (1956)*
Mean Basin width (Wb)	*Wb = A / Lb; where A area of watershed; Lb basin length.*	*238.18*	*Horton (1932)*
Drainage density (Dd)	*Dd = Lu / A; where Lu total length of streams; A area of watershed*	*0.18 Km^2*	*Horton (1932)*
Drainage intensity (Di)	*Di = Fs / Dd; where Fs Stream frequency; Dd Drainage density*	*0.14*	*Faniran (1968)*
Drainage texture (Dt)	*Dt =Nu / P; where Nu total number of streams; P Basin perimeter.*	*1.28*	*Horton (1945)*
Stream frequency (Sf)	*Sf = Nu / A; where Nu total number of streams; A area of watershed*	*0.0243 Km^2*	*Horton (1932)*
Texture ratio (Rt)	*Rt = ΣN1/P, where N1 the total number of streams of 1^{st} order, P perimeter of watershed.*	*0.004*	*Schumm (1956)*
Form factor (Rf)	*Rf = $A/(L)^2$; Where A area of watershed; L basin length.*	*0.32*	*Horton (1932)*
Circularity ratio (Rc)	*Rc = $4\pi A/P^2$; π=3.14, A area of watershed, P perimeter of watershed.*	*0.197*	*Miller (1953)*
Elongation ratio (Re)	*Re = $2\sqrt{(A/\pi)}/L$; where π = 3.14, A area of watershed, L length of watershed.*	*0.0209*	*Schumm (1956)*
length of overland flow (Lof)	*Lof = 1/2Dd; Dd Drainage density*	*2.8 mature stage*	*Horton (1945)*
Infiltration number (In)	*In=Dd * Sf; Sf Stream frequency, Dd Drainage density.*	*0.0044*	*Faniran (1968)*
Constant channel maintenance (Ccm)	*Ccm = 1 / Dd; where Dd Drainage density*	*5.5*	*Schumm (1956)*

Table (3). List of the relief parameters and the formulas used in Kufrah Paleo-river analysis.

RELIEF PARAMETERS	FORMULA	RESULTS	REFERENCE
Maximum Elevation in the Area (h_{Max})	_	*1887m*	_
Minimum Elevation in the Area (h_{Min})	_	*239m*	_
Mean Elevation	_	*527m*	_
Basin Relief (H)	$H = h_{Max} - h_{Min}$	*1648m*	*Schumm (1956)*
Relief Ratio (Rf)	*Rf = H/L; where H basin relief; L length of basin.*	*2.25*	*Schumm (1956)*
Ruggedness Index (Rn).	*Rn = H* Dd; where H basin relief, Dd drainage density.*	*0.29 high erosion*	*Melton (1957)*
Dissection Index (DI)	*DI = H/ $h_{Max;}$ where H basin relief, h_{Max} maximum elevation in the area.*	*0.873*	*Schumm (1956)*

1. **Slope, aspect, and relative relief parameters**

The slope parameter deems to be one of the most significant parameters for morphometric analysis, whereas the rain water that making a network of the river basin will be run-off under the effecting of slope elements, (Villela, & Mattos, 1975**).** The slope degree map, elevation map and the relative relief map have shown the study area as a flat area with low relief topography which making the runoff slow (Fig, 3). As a result, the water will get more time to penetrating into sub-surface and then the ground water will be highly recharged. However, the highest slope in the study area is only noticed on the far east, where the Jebel Uweinat and Jabal Arkenu are located.

The paleo-river starts from an elevation 1887m in the south and terminated in the inland delta at Al-Jaghbub depression in the north with 239m. It has a dendritic drainage pattern, which demonstrates homogeneity and uniformity in the soil type and rocks.

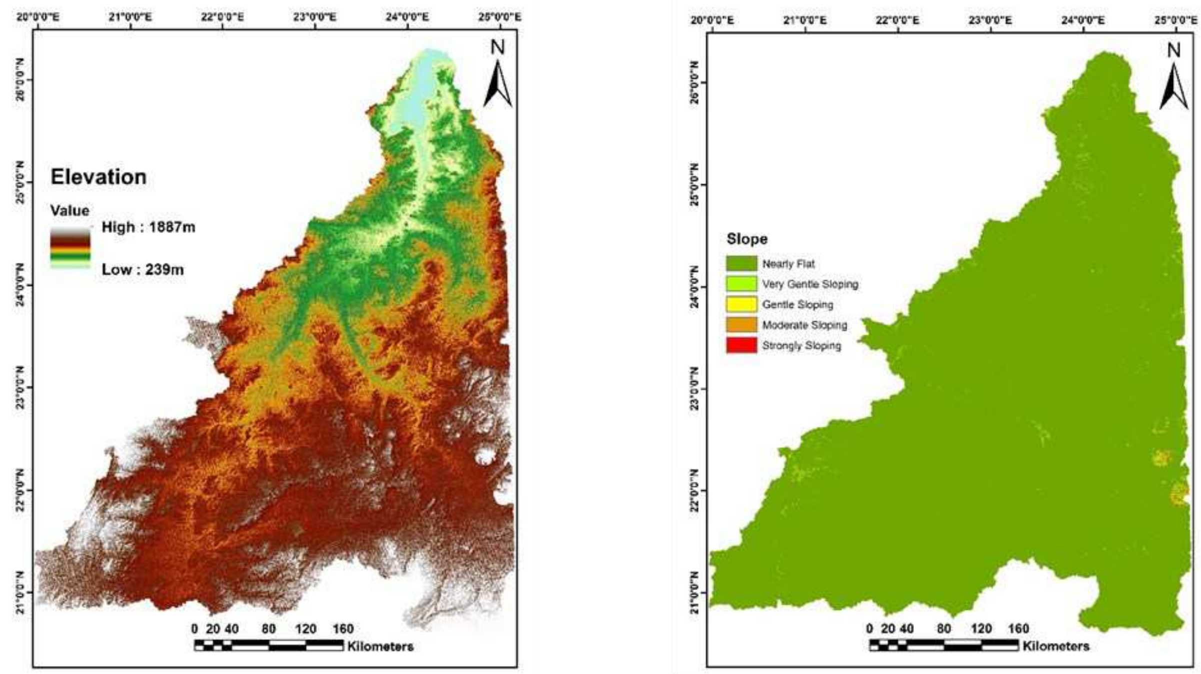

Figure (3). Illustrates the elevation map (a); and the slope map of the Kufrah basin(b).

Aspect generally refers to the direction of slope terrain to which it faces. The slope aspect can make very significant influences on the pattern of precipitation, distribution of vegetation and biodiversity in the study area (Zamot & Afkareen, 2020; Khakhlari & Nandy, 2016). The compass direction of the aspect was derived from the output raster data value. The aspect map of Kufrah basin is mainly dominated by flat to very gentle aspect slope (Fig, 4).

The hillshade map is highlighted the structural effect of Jebel Awaynat and Jabal Arkenu on the eastern flank of the basin, while the rest of the region is not (Fig, 4).

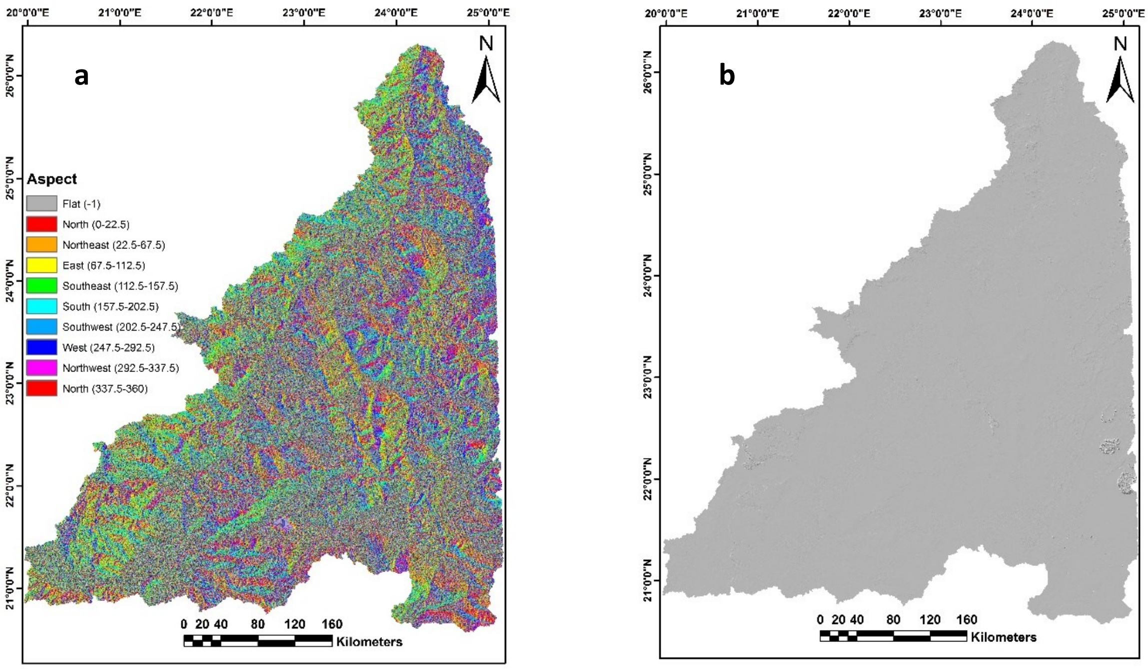

Figure (4). Shows the aspect map(a); and the hillshade map of the Kufrah basin (b).

2. *Aerial morphometric aspect*

The aerial aspects consist of morphometric parameters such as drainage density (Dd), Drainage Texture (T), Texture Ratio (Rt), Infiltration number (In), Form factor (Rf), stream frequency (Fs), elongation ratio (Re), circulatory ratio (Rc), and length of overland flow (Lof). These aspects of a drainage basin illustrate the effect of the climatic conditions, geological structure and the lithology of the basin (Resmi et al., 2019). Kufrah paleo-river is believed to be developed over unconsolidated rocks and thereby the number and order of its streams is high with the 7th order of streams (Fig, 5).

Drainage density (Dd)

Drainage density (Dd) was first introduced by Horton (1932) as an important indicator of the linear scale of the landform element in stream eroded topography. He defined Drainage density as the ratio of the total length of the stream in a given drainage basin and the area of that drainage basin. Moreover, high and low Drainage density values are gained due to different factors such as the sub-surface material, relief, surface runoff, infiltration capacity, flood volumes and vegetation density. The drainage density of the study river is 0.18 Km^2 indicates high permeable subsurface and coarse drainage, (Fig, 5).

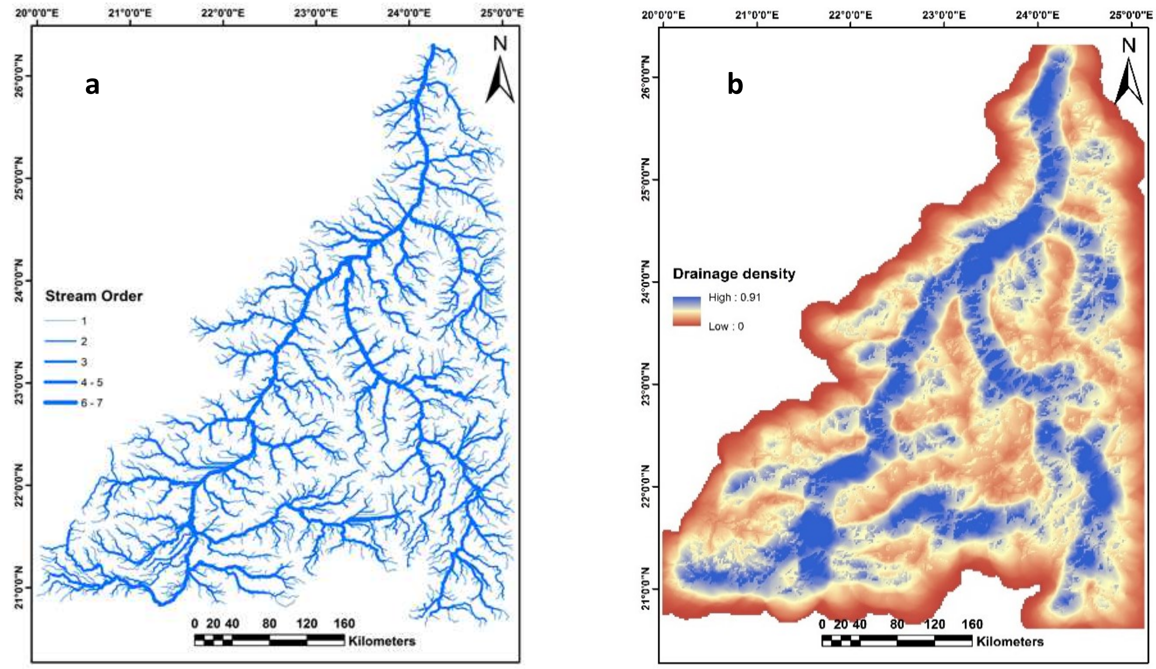

Figure (5). Shows the stream orders (a); and the drainage density of the Kufrah Paleo-river (b).

Drainage Texture (T)

Drainage texture in the present study shows the value of Kufrah paleo-river with 1.28 which indicates a texture pattern to be a coarse drainage texture.

Texture Ratio (Rt)

The study area has very low texture ratio with 0.004, indicates permeable sub-surface materials, low relief conditions, and high infiltration capacity with very coarse drainage texture.

Infiltration number (In)

The infiltration number of the basin is 0.0044 indicating high infiltration materials and low surface run-off.

Form factor (Rf)

The value of the form factor of the Kufrah paleo-river basin is 0.32 which depicts that the basin form belongs to slightly elongated shape, and it is the indication of low peak flow of the basin.

Stream frequency (Fs)

The high value of stream frequency indicating more surface runoff and vice versa. In the present study the stream frequency value of the paleo-river is low which indicates more ground water potential.

Elongation ratio (Re)

The elongation value of the paleo-river is 0.0209. The low value indicates that the basin has low relief with moderate to high infiltration capacity and low runoff.

Circularity ratio (Rc)

A circular basin is more efficient in runoff discharge than an elongated basin. Circularity ratio is 0.197 indicates less elongated basin with low relief, high infiltration capacity.

length of overland flow (Lof)

The length of the overland flow of the study river is 2.8, the value is slightly high, indicates the basin is consists of low relief and slope, and the river is in the mature stage.

3. ***Relief aspects.***

The relief aspects include Dissection index (Di), Ruggedness Index (RI), and Relief Ratio (Rf). These aspects are calculated and presented in Table (2).

Dissection index

According to Singh (2000), the *Dissection index* is an important morphometric indicator of nature and magnitude of dissection of terrain or vertical erosion. Dissection index (DI) is expressing the ratio of the maximum relative relief to a maximum absolute relief. The DI value is between zero, which indicates complete absence of dissection or vertical erosion, and one that reveals vertical cliff. Generally, the areas with high DI indicate high relative relief where the slope of the land is steep and unstable that results in enhanced erosion. On the contrary, low DI corresponds with low relative relief, and with the subdued relief or old stage where the land is flat and more stable (Deen, 1982). The DI of the study area is 0.873 which indicates the basin is a moderately to highly dissected, (Fig, 6).

Ruggedness Index (RI).

The ruggedness number of the basin is 0.29 indicates higher soil erosion susceptibility, (Fig, 6).

Relief Ratio (Rf)

The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as a relief ratio (Schumm, 1956). The relief ratio of the river basin is 2.25 that indicating this basin is composed of non-resistant rocks, and the basin is under low relief and gentle slope.

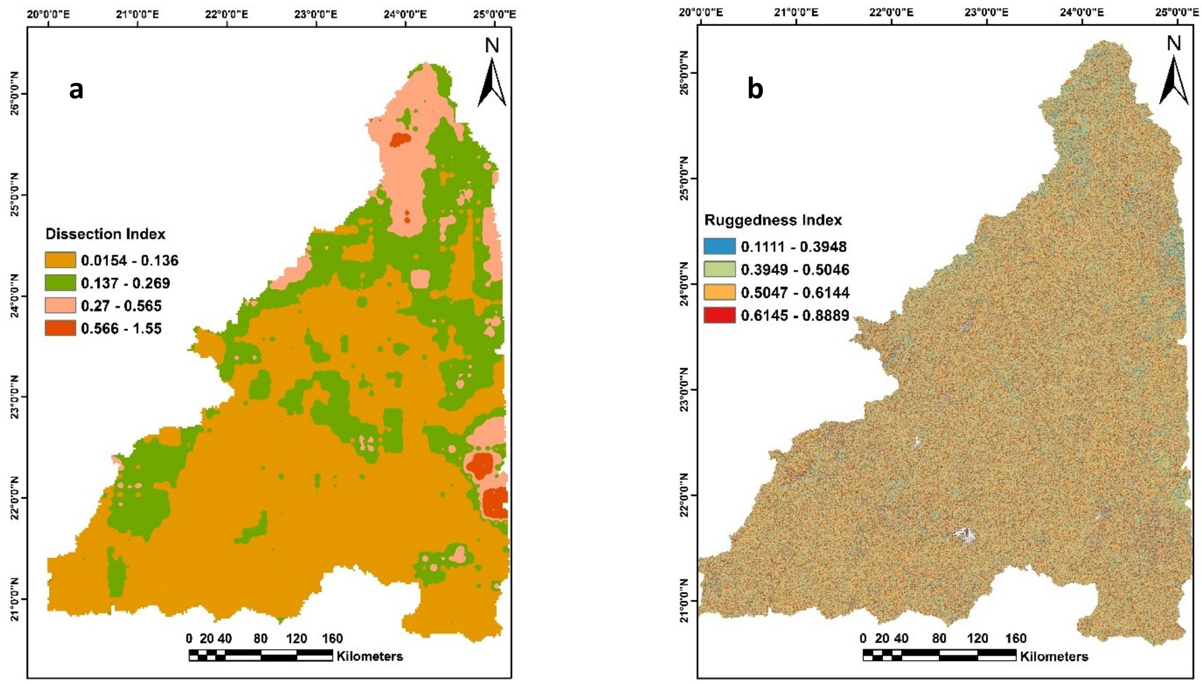

Figure (6). Displays the dissection index map (a); and the ruggedness index map of the Kufrah basin (b).

4. Bifurcation ratio

The bifurcation ratio (Rb) can be defined as a ratio of the number of stream branches of given order to the number of branches of next higher order, (Gupta. et al;2018). From the bifurcation analysis, it can define the drainage integration, geological and the lithological development of the drainage basin from the irregularities of bifurcation ratio, and the structural disturbances on the drainage pattern, (Strahler, 1964). The bifurcation ratio of the Kufrah paleo-river is given in Table (4), where the Bifurcation ratio is (1.8) reveals that the area does not structurally control with flat terrains.

Table (4). Shows the Bifurcation ratios (Rb) of streams order of the Kufrah Paleo-river.

Rb = Nu/Nu + 1, where Nu = Total number of stream segments of order; Nu + 1 = Number of segments of next higher order	**Bifurcation ratios (Rb)**
$1^{st}/2^{nd}$	**2.09**
$2^{nd}/3^{rd}$	**1.7**
$3^{rd}/4^{th}$	**2.8**
$4^{th}/5^{th}$	**1.9**
$5^{th}/6^{th}$	**0.8**
$6^{th}/7^{th}$	**1.8**

5. Valley stage

The hypsometric curve of a catchment represents the relative area below (or above) a given altitude (Strahler, 1952). The shape of the hypsometric curve provides valuable information on the erosional stage of the basin, and also on the tectonic factors controlling it, (Talampas, 2015). To speculate the stage of development of the drainage network, a hypsometric curve for the Kufrah basin was created by plotting the proportion of total basin height against the proportion of total basin area (Fig, 7; Table 5). The resulted curve shows a more S-shaped feature and displays a concave upward feature at higher elevation and concave downwards at lower elevations. In addition, calculating the hypsometric integral (HI), which is known as the region under the hypsometric curve, is a simple way to explain the shape of the hypsometric curve for a given drainage basin (Sarp., et al.; 2011). The hypsometric integral values are ranges between 0 and 1, where low hypsometric integral values indicate old and more eroded areas and dissected drainage basins, while the high values indicate that young and less eroded areas.

The Hypsometric Integral values of a drainage basin can determine by using formula as;

$$Mean\ Elevation\ - Minimum\ Elevation \div Maximum\ Elevation - Minimum\ Elevation$$

The HI value of the Kufrah basin is with 0.17 that indicates old age and highly eroded drainage basin.

Table (5) Estimation of development stages using hypsometric curve statistics.

Altitude range (m)	**Area(km^2)**	**Height(m)**	**Area sum**	**Area percentage**	**stage**
0-200	*0*	*0*	*0*	*0%*	
200-450	*33861*	*200*	*0*	*0%*	*old*
450-550	*57709*	*450*	*33861*	*5.43%*	*old*
550-650	*57860*	*550*	*91570*	*14.68%*	*old*
650-850	*24796*	*650*	*149430*	*23.96%*	*old*
850-1900	*361*	*850*	*174226*	*27.94%*	*mature*
sum	*174587*	*1900*	*174587*	*27.99%*	*mature*

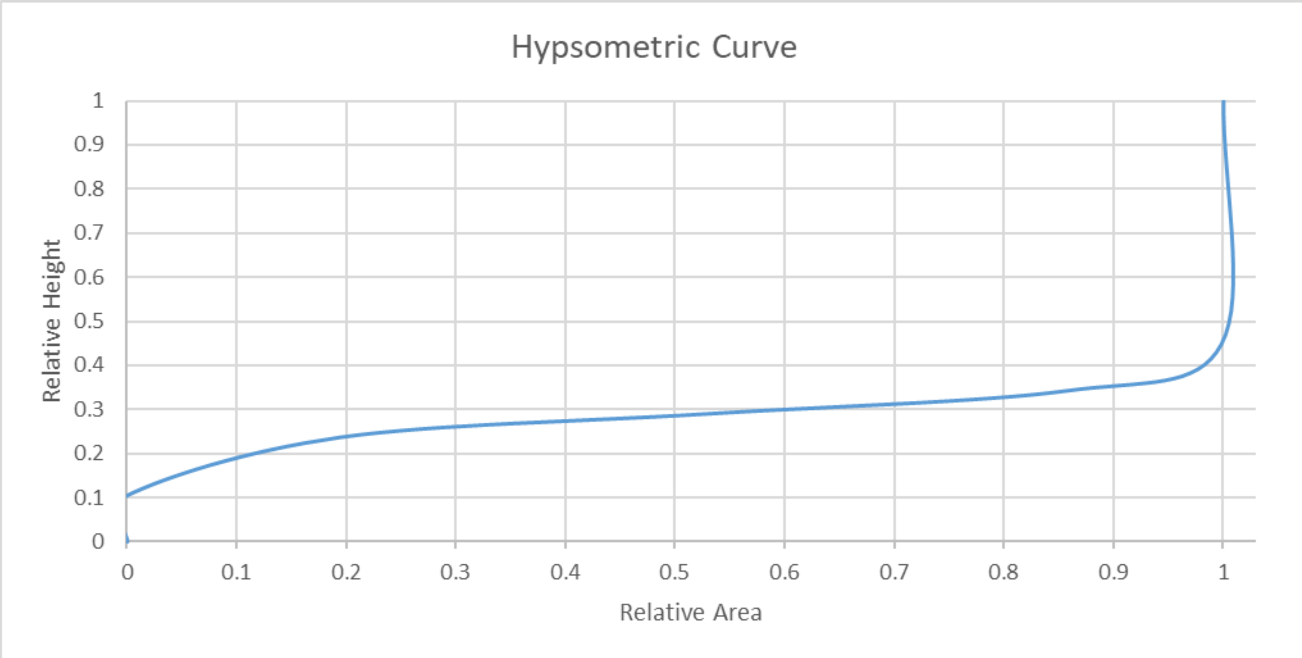

Figure (7). Shows a hypsometric curve for the Kufrah paleo-river.

Conclusion

The present study has used GIS applications and remote sensing techniques for morphometric analysis of the Kufrah Paleo-river. These techniques have demonstrated their ability to penetrate the ground surface and identify the morphometry of the buried river. Therefore, these tools were significantly used in this study for identifying, discovering and mapping the Kufrah Paleo-river in Libya.

All the morphometric parameters that analysed yielded positive results. The used tools have revealed that the Kufrah Paleo-river was running from the south to the north and drained internally into the inland delta of the Al-Jaghbub depression. The Kufrah paleo-river has a very coarse drainage texture with high infiltration capacity. Also, the sub-surface material is highly permeable that leads to low surface runoff. Furthermore, the basin is composed of non-resistant rocks, and thus higher soil erosion susceptibility. The water basin is a moderately to highly dissected with low structural effects. Finally, the Kufrah paleo-river is an “Old age” river.

References

Bellini, E., Massa, D., 1980. A Stratigraphic Contribution to the Palaeozoic of the Southern Basins of Libya. In: Salem, N.J., Busrewil, M.T. (Eds.), The Geology of Libya, Vol. 1. Academic Press, Tripoli, pp. 1–56.

Bellini, E., Giori, I., Ashuri, O., Bellini, F., 1991. Geology of Al Kufrah basin, Libya. In:
Ghoneim, E., Benedetti, M. and El-Baz, F., 2012. An integrated remote sensing and GIS analysis of the Kufrah Paleoriver, Eastern Sahara. *Geomorphology*, *139*, pp.242-257.

Boaz, N.T., 1987. Sahabi and Neogene Hominoid Evolution. In: Boaz, N.T., El-Arnauti, A., Gaziry, A.W., de Heinzelin, J., Boaz, D.D. (Eds.), Neogene Paleontology and Geology of Sahabi, Libya. Alan R. Liss, New York, pp. 129–134.

Coulthard, T.J., Ramirez, J.A., Barton, N., Rogerson, M. and Brücher, T., 2013. Were rivers flowing across the Sahara during the last interglacial? Implications for human migration through Africa. *PloS one*, *8*(9), p.e74834.

Deen, M. 1982. Geomorphology and Land use: A Case Study of Mewat, thesis submitted to the center for the study of regional development, JNU, New Delhi.

De Menocal, P., Ortiz, J., Guilderson, T., Adkins, J., Sarnthein, M., Baker, L. and Yarusinsky, M., 2000. Abrupt onset and termination of the African Humid Period: rapid climate responses to gradual insolation forcing. *Quaternary science reviews*, *19*(1-5), pp.347-361.

El-Baz, F., Mainguet, M., Robinson, C.A., 2000. Fluvio-aeolian dynamics in the North-eastern Sahara: interrelation between fluvial and aeolian systems and implications to ground water. Journal of Arid Environments 44, 173–183.

Faniran, A., 1968. The index of drainage intensity: a provisional new drainage factor. Aust J Sci, 31(9), pp.326-330.
Gindre, L., Le Heron, D. and Bjørnseth, H.M., 2012. High resolution facies analysis and sequence stratigraphy of the Siluro-Devonian succession of Al Kufrah basin (SE Libya). *Journal of African Earth Sciences*, *76*, pp.8-26.

Ghoneim, E., El-Baz, F., 2007a. The application of radar topographic data to mapping of a mega-paleodrainage in the Eastern Sahara. Journal of Arid Environments 69, 658–675

Ghoneim, E., Benedetti, M. and El-Baz, F., 2012. An integrated remote sensing and GIS analysis of the Kufrah Paleoriver, Eastern Sahara. *Geomorphology*, *139*, pp.242-257.

Gupta, R, P. 2018. Remote Sensing Geology. Springer; Third Edition, 437 p.

Hallett, D., 2002. Petroleum Geology of Libya. Elsevier, Amsterdam.

Hecht, M.K., 1987. Fossil snakes and crocodilians from the Sahabi Formation of Libya.
In: Boaz, N.T., El-Arnauti, A., Gaziry, A.W., de Heinzelin, J., Boaz, D.D. (Eds.), Neogene Paleontology and Geology of Sahabi, Libya. Alan R. Liss, New York, pp. 101–106.

Horton, R. E. 1932. Drainage basin characteristics. American Geophys Union Transactions, 13, 348–352.

Horton, R. E. 1945. Erosional development of streams and their drainage basins: Hydro-physical approach to quantitative morphology. Geological Society of American Bulletin, 56, 275–370.

Khakhlari, M. and Nandy, A., 2016. Morphometric analysis of Barapani river basin in Karbi Anglong District, Assam. International Journal of Scientific and Research Publications, 6(10), pp.238-249.

Lüning, S., Craig, J., Fitches, B., Mayouf, J., Busrewil, A., El Dieb, M., Gammudi, A., Loydell, D., McIlroy, D., 1999. Re-evaluation of the petroleum potential of the Kufra Basin (SE Libya, NE Chad): does the source rock barrier fall? Marine and Petroleum Geology 16, 693–718.

McCauley, J.F., Schaber, G.G., Breed, C.S., Grolier, M.J., Haynes, C.V., Issawi, B., Elachi, C., Blom, R., 1982. Subsurface valleys and geoarchaeology of the eastern Sahara revealed by shuttle radar. Science 218, 1004–1020.

Melton, M.A., 1957. An analysis of the relations among elements of climate, surface properties, and geomorphology. Columbia Univ New York.

Miller, V.C., 1953. Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Technical report (Columbia University. Department of Geology); no. 3.

Paillou, P., Tooth, S. and Lopez, S., 2012. The Kufrah paleodrainage system in Libya: A past connection to the Mediterranean Sea? *Comptes Rendus Geoscience*, *344*(8), pp.406-414.

Paillou, A., Schuster, M., Tooth, T., Farr, T., Rosenqvist, A., Lopez, S., Malezieux, J., 2009. Mapping of a major paleodrainage system in eastern Libya using orbital imaging radar: the Kufrah River. Earth and Planetary Science Letters 277, 327–333.

Resmi, M.R., Babeesh, C. and Hema, A., 2019. Quantitative analysis of the drainage and morphometric characteristics of the Palar River basin, Southern Peninsular India; using bAd calculator (bearing azimuth and drainage) and GIS. *Geology, Ecology, and Landscapes*, *3*(4), pp.295-307.

Robinson, C.A., El-Baz, F., Al-Saud, T.S.M., Jeon, S.B., 2006. Use of radar data to delineate palaeodrainage leading to the Kufra oasis in the eastern Sahara. Journal of African Earth Sciences 44, 229–240.

Roth, L.E., Elachi, C., 1975. Coherent electromagnetic losses by scattering from volume inhomogeneities. IEEE Transactions on Antennas and Propagation 23, 674–675.

Sarp, G., Duzgun, S. and Toprak, V., 2011. Hypsometric properties of the hydrolic basins located on western part of NAFZ. In *34th International Symposium on Remote Sensing of Environment, The GEOSS Era: Towards Operational Environmental Monitoring, Sydney, Australia*.

Schumm, S. A. 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67, 597–646. doi:10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2.

Singh, S. 2000. Geomorphology, (Allahabad: Prayag Pustak Bhawan), P 642.

Strahler, A. N. 1952. Hypsometic (area-altitude) analysis of erosional topography. Bulletin of Geological Society of America, 63, 1117–1142.

Strahler, A.N., 1964. Part II. Quantitative geomorphology of drainage basins and channel networks. Handbook of Applied Hydrology: McGraw-Hill, New York, pp.4-39.

Talampas, W.D. and Cabahug, R.R., 2015. Catchment Characterization to Understand Flooding in Cagayan De Oro River Basin in Northern Mindanao, Philippines. Mindanao Journal of Science and Technology, 13.

Villela, S.M. and Mattos, A., 1975. Hidrologia aplicada. In Hidrologia aplicada. McGraw-Hill.

Zamot, Jamal. and Afkareen, Mohammed., 2020. Geomorphological parameters by remote sensing and GIS techniques (A case study of flash flood in Mikhili Village, Al Jabal Al Akhdar, NE of Libya). Paper presented at The Forth International Conference for Geospatial Technologies – Libya GeoTec 4, Tripoli, Libya, 3 – 5 March 2020.