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Topographic and morphometric analysis of Sebou watershed (Morocco) using geographic information system and digital elevation model

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Abstract

The Sebou watershed, object of this study, is considered one of the most important basins in Morroco due to its high agricultural and industrial activities and water resources. The topographic and morphometric characteristics have been derived from digital elevation model using geographic information system. The study reveals that the majority area of the basin presents low slope and is directed towards NW. The watershed has 5 orders of stream. The number of stream segments is 400, dominated by 1st order streams (53.3%). The stream number and the stream length decrease while stream order increase. The mean bifurcation ratio is 4 in which the influence of geologic structures is negligible. The drainage density and frequency are low and drainage texture is very coarse. Form factor and elongated ratio indicates that the basin is close to oval shape. The stream gradient is high in first order and low in fifth orders. The hypsometric analysis indicates an old stage.

Keywords: GIS, DEM, topography, morphometry, sebou watershed.

Introduction

In Morocco, water resources are low and overexploited, aggravated by climate aridity and the population growth. In the Sebou watershed, the Sebou river Basin is one of Morocco's most important river basins. This watershed contributes with 30% of the national potential of surface water resources and 20% of the ground water resources; also, it is the most important agricultural and industrial region of Morocco. Land use and management changes lead to an increase in runoff, soil erosion and sedimentation of downstream reservoirs, reducing water availability across the watershed[1-3].

Morphometric analysis is a major advance in studies related to neotectonics, geomorphology, and hydrology. Morphometric parameters are subdivided into three classes: Linear parameters, shape parameters and parameters dealing with the relief aspect of subwatersheds. The basin geomorphic characteristics have been used in various studies such as sediment yield, runoff, catchment characterization, hydrology, modeling surface processes, neotectonics, flood, and prioritization of watershed[4-13].

Study area: Geographically the watershed area is bounded by the rif mountains to the north, in the Eastern side by the corridor Fès-Taza, in the west by the Atlantic ocean, and in the south by the middle atlas mountains (Figure-1). The basin can be divided into three distinct geomorphic regions: the upper, mid, and lower Sebou[14].

Methodology

This study is based on the processing of the digital elevation model collected from satellite image Aster (Advanced Space Thermal Emission and Reflection Radiometer) with resolution of 30m.

The digital elevation model or DEM has been utilized as one of the core databases in many geographic information system applications, and is the origin for extracting several topographic and morphometric parameters.

The DEM was processed by several operations such as: fill sink, extraction of flow direction, flow accumulation, stream definition, stream segmentation, stream orders, stream to feature, and delineation the watershed.

The morphometric parameters are classified into linear aspects, aerial aspects and relief aspects. Linear aspects include stream order, stream length, mean stream length, stream length ratio, and bifurcation ratio.

Aerial aspects include drainage density, stream frequency, drainage texture, form factor, elongation ratio, length of overland flow, and infiltration number. Whereas relief aspects consist of relief ratio, ruggedness number, gradient stream and hypsometric curve.

Quantitative assessment of these parameters has been carried out using standard mathematical formulae (Table-1). In addition, the hypsometric curve has been drawn for the basin.

Results and discussion

Topographic analysis: The digital elevation model is classified into twelve zones of elevation differences (Figure-2). The maximum elevation is close to 2978m in the north and south borders (Rif Mountains and Atlas) while the minimum elevation is 1m in the outlet of the basin near the Atlantic Ocean. More than 88% of the total area lies below the 1490m elevation value and almost 12% of total area lies above the 1490m contour (Figure-3).

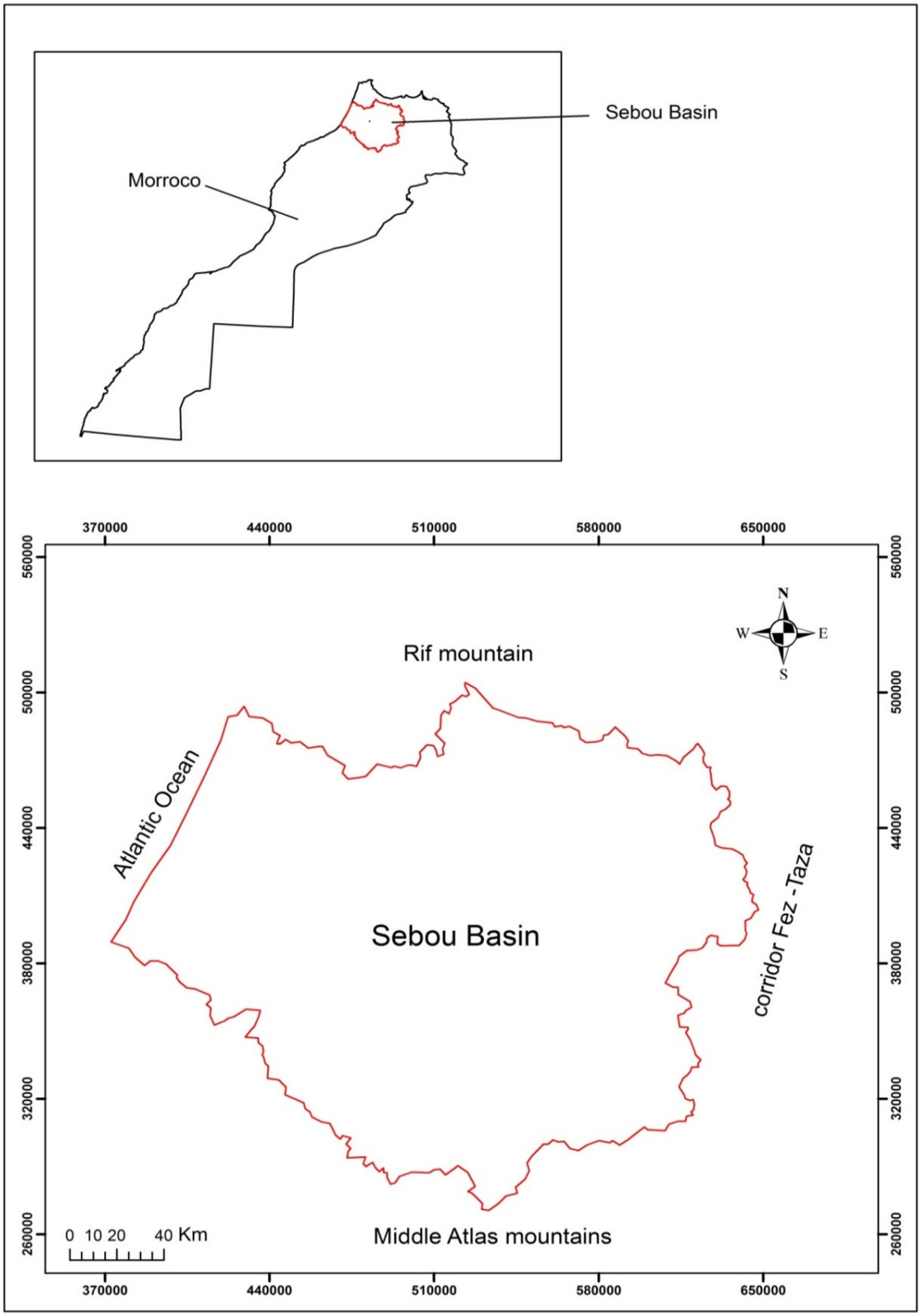

Figure-1: Study area.

Table-1: Equations used for computation of morphometric parameters.

	Morphometric parameters	Equation
Linear aspects	Stream order[15]	Hierarchical rank
	Stream length[16]	Length of stream
	Mean stream length[15]	Lu/Nu Where: Lu=total stream length of order u, Nu=total no. of stream segments of order u
	Stream length ratio[16]	$Lu/Lu-1$ Where: Lu=total stream length of order u, Lu-1=total stream length of its next lower order
	Bifurcation ratio[17]	$Nu/Nu+1$ Where: Nu=total no. of stream segments of the order u, Nu+1=number of segments of the next higher order
Aerial aspects	Drainage density[18]	Lu/A Where: A = total area of the basin km^2, Lu is the total stream length of all orders
	Stream frequency[18]	Nu/A Where: Nu is the total number of streams of all order, A is basin area in km^2
	Form factor[18]	A/Lb^2 Where: $b^2$is the square of the basin length (km), A is the basin area in km^2
	Elongation ratio[17]	$2sqrt(A/\pi)/Lb$ Where: A is the area $(km)^2$ and Lb = basin, length
	Length of overland flow[16]	$1/(D*2)$ Where: D is the drainage density
Relief aspects	Relief ratio[17]	H/Lb Where: H=total relief of the basin, $H=(max-min)elevation$, Lb=basin length
	Ruggedness number[19]	$H*D$ Where: H = watershed relief (km), D = drainage density (km/km^2)
	Gradient stream[12]	$(Es-Em)/Lb$ Where: Es=elevation at source, Em=elevation at mouth, Lb=length of main stream

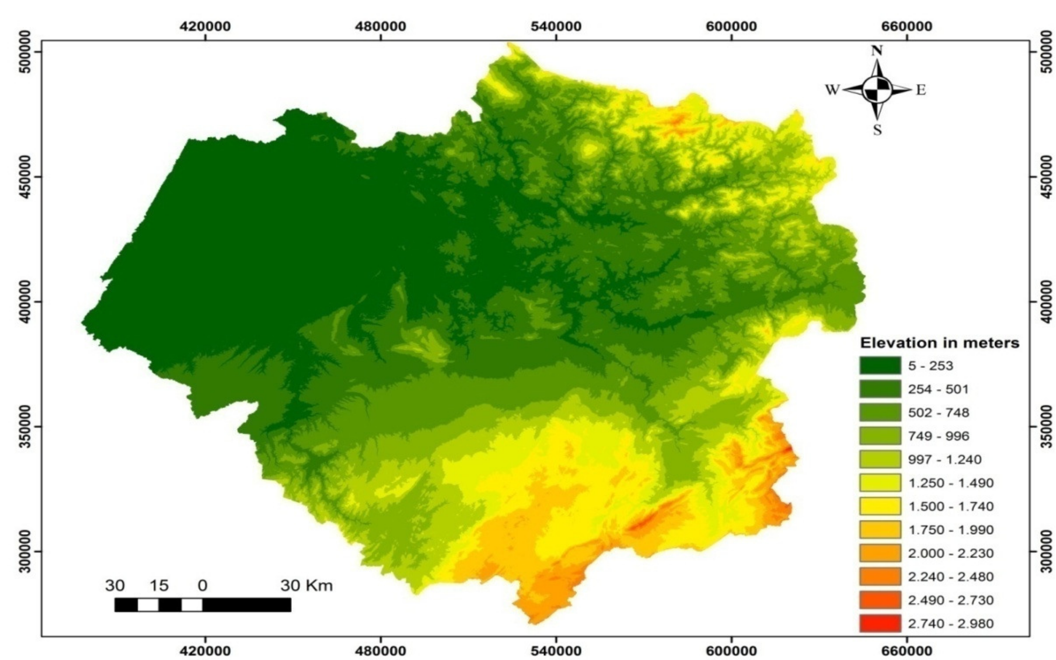

Figure-2: Classified elevation map.

The slope map (Figure-4) of Sebou watershed is classified into six divisions. An area of 69% of total area has a slope of 0-12^0 (low slope) which is the dominant. 24% of the area has moderate slope (13-25^0) and high slope (26-74^0) is represented by 7% (Figure-5).

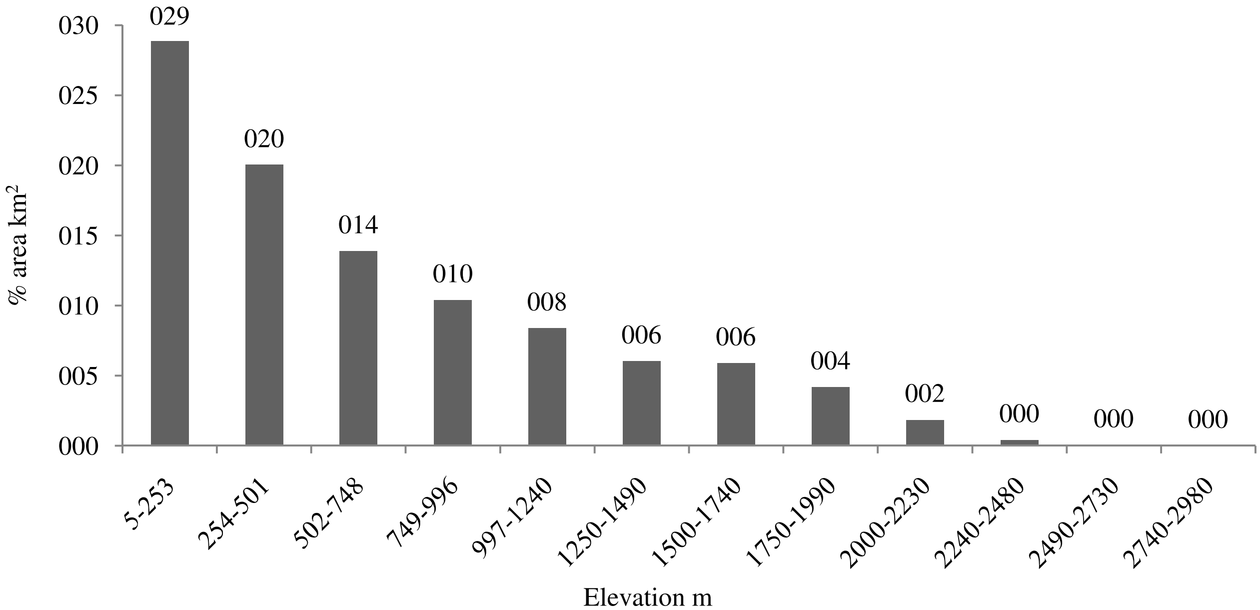

Figure-3: Area distribution within different elevation Classes.

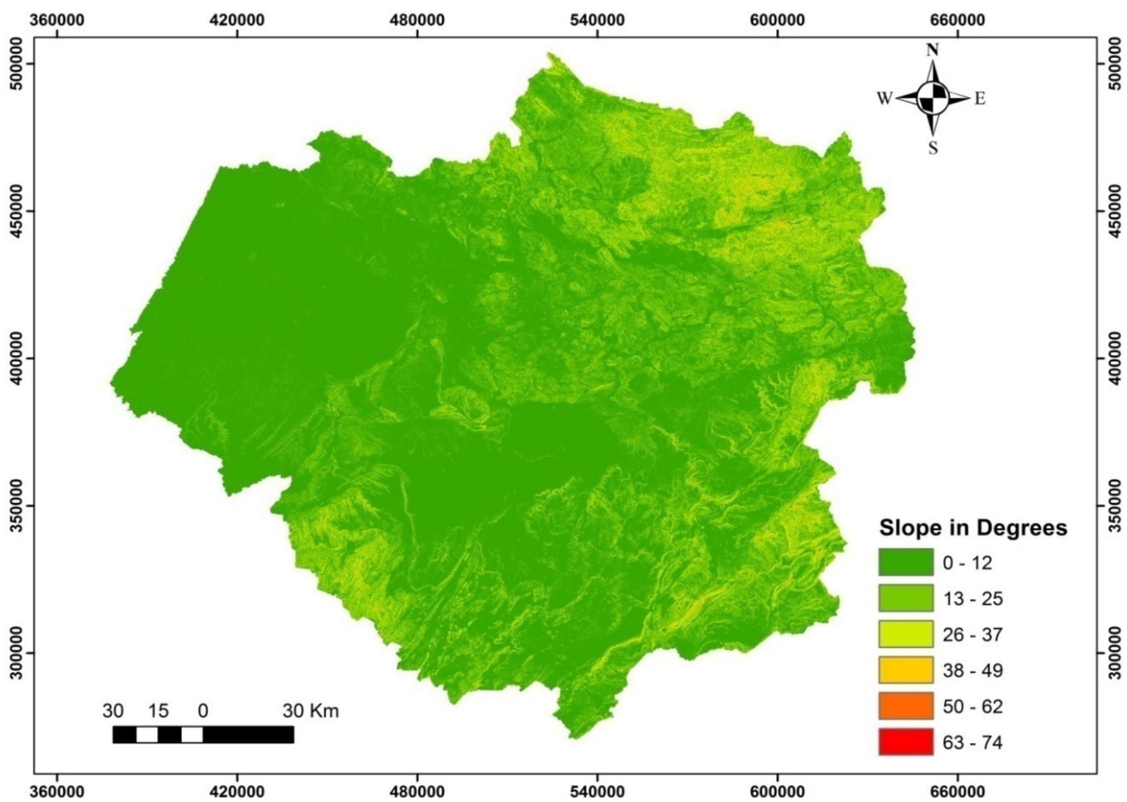

Figure-4: Classified slope map.

The aspect map (Figure-6) is classified into ten divisions which are, Flat (-1), N (0^0-$22,5^0$), NE ($22,5^0$-$67,5^0$), E ($67,5^0$-$112,5^0$), SE ($112,5^0$-$157,5^0$), S ($157,5^0$-$202,5^0$), SW ($202,5^0$-$247,5^0$), W ($247,5^0$-$292,5^0$), NW ($292,50^0$-$337,5^0$), N ($337,5^0$-360^0). The slope faces are directed towards NW (13.02%), followed by S (12.2%), W (12.15%), SW (11.5%), NE (11.37%), SE (11.03%), E (10.91%) and N (6.91%). The 4.6% of area is flat (Figure-7).

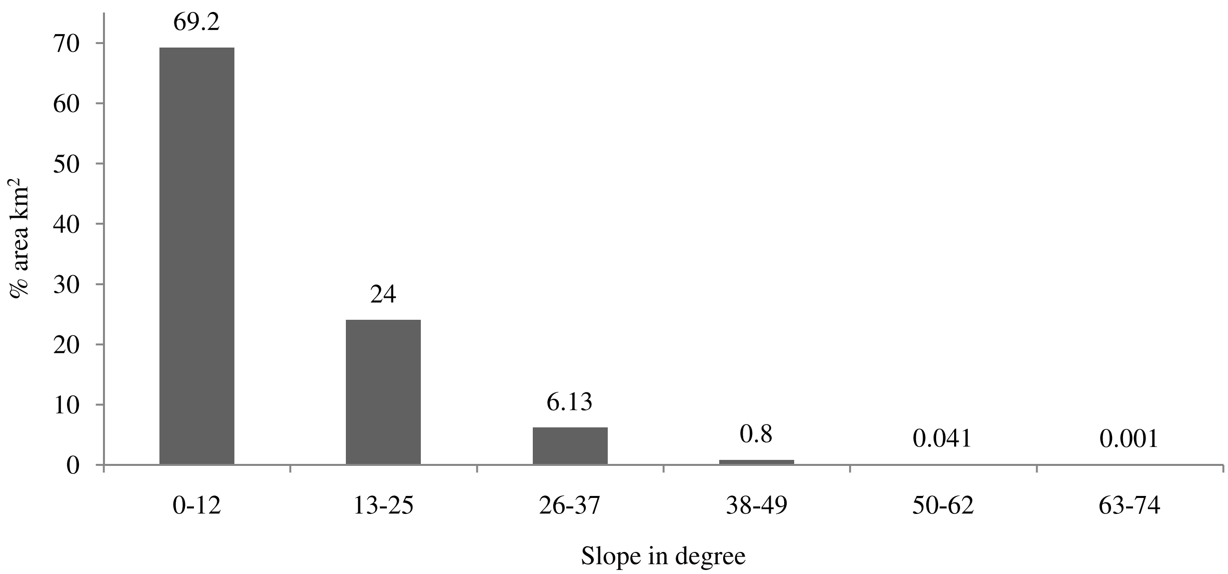

Figure-5: Distribution of areas under different slope classes.

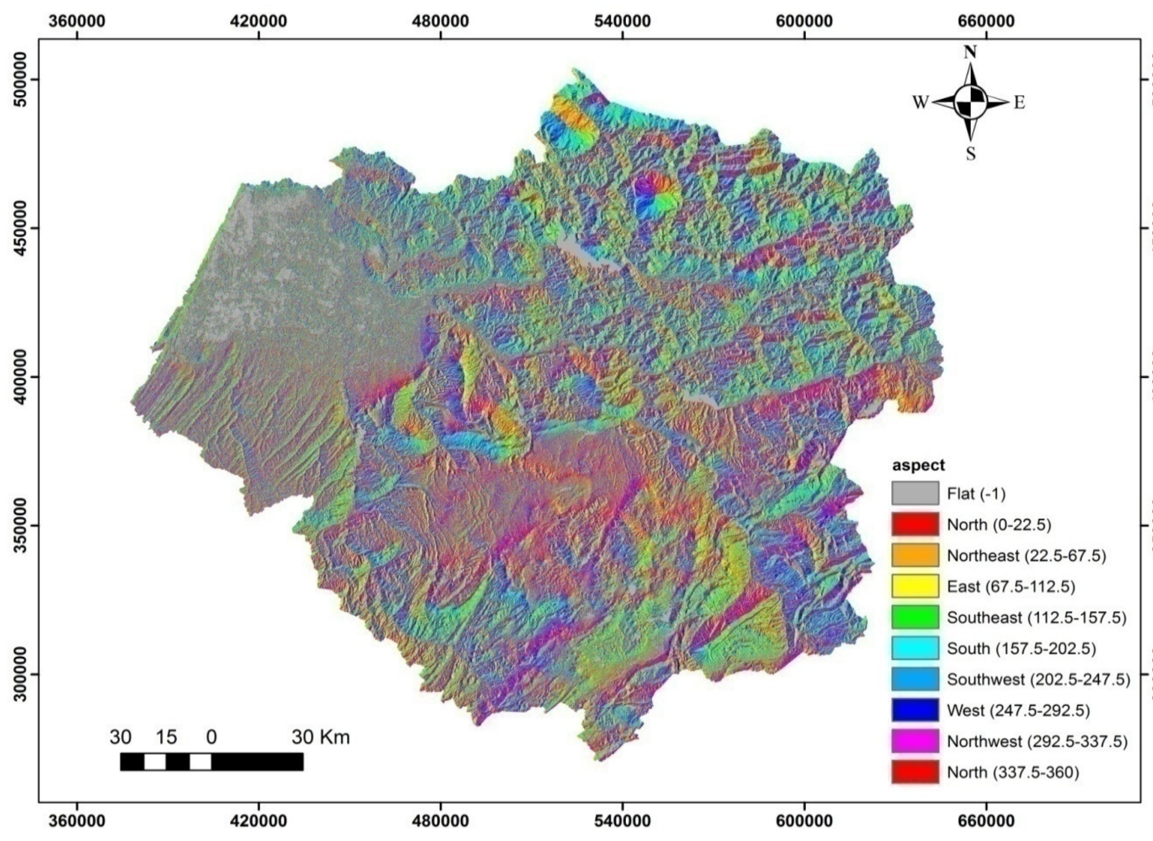

Figure-6: Classified aspect map.

Shaded relief: Shaded relief is a raster surface that provides an orthogonal view of the DEM. Shaded relief surface is created by illuminating values of each cells in a DEM in relation with neighboring cells when illuminate from a point light source. Shaded relief is controlled by the elevation of the area, direction of light and the inclination of the light source.

The fine texture in the shaded relief map indicates smooth topography in the center part of the basin (alluvial plain) while the geomorphic units located in the north and the south are highly dissected (Figure-8).

Morphometric analysis: Linear aspects: The system for ordering stream has been adopted in accordance with classification of Strahler[21]. In this method; the union of two 1st order streams give a stream segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. Sebou watershed has five orders of stream (Figure-9). Total number of streams is 400, the first order represents 53.3% of the total number, and the fifth order covers only 0.25%. The Figure-10 shows the relationship between stream number and stream order and indicate that the stream number decreases while the order increases.

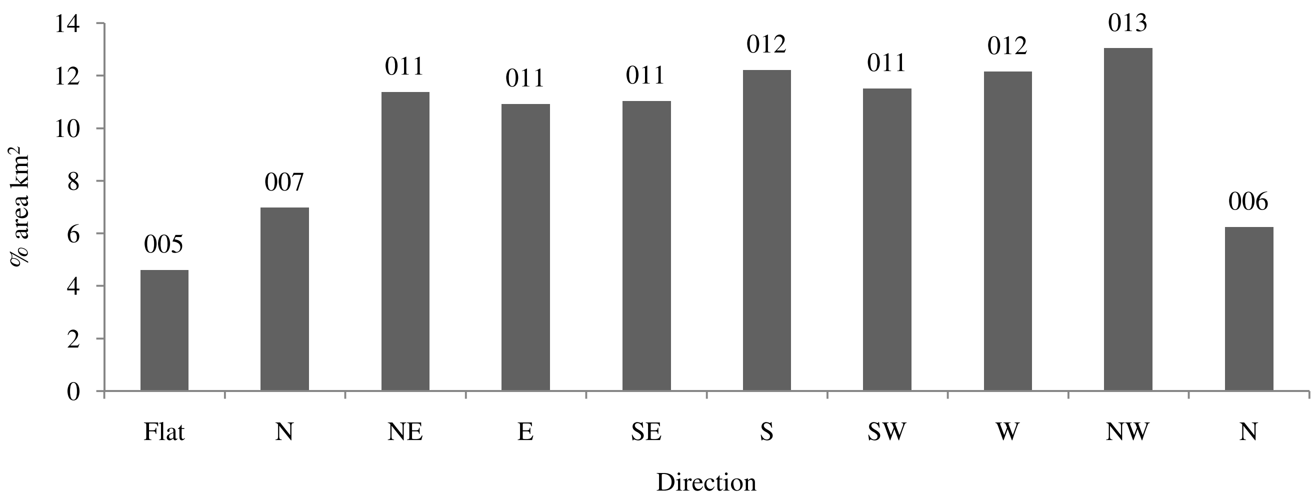

Figure-7: Distribution of slope in different direction.

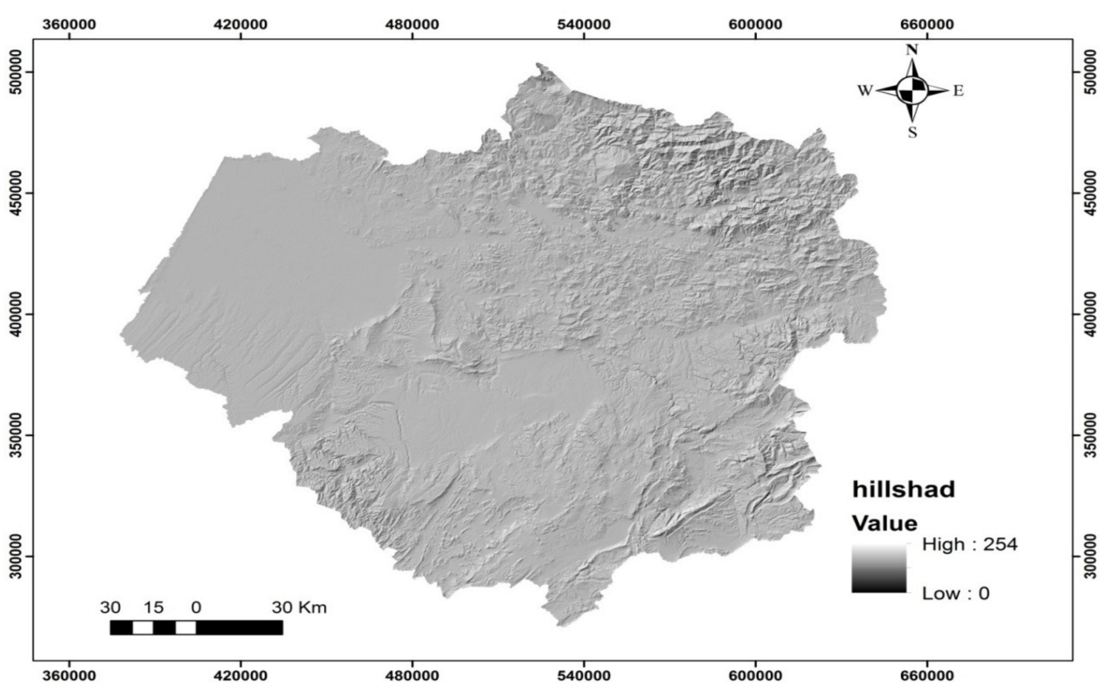

Figure-8: Shaded relief.

The total stream length is 5155, 7 km, the length of first order is 2653,2 km which represents 51% of total length and fifth order has length of 266km (5%). Stream lengths are decreasing with increasing order (Figure-11). The long stream means existence of steep slope while short stream means existence of gentle slope.

The value of mean stream length varies from 11 to 266 km, and increases from lower order to higher order except for third order which may be explained by the slope and topographical variations.

Concerning the stream length ratio, the value ranges from 0.3 to 1.2 and indicates increasing trend from lower to higher order except a value between third and fourth streams which indicates that the watershed was influenced by neo-tectonic deformations.

The bifurcation ratio (br) is dimensional parameter which is the ratio between stream numbers of an order and its next higher order. The Rb is an important parameter showing the degree of ramification of the drainage network, and has a significant control over the runoff[22,23]. For the Sebou watershed, bifurcation ratios range between 1.23 to 16 and the mean bifurcation ratio (mbr) is 4, in which the influence of geologic structures is negligible.

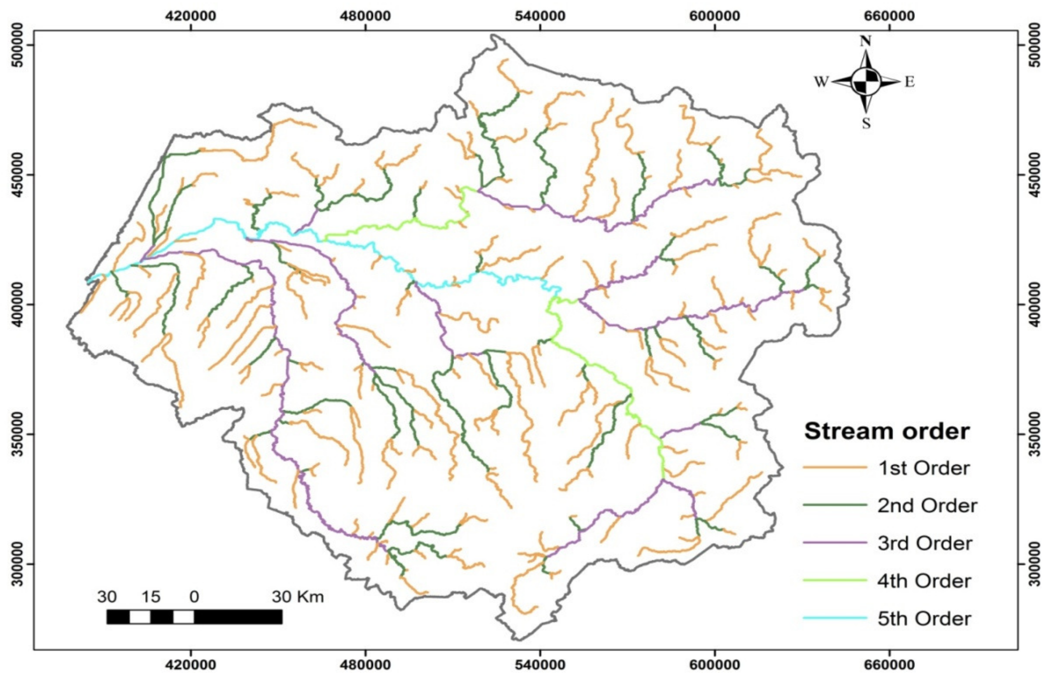

Figure-9: Stream order of Sebou watershed.

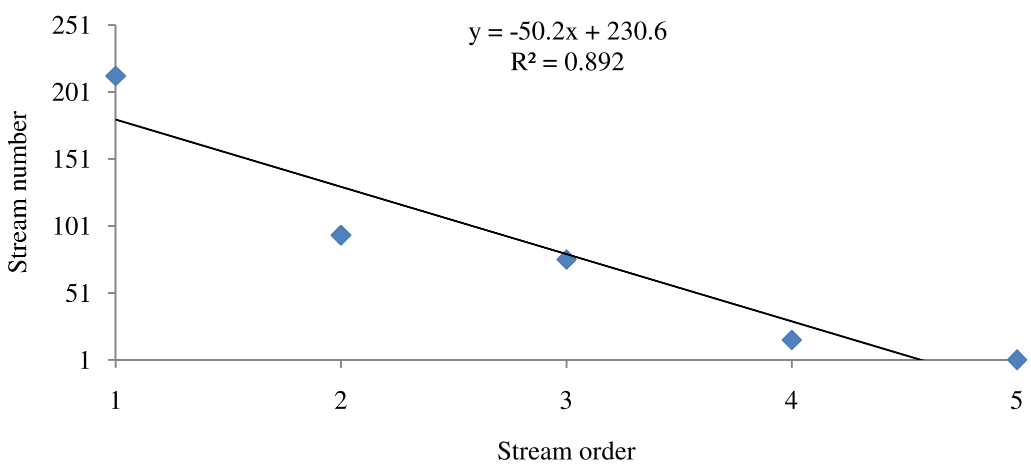

Figure-10: Regression of stream number and stream order.

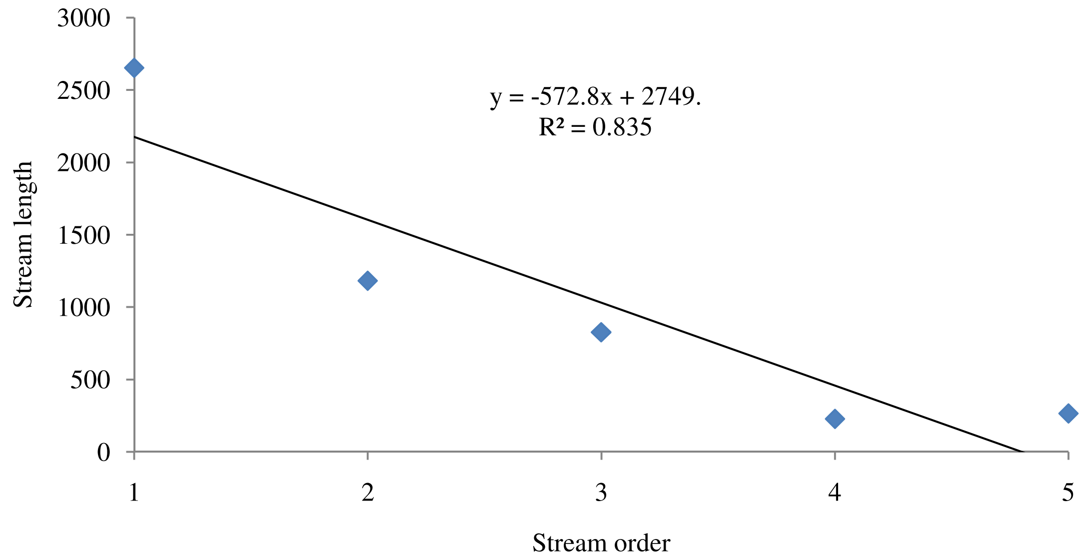

Figure-11: Regression of stream length and stream order.

Areal aspects: The watershed basin area and the length parameters are as important as perimeter. The area, length, perimeter of the Sebou watershed have been calculated using Arcgis software and their value are respectively 38332,3 km^2, 276km, 13181,9 km.

The lithology, the infiltration capacity and relief aspect influence the drainage texture. Smith distinguishes five categories of drainage intensity, i.e. very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8) and very fine (>8) drainage texture[24]. The watershed has a mean value of 0.03 indicating very coarse texture category, less dissection and erosion.

Drainage density depends on several factors such as; erosion, resistance of rock, relief, rainfall, permeability of soil, vegetation. Drainage density in Sebou watershed has low value (equal to 0.14km/km^2) which indicates high permeability of soil, low relief and dense vegetation, and low capacity to generate runoff.

The stream frequency is 0.01 km-2, this low value may be explained by permeable subsurface material and low relief. The low value of infiltration number (0.001) means the slow runoff and high permeability of soil.

The value of elongation ratio is influenced by climate, lithology and slope. In elongated basins the water flows over a longer period than in circular. The elongated watershed presents low risk of erosion and flooding[25]. In general, the elongation ratio varies from 0 (elongated shape) to 1 (circular shape). This factor is classified into four categories: Elongated (0.5-0.7), Less elongated (0.7-0.8), Oval (0.8-0.9), Circular (0.9-0.10)[26]. Sebou watershed has value of elongation ratio equal to 0.8 which means that the basin is close to oval shape.

The length of overland flow controls the quantity of erosion. The length of overland flow of Sebou watershed is 0.07 indicating the development of lower order channels.

Relief aspects: The possible correlation between relief ratio, sediment load and hydrologic characteristics is very well explained by Schumm[17]. This ratio was found equal to 10.8m/km2; this is a low value due to a dominance of low slope in the watershed.

Ruggedness number measures the relationship between relief and drainage density. The value of Sebou basin is 0.4; this value is low and is consequence of low drainage density and low relief.

The stream gradient decreases from lower to higher stream order[27]. Stream gradient of sebou basin varies from 0 to 24 m/km.

Hypsometric analysis: The hypsometric analysis measures the interaction between the topography of watershed and the erosion by the stream and determines the geomorphologic cycle of watershed.

Hypsometric curves show the correlation between area and relief of the watershed and consequently the geologic evolution of the basin[17,15,28,29]. According to hypsometric curve shape, we identified three types of stage of landforms: young, mature and old[15,21,30,].

The dominance of low elevations in the majority of the sebou watershed, and the intense activity of erosion for a longtime, give a concave hypsometric curve as seen in Figure-12 which indicates old stage.

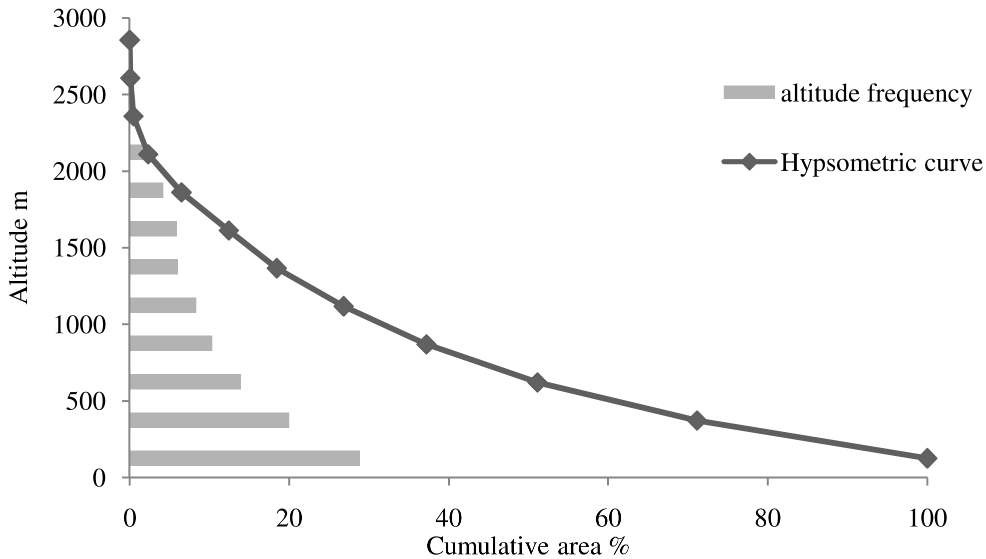

Figure -12: Hypsometric curve and altitude frequency.

Conclusion

This study has been carried out for computation topographic and morphometric parameters for Sebou watershed using geographic information system and digital elevation model.

Topographic analysis based on Digital Elevation Model (DEM) shows that 88% of the total basin areas are below 1490m. About 69% of the total area has a slope 0^0-12^0. The aspect map of Sebou watershed indicates that the topographic gradient is generally towards NW.

The stream analysis shows that Sebou watershed is of five orders, and a strong relationship has been found between stream order and stream numbers, and between stream order and stream length. The variation in stream length ratio and bifurcation ratio might be due to changes in slope and topography. Drainage density of watershed is low, and drainage texture indicates very coarse texture. The elongation ratio shows that basin is close to oval shape. Relief aspects of watershed show low slope, which gives low runoff and high infiltration. The hypsometric analysis indicates the old stage of the basin.

This study can be useful for integrated water management such as watershed prioritization and natural hazard management.

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