

# Morphometric analysis of a Guigou Sub-Watershed, Sebou Basin, Middle Atlas, Morocco Using GIS Based ASTER (DEM) image

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**Abstract:** Morphometric analysis of watersheds involves the quantification of the channel network and related parameters such as drainage area, gradient and relief. They play a vital role for understanding the geo-hydrological behavior of drainage basin and express the prevailing climate, geology, geomorphology, structural, etc. The present work is an attempt to carry out a detailed study of linear and shape Morphometric parameters of Guigou watershed by using ASTER (DEM) image and Geographical Information System (GIS) techniques. Drainage pattern of the study area is sub-dendritic and parallel with moderate drainage texture. Sub-dendritic drainage pattern of the study area exhibit homogeneity in texture and lack of structural control but parallel drainage pattern suggest that the area has a gentle, uniform slopes and with less resistant bed rock. The mean bifurcation ratio value is 3.88 which indicates geologically controlled drainage pattern. The variation in stream length ratio might be due to changes in slope and topography. The study of morphometric analysis using remote sensing and GIS techniques plays a major role in determining the fluvial landforms in a basin scale and considered very useful for planning and management of drainage basin.

**Keywords:** Morphometric analysis, Remote sensing, GIS, DEM, Guigou sub-watershed, Sebou Basin, Middle Atlas.

## I. INTRODUCTION

Morocco's most populated hydrographical basins, with 5.8 million inhabitants, who account for about 20% of the country's population. According to the 2004 General Census, the population is equally split between urban (3.01 million) and rural areas (2.78 million). The Sebou basin is the site of the most dynamic agricultural and industrial activities in Morocco. This has created high demographic growth and increasing pressure on surface and underground water resources. The Sebou basin is located in northwestern of Morocco. This basin which comprises 1/3 of surface water of Morocco is drained by Sebou river (Oued) that originates in the Middle Atlas and traveled about 500 km before reaching the Atlantic Ocean near Kenitra; 40 km north of Rabat. Climate prevailing in the whole basin is Mediterranean with oceanic influences, and becomes more continental inside the basin.

The average annual rainfall across the Sebou basin, calculated on the period 1973-2002, are about 600 mm. Values minimum, between 400 and 550 mm are observed on the basins Upper Sebou and on the Middle Sebou (region of Fez, Oued Rdat, Oued R'dom, Oued Beht). They are slightly higher (500-600 mm) in the coastal border and far exceed these values in relief areas (700 to 900 mm on the Middle Atlas of Ifrane 1000-1500 mm on the reliefs of the Rif (upper basin of Oued Ouergha). The present work is an attempt to carry out a detailed study of linear and shape morphometric parameters in Guigou sub-watershed of Sebou basin and a comprehensive development plan for optimum use of its resources. The drainage basin is the fundamental unit for the collection and distribution of water, solutes, and sediment in fluvial landscapes [1].

Morphometric analysis of a watershed requires measurement of linear features, aerial aspects and gradient of channel network of the drainage basin [2] and provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds [5] (Table 1,2,3). Linear morphometric relationships describe 'streams'

hierarchical location in the drainage network, stream number and lengths of segments, and offer a measure of the basin's geometric homogeneity. Stream ordering schemes were first proposed by Horton [8] then revised by Strahler [3,4] and Shreve [9]. Stream ordering involves applying a numerical value to a stream's position and size in the basin. The smallest (most upstream) segments farthest from the outlet of the basin are numbered as first order streams. Increasingly larger downstream segments have larger values of stream order. Areal relationships provide useful data on the characteristics of streams as regards the basin, including the collection of rainfall and concentration of runoff, the interaction of climate and geology, and the area necessary to maintain measured units of channel length. Relief relationships provide information regarding differential elevations within the basin and corresponding elevational organization of various stream segments. Though relief calculations may be extremely involved due to their complicated three-dimensional aspect, they have been effective in quantitatively describing successive phases of landscape evolution [10]. Increasingly, linear, areal, and relief relationships evolved beyond basic analysis and have been refined to predict geomorphic processes.

**II. STUDY AREA**

The Guigou watershed (Fig. 1) is located between 33° North Latitude and 34° South, 4°30' Est and 5°20' West Longitude forming a part of Sebou river basin. The study area covers an area of 1871 km<sup>2</sup> and draining into river Guigou in Timahdite-Boulmane region of Middle Atlas. Physiographically the area is characterized by undulating topography with plains and shallow valleys. The study area attains maximum elevation of 2802 m and a minimum of 788 m.

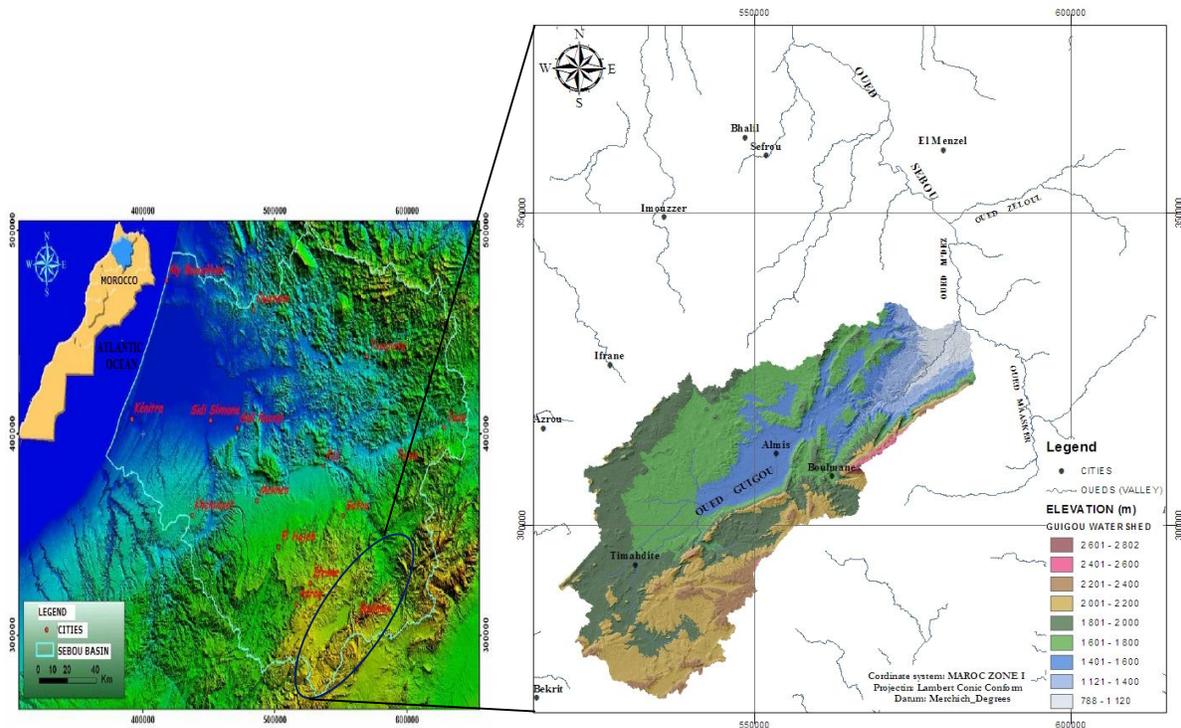


Fig. 1 Location Map of the Study Area

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(An ISO 3297: 2007 Certified Organization)

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## III. MATERIALS AND METHODS

For detailed study, we used ASTER data for preparing digital elevation model (DEM), and geographical information system (GIS) was used in evaluation of linear, areal and relief aspects of Morphometric parameters. The ASTER GDEM is being distributed by METI and NASA through the Earth Remote Sensing Data Analysis Center (ERSDAC) and the NASA Land Processes Distributed Active Archive Center (LP DAAC) at no charge to users worldwide as a contribution to the Global Earth Observing System of Systems (GEOSS). It is packaged in 1°-by-1° tiles, and covers land surfaces between 83°N and 83°S with estimated accuracies of 20 meters at 95 % confidence for vertical data and 30 meters at 95 % confidence for horizontal data. The ASTER GDEM is in geotiff format with geographic lat/long coordinates and a 1 arc-second (30m) grid.

The morphometric parameters for the delineated watershed area were calculated in GIS environment based on the formula suggested by Strahler [5], Horton [8], Hardley [11], Schumm [12], Miller [14] and Nookaratanm et al. [15].

## IV. RESULTS AND DISCUSSION

The morphometric parameters were analysed and divided in three categories: (1) linear aspect includes Number of Stream (Nu), Stream Length (Lu), Mean Stream Length (Lsm), Stream Length Ratio (Rl), Bifurcation Ratio (Rb) and Mean Bifurcation Ratio (Rbm), (2) areal aspect includes Drainage density (Dd), Drainage texture (T), Stream Frequency (Fs), Elongation ratio (Re), Circularity ratio (Rc) and Form factor (Ff), (3) relief aspect includes basin relief (R), Relief Ratio (Rr), Dissection Index (Dis) and Ruggedness Number (Rn)

Based on the drainage orders, the Guigou sub-watershed has been classified as seven order basin to analyse linear, relief and areal morphometric parameters as shown in Table 1, proposed by authors [5, 7, 8, 11, 12, 13, 17, 18].

### A. Linear Aspect

The drainage network transport water and the sediments of a basin through a single outlet, which is marked as the maximum order of the basin and conventionally the highest order stream available in the basin considered as the order of the basin.

Computation of the linear aspects such as stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and length ratio are described below (Table 1).

The designation of stream order is the first step in morphometric analysis of a drainage basin, based on the hierarchic making of streams proposed by Strahler [5]. It is defined as a measure of the position of a stream in the hierarchy of tributaries. There are 3347 streams linked with 7th order of streams sprawled over an area of 1871 km<sup>2</sup>, which 2478 segments are first-order streams, accounting for 74 % of all segments. The second-order stream segments number 655 and account for 19.5% of all segments. Third-order stream segments number 176 and account for 5.26%; fourth order stream segments number 28 and account for 0.83%; fifth-order stream segments number 7 and account for 0.2 %; and sixth order stream segments number 2 and account for 0.06%, and seventh order stream segments number 1 and account for 0.03%. The results are presented in Table 1 and Fig. 2 (a). Relation between stream order (u) and stream numbers (Nu) shows a negative correlation, it means that the several streams usually decreases in geometric progression as the stream order increases (Fig. 2. b). The variations in rock structures in the basin are responsible for inequalities in stream frequencies of each order. The total stream length in Guigou sub-watershed is 3206 km. The mean length of channel Lu of order u is about 114 km. Stream length is one of the most important hydrological features of the basin indicate the variation of surface run-off behaviors. The 5th, 6th and 7th order stream segments occur in comparatively plain lands (Guigou plain), upper to 4th order traverse parts of the high to moderate altitudinal zones characterized by steep to moderate slopes.

Bifurcation ratios ranges from 2 to 6.28 (Table 1). The bifurcation ratio is an index of relief and dissection [8]. The average bifurcation ratio in the study area is 3.88, because of possibility of variations in geometry and lithology. The highest Rb (6.28) is found between 3rd and 4rd order, indicates higher runoff and discharge attributable corresponding to the formation of less permeable rock hills associated with steep slopes. In addition, the irregularities in peak flows depend on the geological and lithological development of drainage basin [5].

The Guigou river (Oued Guigou) crossing in its passage NW (at the tabular Middle Atlas platform) to the SE (at the Folded Middle Atlas) on carbonate formations of the lower and medium Lias (Timahdite-Gugou plateaus), basaltic

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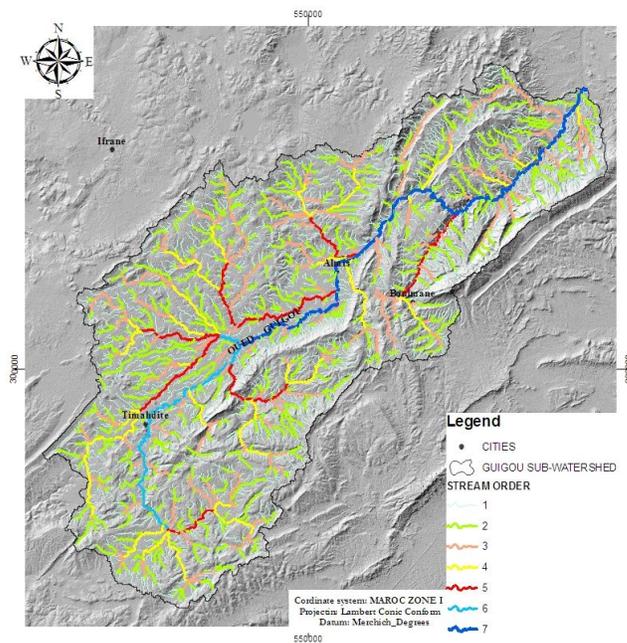
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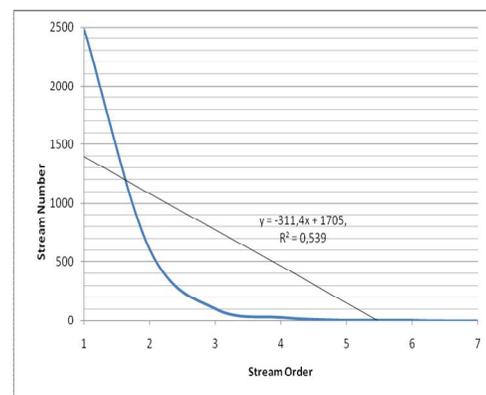
Plio-Quaternary formations (Guigou plain) to the Guigou synclinal on marly-calcareous and marly-sandstone formations.

Table 1 Linear morphometric parameters of Guigou Sub-Watershed

Parameters	Formula	Stream order (Su)								Reference
		1	2	3	4	5	6	7	Total	
Number of Stream (Nu)	Hierarchical Ranks	2478	655	176	28	7	2	1	3347	Strahler (1952)
Stream Length (Lu)	Length of the stream (Km)	1638	811	374	176	97	39	71	3206	Horton (1945)
Mean Stream Length (Lsm)	Lsm=Lu/Nu Lu=Total stream length of order 'u' Nu=Total no. of stream segments of order 'u'	0,66	1,24	2,12	6,3	13,8	19,5	71	114,62	Horton (1945)
Stream Length Ratio (Rl)	Rl= Lu/Lu-1 Lu=Total stream length of the order 'u' Lu-1=Total stream length of its next lower order	-	0,49	0,46	0,47	0,55	0,40	1,83	-	Horton (1945)
Bifurcation Ratio (Rb)	Rb=Nu/Nu+1 Nu=Total no. of stream segments of order 'u' Nu+1= Number of segments of the next higher order	3,78	3,72	6,28	4	3,5	2	-	-	Schumm (1956)
Mean Bifurcation Ratio(Rbm)	Rbm= Average of Bifurcation ratios of all orders	3,88								Strahler (1957)



(a)



(b)

Fig. 2 Stream Orders (Su) (a) Regression of number of streams versus stream order (b)

*B. Aerial Aspect*

Aerial aspects of a watershed of given order  $u$  is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order.

Basin area is hydrologically important because it directly affects the size of the storm hydrograph and sizes peak and average runoff. It is interesting to note that the maximum flow per unit of area is inversely related to size [19]. Table 2, shows that the value of form factor ( $F_f$ ), circulatory ratio ( $R_c$ ) and elongation ratio ( $R_e$ ) are 0.29, 0.17, 0.61 and respectively. The low value of form factor represents elongated watershed. In this case, the value of  $R_e$  was considered 0.61 indicating relatively moderate relief of the land and elongated shape of the drainage basin. The calculated  $R_c$  value of 0.52 indicates that the drainage basin is more or less elongated and is characterized by an environment of low relief. Such drainage is partially controlled by structural perturbations [14, 20].

The drainage density ( $D_d$ ) is calculated as a ratio of the sum of streams lengths to the size of area of the grid considerate [21]. This criterion favoring drainage basins reduces the duration of infiltration favoring runoff [22]. The higher the infiltration rate, the lower the density of surface-water drainage, which is a major control on groundwater recharge [23]. This thematic layer was extracted from the Aster DEM image. Then, very high density is considered as a very low capacity for groundwater potentiality and conversely (Fig. 3.a).

Stream frequency reflects the degree of dissection of the terrain. The high stream frequency, indicate high degree of dissection. The Stream frequency depends on the rock structure, infiltration capacity, vegetation cover, relief, nature and amount of rainfall and subsurface material permeability. For the present study, the stream frequency is 1.78. Stream frequency was positively correlated with drainage density. Less drainage density and stream frequency in a basin, the flow is slower, and therefore is less likely flooding in basins with a low to moderate drainage density and stream frequency [24].

The drainage texture depends upon several natural factors such as climate, vegetation type and density, rock and soil type, infiltration capacity, relief and stage of development [25]. The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin ( $R_t = N_1 / P$ ). Based on ratios texture ( $R_t$ ) values, [16] proposed a classification of drainage texture. For  $R_t$  value of 4.0 and below, the texture is coarse; value between 4.0 to 10.0, has intermediate texture; value above 10.0, has fine texture and for  $R_t$  value above 15.0, the texture is ultra fine (bad land topography). The  $R_t$  value of the present study is 6.77, which indicates an intermediate texture for the study area.

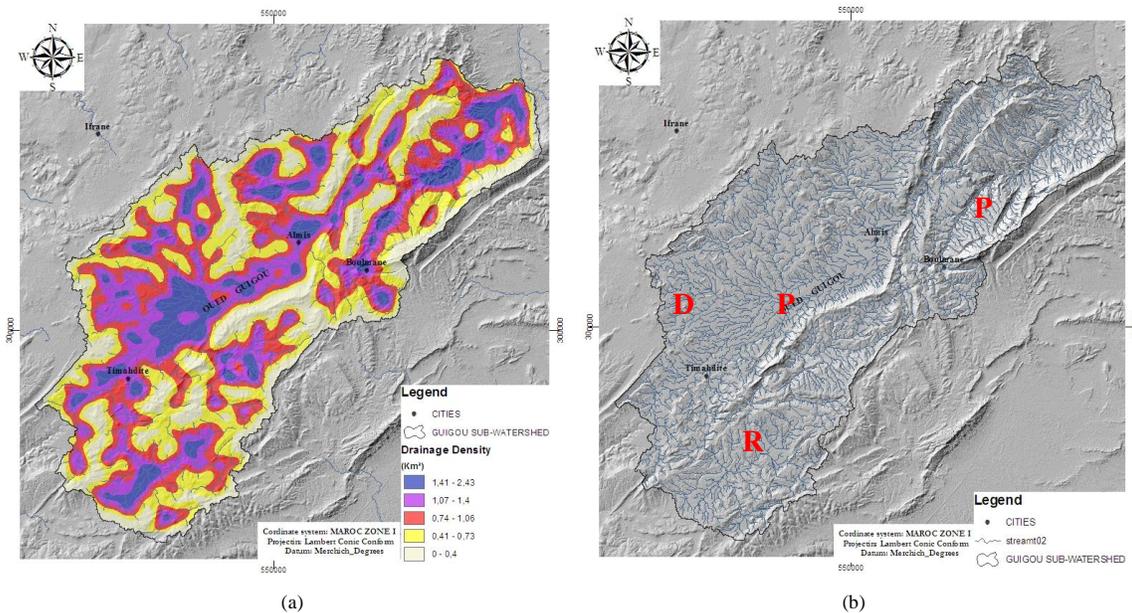


Fig. 3 Drainage Density (a) Drainage Map and Network Typology (b)

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Table 2 Aerial morphometric parameters of Guigou Sub-Watershed

Parameters	Formula/Symbol	Reference	Result
Area (km)	A	GIS	1871
Perimeter (km)	P	GIS	366
Basin Length (km)	L	GIS	80
Drainage density (Dd)	$Dd = Lu/A$	Horton (1945)	1,71
Stream Frequency (Fs)	$Fs = \sum Nu/A$	Horton (1945)	1,78
Texture Ratios (Rt)	$Rt = N1/P$	Smith (1950)	6,77
Elongation ratio (Re)	$Re = (2/L)*(A/\pi)^{0.5}$	Schumm (1956)	0,61
Circularity ratio (Rc)	$Rc = 4 \pi A / P^2$	Strahler 1964	0,17
Form factor (Ff)	$Ff = A / L^2$	Horton (1945)	0,29

The type of network is a function of the frequency which determines the lithology of the headers. Over the substrate is impermeable, the most significant and will run the network is dense. The analysis of the hydrographic network is based on the descriptive classification of Howard [26]. The study area (Fig.3. b) is drained by a network of dendritic to sub-dendritic type evenly distributed in the highest Collins of Guigou plain characterized by Basaltic Plio-Quaternary deposits. When the grounds are pleated and slope became moderate to flat, the drains are parallel and oriented NE -SW, which features an array of parallel type, in the main direction of the major regional faults (North Middle Atlas Fault). Foded middle Atlas area (Figure 7) is marked by significant fracturing. It is characterized by a network of rectangular type where confluences between the channels and drains are perpendicular undergo sudden changes in direction. Changes in the length of talwegs, are correlative with deep tectonic structures buried under a more or less thick sedimentary cover [27]. According to these authors is interpreted morphometric maps is based on the repeated finding axes only short lengths of drains match "positive" structures (antiforms, horst ..) while conversely the strong axis values correspond to "negative" structures (synforms, grabens ..), (Fig. 4).

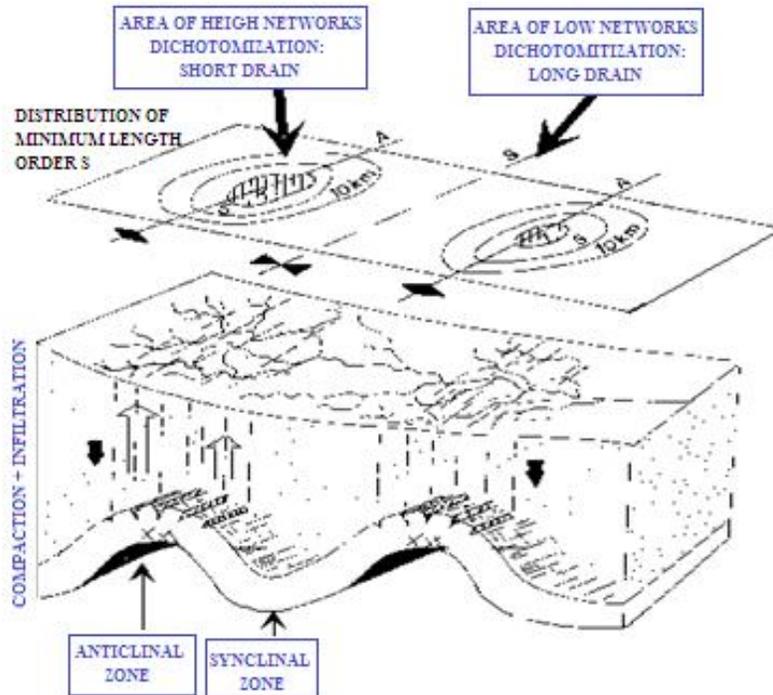


Fig. 4 Diagram shows interpretative correlations between buried structures and the thalwegs network (Collina-Girard & Griboulard 1990)

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### C. Relief Aspect

The relief of a watershed is defined as the difference between the highest and lowest elevation points. The total relief of Guigou sub-watershed is calculated as  $R = H - h = 2802 - 788 = 2014$  m (H= maximum elevation of sub-watershed, h= minimum elevation of sub-watershed; the high relief value indicates high gravity of water flow, low permeable and high runoff conditions. The value of relief ratio  $R_r$  is 0.025 indicates moderate relief and steep to moderate slope. It's calculated as the ratio between the total relief of a watershed and the longest dimension of the watershed parallel to the main drainage line [10]. Moderate value of relief ratios may indicate the areas with low to moderate relief and slope. Low relief ratios also indicate that the discharge capabilities of the watershed are low and chances of groundwater potential are good.

Dissection index (Dis) is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed [28]. On average, the values of Dis vary between '0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and '1' (in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore). Dis value of Guigou sub-watershed is 0.72, which indicate the watershed is a moderate dissected.

Ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length [6]. Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but long, as well. For the present sub-watershed, the ruggedness number is 3.44, which indicate both relief and drainage density are high. These results are shows in Table 3.

Table 3 Relief morphometric parameters of GUIGOU Sub-Watershed

Parameters	Formula	Reference	Result
Relief	$R = H - h$	Hardley and Schumm (1961)	2014
Relief Ratio	$R_r = R/L$	Schumm (1963)	0,025
Dissection Index (Dis)	$Dis = R / H$	Singh (1994)	0,72
Ruggedness Number (Rn)	$Rn = Dd * (R / 1000)$	Strahler (1968)	3,44

Aspect refers to the direction that the mountain slope faces. The output raster image created from the DEM data is represented in eight directions (Fig.5.a and b). The aspect of a slope can greatly affect its climate. This can influence the vegetation in the study area. Slope analysis is an important parameter in geomorphic studies. A detailed understanding of slope distribution as the map helps in planning for various aspects like, settlement, agriculture, planning of engineering structure, etc. [16]. A lower slope value indicates relatively flat terrain, and a higher slope value indicates steeper terrain. Fig. 6 (a,b) shows that the steepest slopes were found in the north-eastern part of the basin. Low slope values were found in the North-western and river-mouth parts of the basin. Hence the slope map can be used to identify areas with high runoff and high erosion rates, which correspond to areas with steep slopes.

Three-dimensional visualization of DEM can reproduce the topography and to clearly structured reliefs. It's indicated the geomorphology of Guigou sub-watershed; shows the average North Middle Atlas Fault separating the folded to tabular Middle Atlas, and crossing of Guigou river (Oued) at the Guigou plain towards the synclinal in embouchure to M<sup>o</sup>Dez river giving to major river of Sebou Basin (Fig. 7).

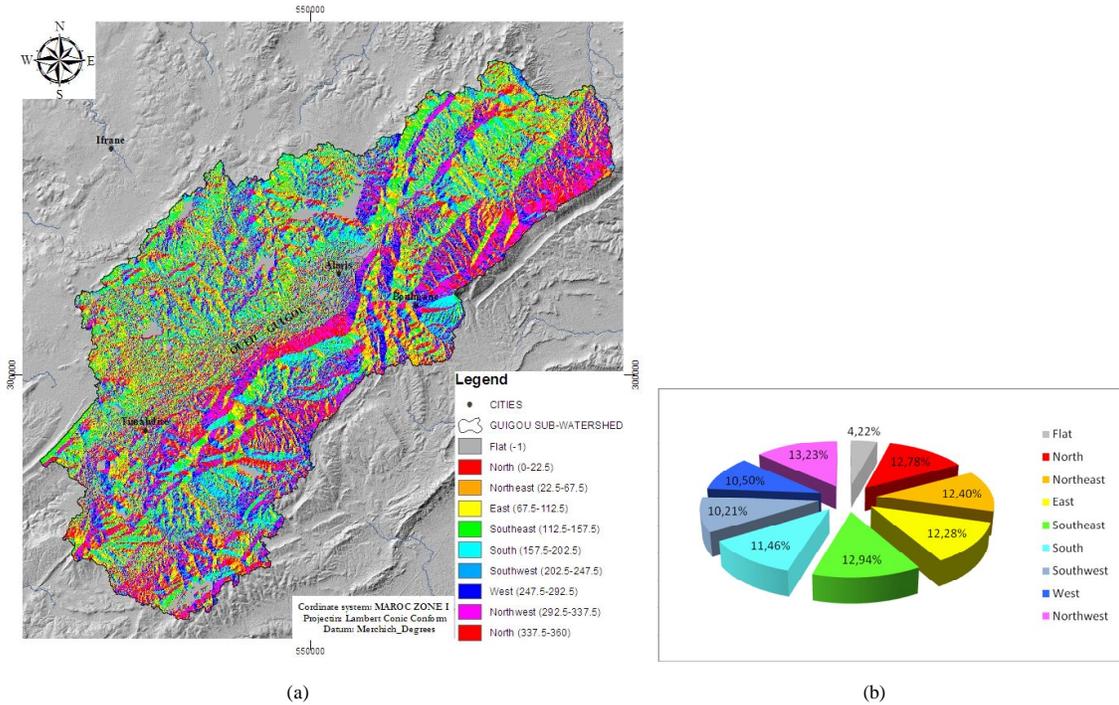


Fig. 5 Aspect Map (a) Diagram showing % of various directions (b)

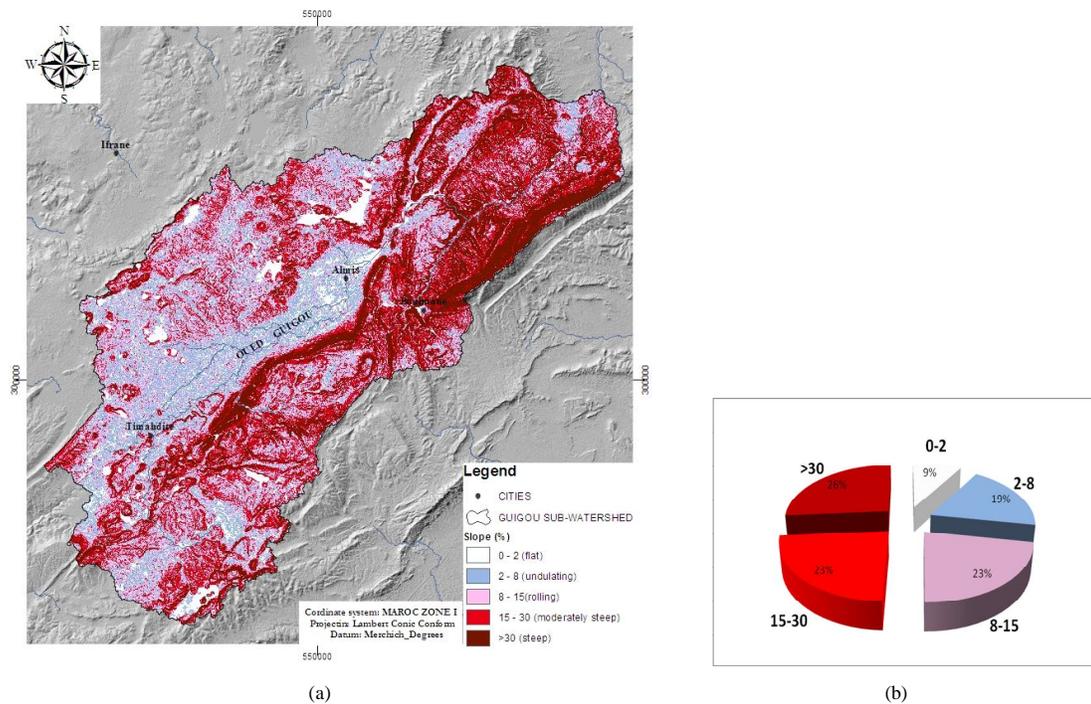


Fig. 6 Slope Map (degrees) (a) Diagram showing % of each class (b)

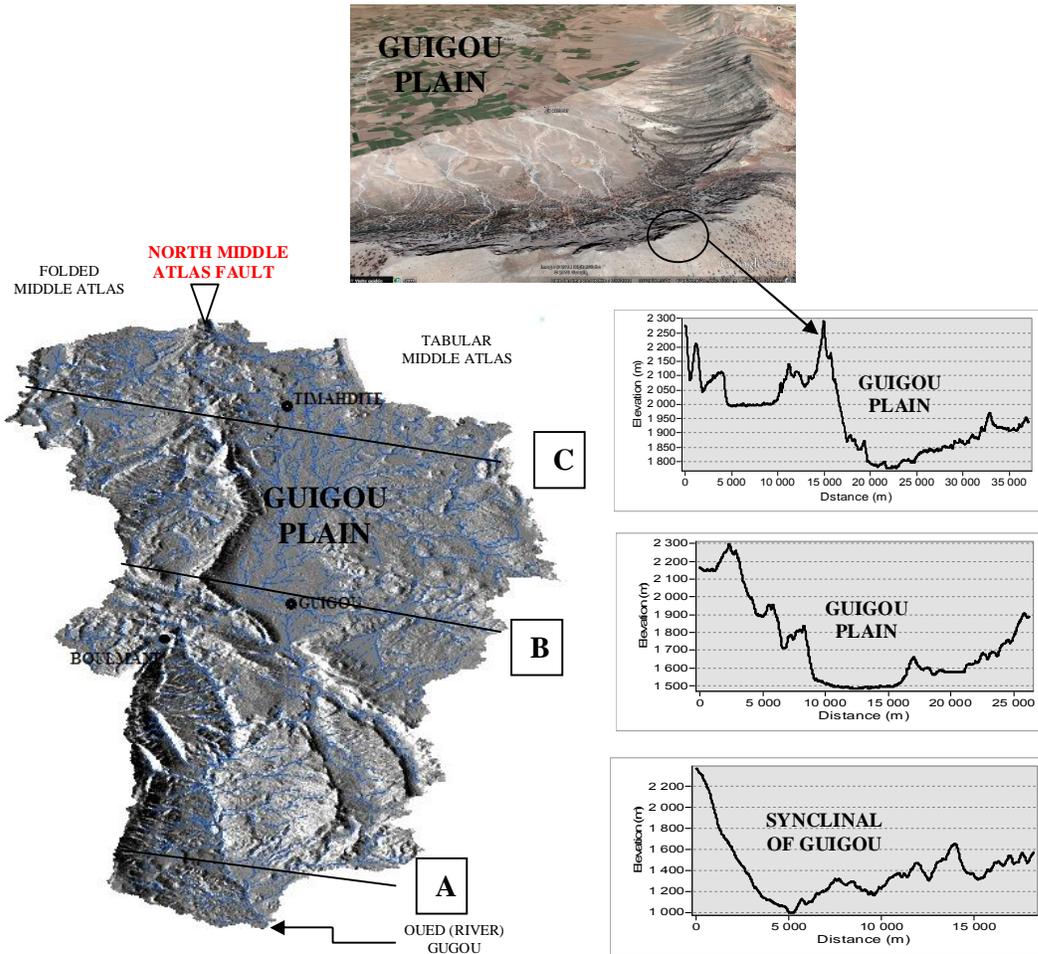


Fig. 7 Morphometric parameters of Guigou Sub-watershed, deriving from ASTER DEM, Representing Google Earth image, 3D-DEM surface view and profiles (A, B, C) transect

## V. CONCLUSION

Remote Sensing coupled with GIS techniques have proved to be an efficient tool for the morphometric analysis of watersheds. This study has shown that the Guigou sub-watershed is susceptible to hydrologic processes like flooding, erosion and landslide. The highest bifurcation ratios  $R_b$  (6.28) is found between 3rd and 4rd order, indicates higher runoff and discharge attributable corresponding to the formation of less permeable rock hills associated with steep slopes. Form factor (Ff), circulatory ratio ( $R_c$ ) and elongation ratio ( $R_e$ ) indicates elongated shape of the drainage watershed. High drainage density and stream frequency in a basin, the flow is faster, and therefore is high likely flooding (plain Guigou). The texture ratio ( $R_t$ ) value of the present study is 6.77, which indicates an intermediate texture for the study area drained by a network of dendritic to sub-dendritic type evenly distributed in the highest Collins of Guigou plain characterized by Basaltic Plio-Quaternary deposits. When the grounds are pleated and slope became moderate to flat, the drains are parallel and oriented NE -SW, in the main direction of the major regional faults (North Middle Atlas Fault). The area of Folded Middle Atlas is marked by significant fracturing. It is characterized by a network of rectangular type where confluences between the channels and drains are perpendicular undergo sudden changes in direction. Relief ratio  $R_r$  is 0.025 indicates moderate relief and steep to moderate slope. Dissection Index

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(Dis) value is 0.72, indicate that the Guigou sub-watershed is moderate dissected. The ruggedness number is 3.44, which indicate both relief and drainage density are high. The photo-interpretation technique is far less time consuming than the actual field surveys and coupled with the field checks may yield valuable results.

## REFERENCES

- [1] Ritter, D.F., Kochel, R.C., Miller, J.R., "Process Geomorphology 3rdEd", W.C. Brown Publishers, Dubuque, IA, 539 p, 1995.
- [2] Nautiyal, M.D., "Morphometric analysis of a drainage basin, district Dehradun, Uttar Pradesh", J. Indian Soc. Remote Sensing, 22(4), pp. 251-261, 1994.
- [3] Strahler, A.N., "Dynamics Basis of Geomorphology", Geophysical Society of American Bulletin, 63(9), pp. 923-938, 1952.
- [4] Strahler, A.N., "Quantitative analysis of watershed geomorphology", Trans. Am. Geophys.Union. 38, pp. 913-920, 1957.
- [5] Strahler, A.N., "Quantitative Geomorphology of Drainage Basins and Channel Networks", In: VT Chow (ed), Handbook of Applied Hydrology. McGraw Hill Book Company, New York, Section 4-11, 1964.
- [6] Strahler, A.N., "Quantitative geomorphology, In: Fairbridge, R.W. (eds)", The Encyclopedia of geomorphology, Reinhold Book Crop, New York, 1968.
- [7] Horton, R.E., "Drainage Basin Characteristics", Transactions of American Geophysics Union, 13, pp. 350-361, 1932.
- [8] Horton, R.E., "Erosional Development of Streams and their Drainage Basins: A Hydrophysical Approach to Quantitative Morphology" Geological Society of America Bulletin, 56 (3), pp. 275-370, 1945.
- [9] Shreve, R.L., "Infinite topologically random channel networks", Journal of Geology, vol. 77, pp. 397-414, 1967.
- [10] Rodrigue-Itrube, I., Valdes, J.B., "The geomorphologic structure of hydrologic response", Water Resources, vol.15, pp. 1409-20, 1979.
- [11] Hardely, R.F., Schumm, S.A., "Sediment sources and drainage basin characteristics in upper Cheyenne river basin", United states Geological survey water-supply paper, 1531-B, pp. 10-19, 1961.
- [12] Schumm, S.A., "Evolution of Drainage systems and Slopes in Badlands at Perth Amboy, New Jersey", Geological Society of America Bulletin, 67, pp. 597-646, 1956.
- [13] Schumm, S.A., "Sinuosity of Alluvial Rivers on the Great Plains", Bulletin of the Geological Society of America, 74, pp. 1089-1100, 1963.
- [14] Miller, V.C., "A Quantitative Geomorph Study of Drainage Basin Characteristics on the Clinch Mountain Area", Virginia and Tennessee, Proj. NR, pp. 389-402, Tech Rep 3, Columbia University, Department of Geology, ONR, New York, 1953.
- [15] Nookaratanam, K., Srivastava, Y.K., Venkateswararao, V., Amminedu, E., Murthy, K.S.R., "Check dam positioning by prioritization of microwatersheds using SYI model and morphometric analysis – Remote sensing and GIS perspective", Journal of the Indian Society of Remote Sensing, 33(1), pp. 25:28, 2005.
- [16] Smith, K.G., "Standards for grading textures of erosional topography". Am. Jour. Sci. 248, pp. 655-668, 1950.
- [17] Sreedevi, P.D., Subrahmanyam, K., Shakeel, A., "The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain", J Environ Geol, Vol. 47, No. 3, pp. 412-420, 2005.
- [18] Mesa, L.M., "Morphometric Analysis of a Subtropical Andean basin (Tucuman, Argentina)", Environmental Geology, 50, pp. 1235-1242, 2006.
- [19] Chorley, R.J., Malm, D.E., Pogorzelski, H.A., "A new standard for estimating basin shape", American Journal of Science, vol. 256, pp. 138-141, 1957.
- [20] Sarma, P.K., Sarmah, K., Chetri, P.K., Sarkar, A., "Geospatial study on morphometric characterization of Umtrew River basin of Meghalaya, India". International Journal of Water Resources and Environmental Engineering 5, pp. 489-498, 2013.
- [21] Greenbaum, D., "Hydrogeological applications of remote sensing in areas of crystalline basement", Paper presented at the In: Proc Groundwater Exploration and Development in Crystalline Basement Aquifers, Zimbabwe, 1989.
- [22] Gresillon, J.M., "Pour un modèle d'infiltration adapté à l'échelle d'un bassin. Soil Water in the Sudano-Sahelian Zone", Proceedings of the Niamey Workshop, Feb. 1991, IAHS Publ., n°199, 1991.
- [23] Krishnamurthy J., Mani A., Jayaraman V., Manivel, M., "Groundwater resources development in hard rock terrain-an approach using remote sensing and GIS techniques", International Journal Applied Earth Observation Geoinformation, vol. 2, No. 3/4, pp. 204-215, 2000.
- [24] Carlston, C.W., "Drainage density and streamflow", U.S Geological Survey Professional Paper, 1963.
- [25] Kale, V.S., Gupta, A., "Introduction to Geomorphology", Orient Blackswan Private Limited, 2001.
- [26] Howard, A.D., "Drainage analysis in geologic interpretation: A summation", Bulletin of American Association of Petroleum Geology, 21, pp. 2246-2259, 1967.
- [27] Collina-Girard, J., Griboulard, R., "La structuration profonde du plateau de Valensole (Alpes): Apport des analyses des réseaux d'entailles et des surfaces topographiques". Géol. Médit. XVII, 2, pp. 153-171, 1990.
- [28] Singh, Y., Dubey, D.P., "Deep zone karst aquifer as a boon in Central India. The Engineering Geology and Hydrogeology of Karst Terrain", In: Beck and Stephenson (eds), Balkema, Retterdam, pp.245-249, 1997.