GIS analysis of hypsometry and basin asymmetry factor in Htab river basin and tectonic implications (Central Atlas, Tunisia)

Ali Chaieb, **Noamen Rebai**

University of Tunis El Manar, National Engineering School of Tunis, LR14ES03 Geotechnical Engineering and Georisk Laboratory, B.P 37 le Belveldère 1002, Tunis, Tunisia

ABSTRACT. *The geomorphology of the Htab river watershed is mainly guided by the action of the E-W Kasserine fault. This activity influenced the installed hydrographic system. To see the impact of neotectonic on the Htab river watershed, four morphometric indices were applied: the elongation ratio, the hypsometric curve, the hypsometric integral, and the asymmetry factor. The processing and calculation of these indices were based on global DEMs (Digital Elevation Models). The result obtained shows an important link between the activity of the Kasserine fault, the geomorphological behavior of the Htab river watershed and the hydrographic network. Field observations confirmed well these results.*

RÉSUMÉ. *La géomorphologie du bassin versant de la rivière Htab est principalement guidée par l'action de la faille E-W Kasserine. Cette activité a influencé le système hydrographique installé. Pour observer l'impact de la néotectonique sur le bassin versant de la rivière Htab, quatre indices morphométriques ont été appliqués : le rapport d'allongement, la courbe hypsométrique, l'intégrale hypsométrique et le facteur asymétrique. Le traitement et le calcul de ces indices ont été basés sur des MNE (modèles numériques d'élévation) globaux. Le résultat obtenu montre un lien important entre l'activité de la faille Kasserine, le comportement géomorphologique du bassin versant de la Htab et le réseau hydrographique. Les observations sur le terrain ont bien confirmé ces résultats.*

KEYWORDS: *morphometry, GIS, tectonic activity, Htab river watershed-cartography.*

MOTS-CLÉS : *morphométrie, SIG, activité tectonique, activité tectonique, cartographie du bassin versant de la rivière Htab.*

DOI: 10.3166/rig.2019.00082 © 2019 Lavoisier

1. Introduction

Morphometry ties to the measurement and analysis of the earth surface characteristics, shape, and landform dimensions (Horton, 1945; Strahler, 1952; Pareta and Pareta, 2011).

Filosofov (1960) used the morphometric map for the first time in tectonic analysis. Since, the methods of construction and evaluation of morphometric parameters evolved with the development of new techniques through the coupling of GIS with remote sensing.

This study tends to highlight the morphometric response of the Kasserine plain. Thus, we used several morphometric parameters describing the relief behavior and hydrographic catchments that can be extracted from the DEM. Among these parameters, we studied static and dynamic shape parameters. Furthermore, integration of morphometric and morphotectonic analysis with Digital Elevation Model and Geographic Information System (GIS) techniques is useful in quantifying the possible neotectonic activity within this studied domain (Zhang *et al*., 2011; Dar *et al*., 2013). Then, it should be noted that drainage pattern and physiographic characteristic of the catchment of the Kasserine plain highlight active tectonics in this studied area (Holbrook and Schumm, 1999; Chaieb *et al*., 2017; Chaieb, 2019).

2. Morphometric analysis and results

Terrain modeling is a concept based on mathematical algorithms with statistical approaches in order to represent the reality of terrain topography. With the evolution of geographical information systems and relief quantification techniques, the automatic approach is the most adopted for extraction of terrain components (slope of the terrain, hydrographic network, watersheds).

The extraction of these attributes can be obtained currently by two methods: the first, classic, is based on the digitization of the geographical units represented on the topographic map or on a satellite image; while the second, automated and applied in this study (Figure 1), is based on spatial analysis algorithms and Geographic Data Mining.

Th e study area represents twelve watersheds with the largest pond number “1”. The latter is surrounded by the rest of the other basins (from 2 to 12). These basins are located on the reliefs while the large basin represents the plain of Kasserine. This plain is made up by Quaternary and Miocene deposits. Thickness of these deposits exceeds 1000 m. It should be noted that apparent fractures are only found on the edges. For this reason, we are mainly interested in the study of this basin to identify faults hidden by quaternary deposits.

From results that we have obtained, we can note that the distribution of basins varies from one zone to another. Then, we notice that basin No. 1 occupies the whole of the Kasserine plain. The deposits that outcrop in these basins are Quaternary in age. Moreover, these basins are marked by a gentle slope (Figure 2).

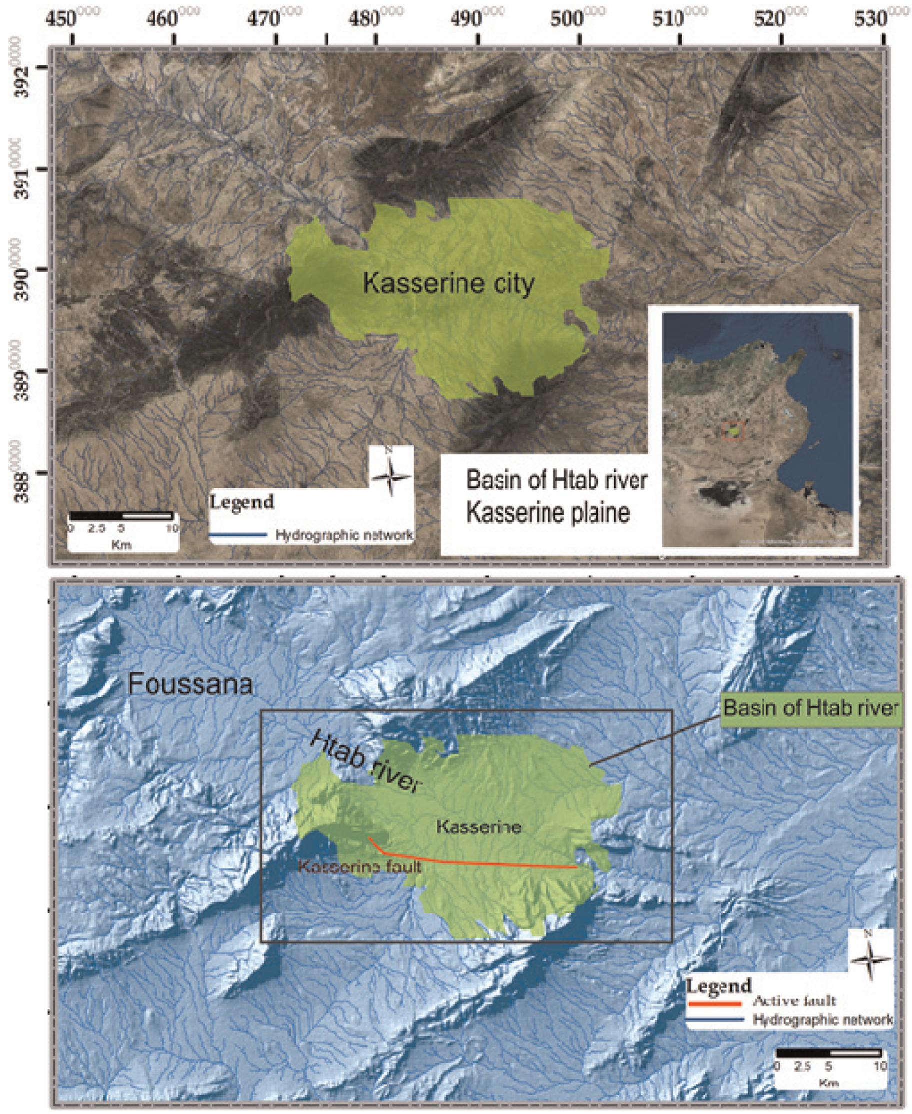

Figure 1. Location of study area: Kasserine domain

3. Elongation ratio

The elongation ratio expresses the ratio between the diameter of a circle having the same area of the basin (S, in Km^2) and the length of the basin (L): $E = 2\sqrt{((S / \pi))} / L$ (Schumm, 1956). This coefficient varies between 0 and 1 (Table 1). For circular basins, E is close to 1 whereas for elongated basins, $E << 1$. It should also be noted that the elongation ratio E can provide information about the maturity of the pond. Thus, if this

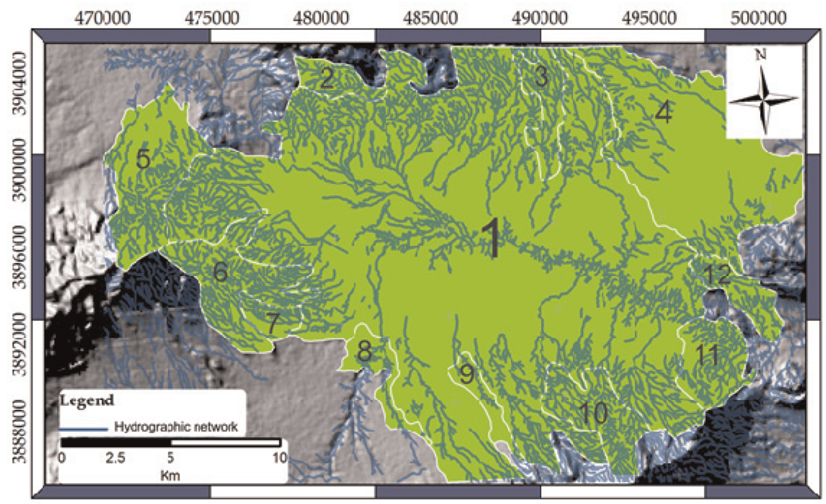

Figure 2. Distribution of the 12 watersheds in the study area

Table 1. Elongation ratio values

Basin	Elongation ratio
1	0.77
2	0.54
3	0.51
4	0.67
5	0.59
6	0.64
7	0.69
8	0.42
9	0.39
10	0.61
11	0.92
12	0.54

ratio E is high (close to 1), the basin is mature whereas if this ratio of elongation E is small (close to 0), the basin is immature (Regard *et al*., 2009).

In our studied domain, each basin has a specific value of the elongation ratio. This elongation ratio is related to the lithology of crossed field and to the tectonic activity of the region as well. Then, this value varies between 0.39 at basin level N ° 9 and 0.92 at basin level 11. This variation can be explained by the degree of maturity of each basin: mature basins are 1, 4, 7 and 11, however, basins 2, 3, 5, 8 and 9 did not yet reach the stage of maturity. This is explained geologically by the presence of recent deposits that outcrop in mature pools due to the weak rate of erosion. Oldest deposits outcropping in studied area are subject to a great rate of erosion and characterize young basins.

Results of the elongation ratio show that the basins 2, 3, 5, 8 and 9 are the youngest ones. They are the most affected by erosion. These later supply other basins 1, 4, 7 and 11, which are more stable. Comparing with the geological map, we find that the areas of the young basins are characterized by ductile lithology while the stable basins are made up of quaternary and brittle lithology. It should be noted also that eroded lands feed the sites of stable basins.

4. The hypsometric curve

For each morphometric study, it is essential to determine the relationship between the variable altitudes and the areas of studied lands: the ratio area-altitude which characterizes the hypsometric curve (Strahler, 1952). The graphical representation of this curve follows the evolution of a landscape. It can take three forms: a little eroded or young landscape, a balanced or mature landscape and a very eroded or degraded landscape.

If we carry on the vertical axis of a coordinate system representing the altitudes, and on the horizontal axis characterizing the surfaces enveloped by the successive isohypses, we can construct a curve indicating the surfaces below a given altitude. This curve represents then the hypsometry one. According to Strahler (1952) the hypsometric curve can show three graphical configurations: concave, convex or sigmoidal.

On our part, the study of the hypsometric curve allows us to distinguish the degree of evolution of such basin as well as the process that controls drainage. In our study area, we note the presence of two types of curve: concave and convex curves. The concave one characterizes sub-basins 3, 4, 7, 8, 10 and 11. These latters testify a highly evolved relief controlled by fluvial processes. Whereas the other sub-basins 1, 2, 5, 6 and 9 have a slightly convex curve with a concave tendency (Figures 3 and 4). In the last case, we can see that the deposits are less evolved. They are controlled by tectonic processes among other recent deformations (Keller and Pinter, 2002; Figueroa and Knott, 2010; Ambili and Narayana, 2014; Jacques *et al*., 2014). This homogeneity in the study area allows us to distinguish that the deposits in question do not have the same age or the same lithology, which is confirmed by geological studies.

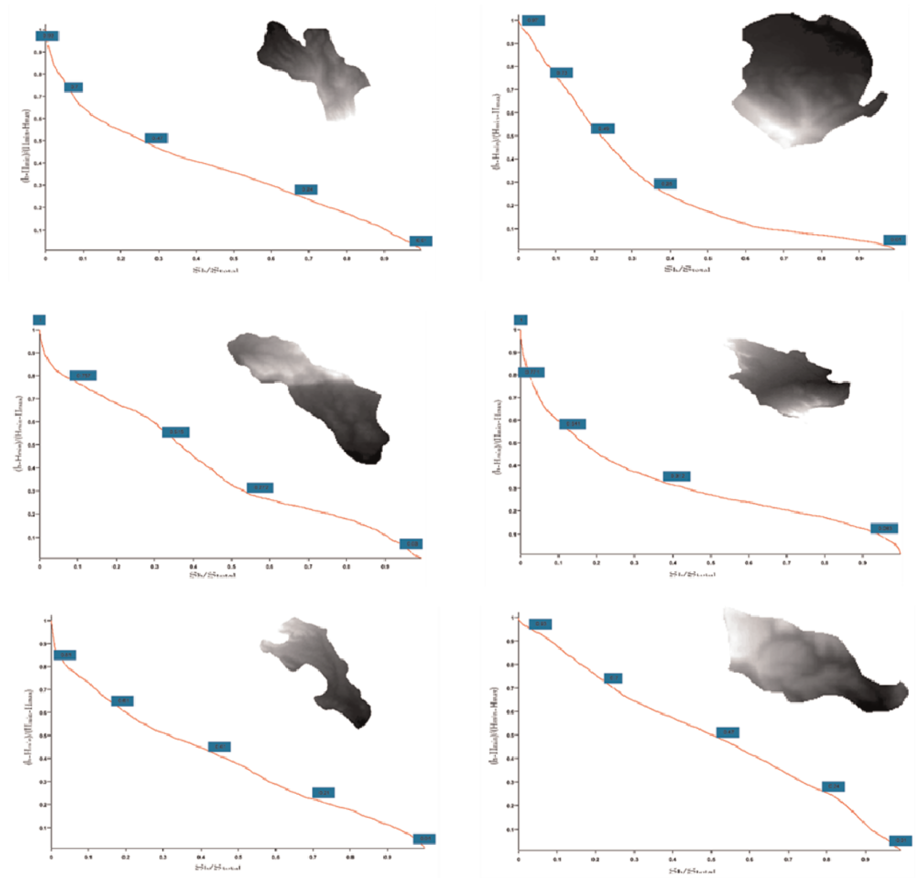

Figure 3. Hypsometric curves of Kasserine watersheds: sub-basins 1 to 6. (See locations in Figure 2)

– For younger basins, the area is small compared to the initial altitude change. This is characteristic of steep basins.

– The old basins present a gentle plain near a stream where the altitude varies very little even though the area is large.

– The third case approaches the so-called "mature" state.

According to this classification and taking into account the rate of erosion, an indication on the age of the basin and the erosive dynamic, whether it is intense or weak, can be highlighted.

5. The hypsometric integral (IH)

The hypsometric integral is a measure of the proportion of the topography above the outlet elevation (Strahler, 1952). The value of this integral expresses the un-eroded

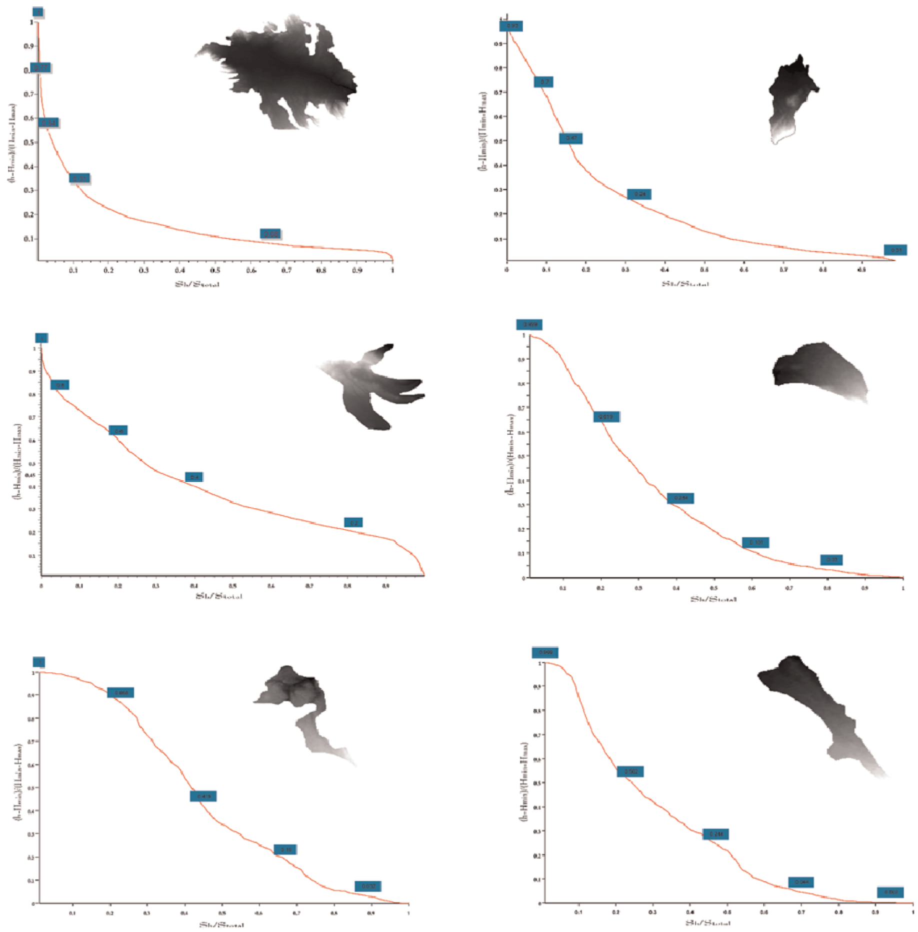

Figure 4. Hypsometric curves of Kasserine watersheds: sub-basins 7 to 12. (See locations in Figure 2)

volume of the sediment in the whole relief or watershed from the formation and evolution of the hydrographic network. This Hypsometric Integral (IH) value is estimated as a percentage. For example, if IH = 0.35, remaining sediment volume is 35% of the initial sediment volume before the erosive action of the water incision. The weak values of IH (IH < 0.35) show evolved terrain strongly eroded. However, the high values (IH > 0.6) indicate immature relief slightly eroded. Median values ($0.35 <$ IH < 0.6) indicate a relief in equilibrium phase (Bishop *et al.*, 2002). The formula adopted to compute the hypsometric integral is: IH = (Elevmean – Elevmin)/(Elevmax-Elevmin). Calculation of this IH was done with the geostatistical analyst module of the ArcGis software.

The hypsometric integral gives indication of the degree of maturity of the watershed. Its value varies from one basin to another. In the study domain, hypsometric integral is weak in sub-basins 1, 5, 8, 9, 11: less than 0.35. Thus, these basins are still immature. Hypsometric integral of the remaining sub-basins varies between 0.35 and 0.6. These latters characterize a phase of equilibrium "mature stage". In this case, the quantity of eroded deposits has practically the same quantity of sedimented deposits. Erosion can be generated by either water or wind. The present study domain seems to be affected by water erosion because of the intensity of the hydrographic network.

6. Drainage basin asymmetry factor (AF)

The asymmetry factor (AF) is widely used to evaluate the existence of tectonic tilting at the scale of a drainage basin (Figure 5). AF is defined by, AF = (Ar /At) × 100. Where "Ar" is the area in right side of the basin of the stream, "At" is the total area of the drainage basin.

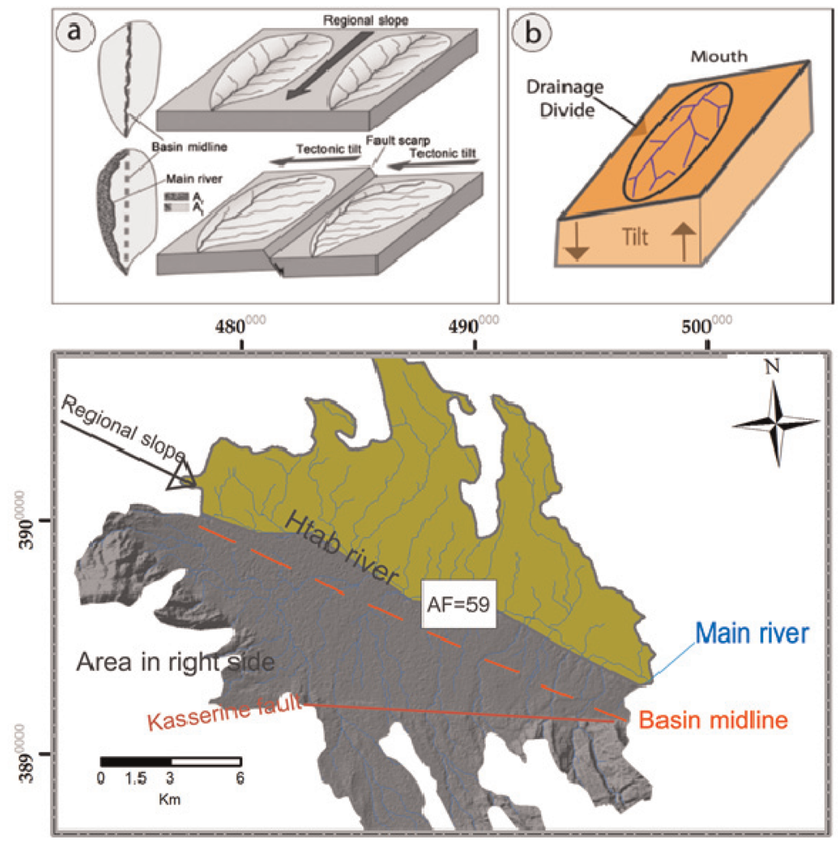

Figure 5. Interpretation of Asymmetry factor in Htab river basin (a) Drainage response to uplift along a fault by migrating laterally in a down-tilt direction by Hamdouni et al. *(2008) and (b) Example of the calculation for drainage basin asymmetry by Molin* et al. *(2004)*

Figure 6. Photos illustrating the activity in Htab river watershed

The asymmetry factor of the Htab river basin is calculated "AF" = 59. Thus, this value indicate an important tectonic activity related to this basin (Figure 6).

7. Conclusion

We calculated the morphometric parameters describing the general appearance of the relief (shape, hypsometry, relief maturation, topographic energy). These parameters were applied to twelve watersheds in the Kasserine plain. The most important basin from a geomorphological point of view is the Oued Htab basin. This latter contains the main river in the whole studied plain. It seems to be superimposed with a major tectonic accident: the Kasserine fault. Detailed geomorphometric study has been developed at the Kasserine Basin. It emphasizes the relationship between the evolution of relief and neo-tectonic activity in the region.

Bibliographie

Ambili V., Narayana A.C. (2014). Tectonic effects on the longitudinal profiles of the Chaliyar River and its tributaries, southwest India. *Geomorphology*, vol. 217, p. 37-47.

Bishop M.P., Shroder J.F., Bonk R., Olsenholler J. (2002). Geomorphic change in high mountains: A western Himalayan perspective. *Global and Planetary Change*, 32, p. 311-329.

Chaieb A., Rebai N., Ghanmi M.A., Moussia Bouaziz S. (2017). Spatial analysis of river longitudinal profiles to cartography tectonic activity in kasserine plain Tunisia. *Geographia Technica*, vol. 12, n° 2, p. 30-40.

Chaieb A. (2019). Analyse des risques naturels par la modélisation des données géologique et topographiques dans un SIG. Etude de cas la Tunisie centrale. Application des approches morphométriques. PhD thesis, University of Sfax.

Dar R.A., Chandra R., Romshoo S.A. (2013). Morphotectonic and lithostratigraphic analysis of intermontane karewa basin of Kashmir Himalayas, India. *Journal of Mountain Science*, vol. 10, n° 1, p. 1-15. doi:10.1007/ s11629-013-2494-y

Figueroa A.M., Knott J.R. (2010). Tectonic geomorphology of the southern Sierra Nevada Mountains (California): Evidence for uplift and basin formation. *Geomorphology*, vol. 123, p. 34-45.

Filosofov V.P. (1960). *Brief Guide To Morphometric Methods In Search Of Tectonic Structures, Saratov*. Saratov Univ. Publ. House.

Hamdouni R., Irigaray C., Fernandez T., Chacon J., Keller E.A. (2008). Assessment of relative active tectonics, southwest border of the Sierra Nevada (southern Spain). *Journal Geomorphology*, vol. 96, n° 1-2, p. 150-173. doi:10.1016/j.geomorph.2007.08.004

Holbrook J., Schumm S.A. (1999). Geomorphic and sedimentary response of rivers to tectonic deformation: a brief review and critique of a tool for recognizing subtle epeirogenic deformation in modern and ancient settings. *Tectonophysics*, vol. 305, n° 1, p. 287-306.

Horton R.E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, vol. 56, n° 3, p. 275-370.

Jacques P.D., Salvador E.D., Machado R., Grohmann C.H., Nummer A.R. (2014). Application of morphometry in neotectonic studies at the eastern edge of the Paraná Basin, Santa Catarina State, Brazil. *Geomorphology*, vol. 213, p. 13-23.

Keller E.A., Pinter N. (2002). *Active Tectonics: Earthquakes, Uplift, and Landscape*. Upper Saddle River, NJ: Prentice Hall, p. 362.

Molin P., Pazzaglia F.J., Dramis F. (2004). Geomorphic Expression of Active Tectonics in a Rapidly. Deforming Forearc, Sila Massif, Calabria, Southern Italy. *American Journal of Science*, vol. 304, p. 559-589. https://doi.org/10.2475/ajs.304.7.559

Pareta K., Pareta U. (2011). Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS. *International Journal of Geomatics and GeoSciences*, vol. 2, n° 1, p. 248.

Regard V., Lagnous R., Espurt N., Darrozes J., Baby P., Roddaz M. *et al* (2009). Geomorphic evidence for recent uplift of the Fitzcarrald Arch (Peru): A response to the Nazca Ridge subduction. *Geomorphology*, vol. 107, p. 107-117.

Strahler A.N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Geological Society of America Bulletin*, vol. 63, n° 11, p. 1117-1142. doi:10.1130/0016-7606 (1952) 63 [1117:HAAOET]2.0.CO;2

Schumm S.A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological society of America bulletin*, vol. 67, n° 5, p. 597-646.

Zhang W., Hayakawa Y.S., Oguchi T. (2011). DEM and GIS based morphometric and topographic-profile analyses of Danxia landforms. *Geomorphometry*, p. 121-124.