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THE RELATION BETWEEN THE MORPHOMETRIC CHARACTERISTICS AND RIVER NETWORK OF THE TAZLĂU BASIN, HIERARCHISED ACCORDING TO THE HORTON-STRAHLER SYSTEM

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Abstract

Tazlău hydrographic basin is located in the eastern half of Romania, at the external region of the Oriental Carpathian Mountains. It is a left side tributary of Trotuș river. It occupies a calculated surface of 1101 km^2. It is mainly developed on the right side, having numerous tributaries of mountaineous origin. The confluence with Trotuș river is situated near Onești city, upstream of which the largest hydrotechnical accident in Romania's recorded history took place (the breaking of the Belci dam). The hydrographic network was generated through manual digitisation, from topographic maps at a scale of 1:25000, and attributes have been given, according to the Horton-Strahler hierarchisation system. The classification has revealed a series of aspects regarding: the morphometry of the river segments, depending of their stream order; procentual values of distribution; the layout of the different river orders along the drainage basin etc. From a morphometric point of view, several representative classes have been chosen, which consisted of the limits used to analise the altitudinal distribution of the river network. The same method was applied to identify tendencies or correlations between the Horton-Strahler stream order system for the entire basin and the classified slopes, for corresponding areas. The classification of all the river segments has revealed the existence of 6 stream orders, for the chosen work scale. Both the slope, and the altitude values, have an important role in the drainage process, because they can reduce or, on the contrary, they can emphasise the erosion and solid flow. Steep slopes imply an acceleration of the flow speed, and also, a faster evacuation of the river water reserves (especially for rivers with a stream order value of "1"). It is also important to identify the areas where there are permanent water supplies, corresponding to certain morphometric features, in order to more efficently manage human activities (specifically agriculture, using irrigation systems). Based on the main classified morphometric features from the Tazlău drainage basin, it was possible to analyze the relation between the river network (hierarchised according to the Horton-Strahler system), and the slope and altitude values.

Keywords: GIS, Horton-Strahler, hypsometry, river network, slope

1. INTRODUCTION

In the domain of potamology, numerous types of classifications for the hydrological network have been developed, based on different applicability logics. Therefore, inside a hydrographic basin, depending on the working scale of the basic reference map, the rivers will receive different classification orders, according to one of the many hierarchisation systems that have been accepted on an international level. Among the oldest types of classifications of a fractalic system, as is the case of the hydrological network, there is the model suggested by Gravelius (1914). He was the one that created a hierarchisation system, by associating the 1st order to the main river, which also had the highest flowrate. Subsequently, other classification models were suggested, like those of Horton, Panov, Scheidegger or Shreve (Fig. 1). Strahler has improved Horton's system, and developed one of the most frequent and largely accepted systems, at a global scale, suggestively named in literature, the "Horton-Strahler" system. In the analitycal steps of this study, this system will be used to classify and analyse the hydrological network of the Tazlău river, at a working scale of 1:25.000.

The drainage basin of Tazlău river is located at the outer side of the Carpathian Arch, in the contact zone of the Carpathian orogenesis, with the East-European platform (Fig. 2). This basin delineates the west of the central group of the Oriental Carpathian mountains, Tazlău river being a left side tributary of Trotus river. Its drainage basin has a 1101 km^2 surface, and it's located in the middle sector of Siret river basin. The biggest tributary of Tazlău is Tazlăul Sarat river, which drains a 211 km^2 basin, dominated by montaneous rivers, with a larger percentage of montaneous rivers than Tazlău river, itself.

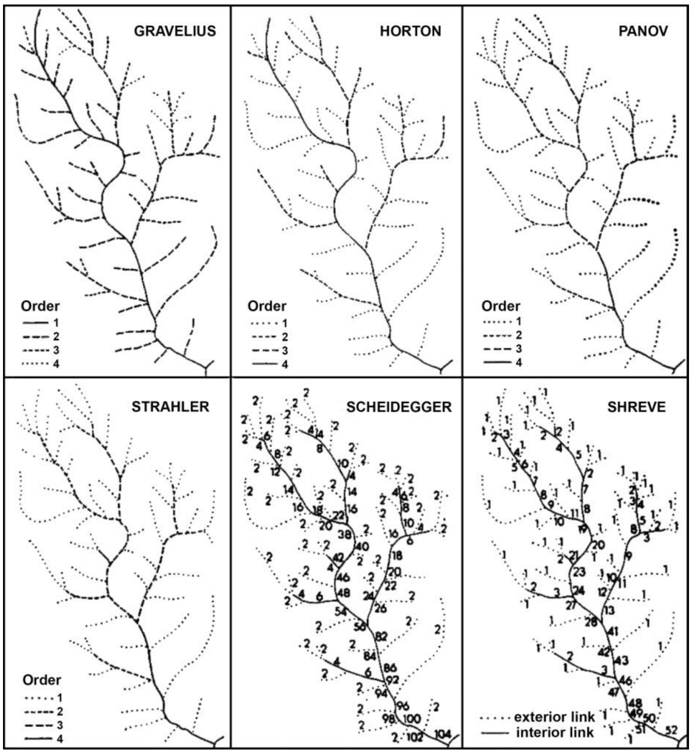


Figure 1 - Classification systems for the hydrological network, common in Romanian literature (image source: Zăvoianu I. 1985, *Morphometry of Drainage Basins*, Elsevier)

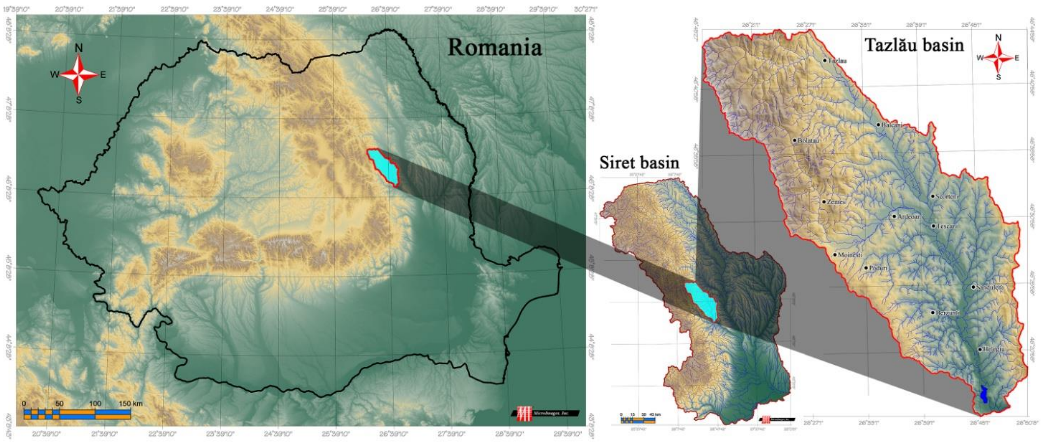


Figure 2. Geographical location of Tazlău river drainage basin

The interest for the study of the hydro-morphometrical parameters of Tazlău drainage basin is great, because in 1991, this is the place where the largest hydrotechnical accident in Romania took place, when, after receiving exceptional quantities of precipitation, the Belci dam collapsed, releasing a record amount of water, because of which numerous human casualties were recorded, as well as large scale material damage. This is one of the reasons for which the study of the hydrologcal network is important, in order to identify potential problems, generated by a problematic distribution of rivers, on altitudinal and slope classes.

Slope and hypsometry are two of the main parameters, directly related to the geomorphology of any drainage basin, which influence runoff concentration, flow speed, meandering degree, and other variables that determine the river's behaviour, at different flow rates.

2. MATERIALS AND METHODS

The analysis consisted of numerous stages, from the moment of obtaining/producing the data, up to generating the maps and graphic results. Therefore, as base materials, topographical maps at a scale of 1:25000 were used (drawn in 1972 and corrected in 1984) and, as a digital terrain model, the SRTM was utilised (in Stereo 70 projection) which, despite its coarse resolution (1 pixel = 80 x 80 meters), is suited for the purpose of this study, taking into account the large sruface of Tazlău drainage basin (1101 km^2).

In order to generate the digital materials, several stages were required: scanning the topographical maps, after which they were imported, a georeference was given according to the projection system, following by the digitizing of the the rivers, at maximum accuracy. Once the hydrological network of the basin was completely digitized, the watershed boundry was also manually drawn. In the next stage, each river segment received an attribute, in order to identify its hierarchisation order, following the Horton-Strahler system, after which specific styles were given, accordingly. Therefore, low order rivers were given a style based on a thin, light, blue line, and the maximum order was associated with the thickest, darkest, blue line, for a very suggestive picture.

The numerical terrain model used is represented by SRTM (Shuttle Radar Topography Mission), downloaded from the Geospatial site (http://earth.unibuc.ro/download). A raster extraction was done, with a mask consisting of the watershed limit, and the altitude range was identified, using the histogram. According to this, and the chosen number of classes (5), several statistical methods were used to find the optimal class limits. Three types of progressions were applied (arithmetic, geometric and quadratic), in order to make a more correct classification of the drainage basin, and chose the best progression, considering the altimetric value distribution of the histogram. The hypsometry layer was classified according to the best progression, calculated through these methods. The newly obtained file was converted from a raster format, into a vector format, generating a vector with 5 attributes (one for each altitude class). This file was split, using these attributes, into 5 different vectors, each of these being used as an extraction mask for the vector with the hierarchised hydrological network.

Having the extraction limits, from the vector file with the entire hydrological network, 5 extractions were made, resulting 5 vector files, with the hydrological network corresponding to each hypsometry class. For each of these vector files, a new attribute table was created, in order to group all the lines, by the hierarchical order, followed by a table-form extraction of the information, in excel format, centralizing the entire information and generating graphic material.

The complementary parameter of hypsometry, is the slope, expressed in degrees and also classified in 5 classes. The same logic was applied, based on the statistics of progression, with the mention that the geometric progression could not be applied, because it requires the strict usage of positive numbers, larger than 0 (but there were numerous areas were the slope values recorded the value of absolute 0). Several issues occured, generated by the generalised dispersion of the pixels representing the same value class, resulting in a slope raster layer which was extremely mosaiced, and when converting from raster to vector, the resulting file consisted of numerous interconnected polygons, which surrounded the attribute of another class, therefore, for the 3rd slope value class, the corresponding river network could not be properly extracted. For this reason, other alternative methods to identify the extraction limit for the 3rd slope class were applied. The first method consisted in applying some spatial filters, at different values, to try to group the polygons that would later be used as extraction masks, and eliminate the potential extraction errors. But this method did not generate improved results (even at different filter values) because, despite its ability to generate error-free layers, the new spatial configuration of the slopes was significantly different, compared to the original situation, and during the extraction process, other areas would be extracted, compared to the original, real ones, specific to the 3rd slope class. Some classes, represented by pixels arranged as strips, dissapear entirely, the larger the value of the spatial filter. Therefore this approach is not applicable, because it would alter the real situation, and it is not usable, for any value of any of the filters (Fig. 3). The solution was calculating the difference between each value of each order, from the entire hydrological network classified according to Horton-Strahler, and the sum of river segments for each order, from the 1,2,4 si 5 classes.

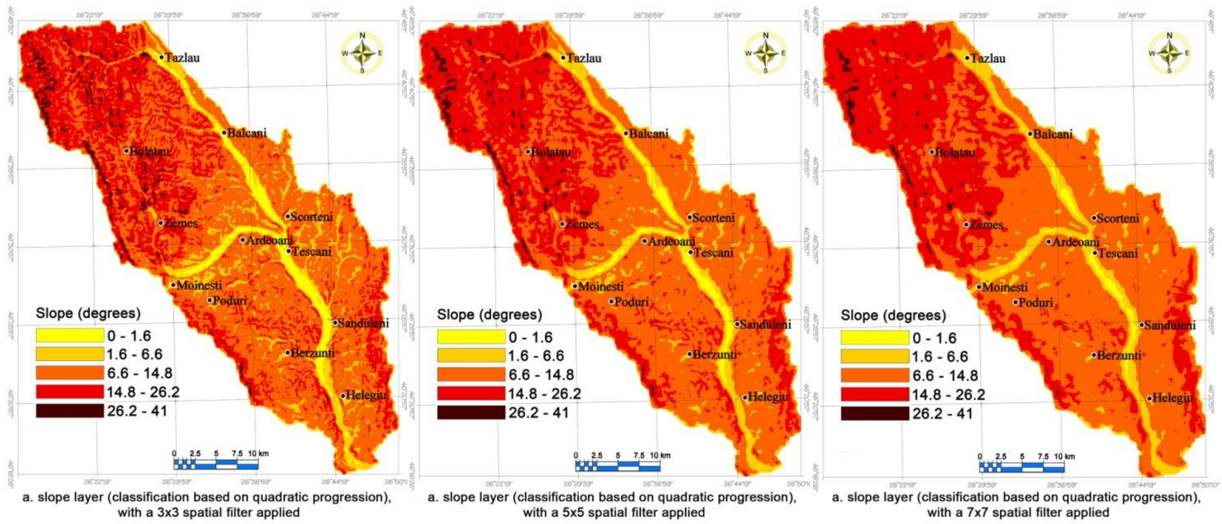


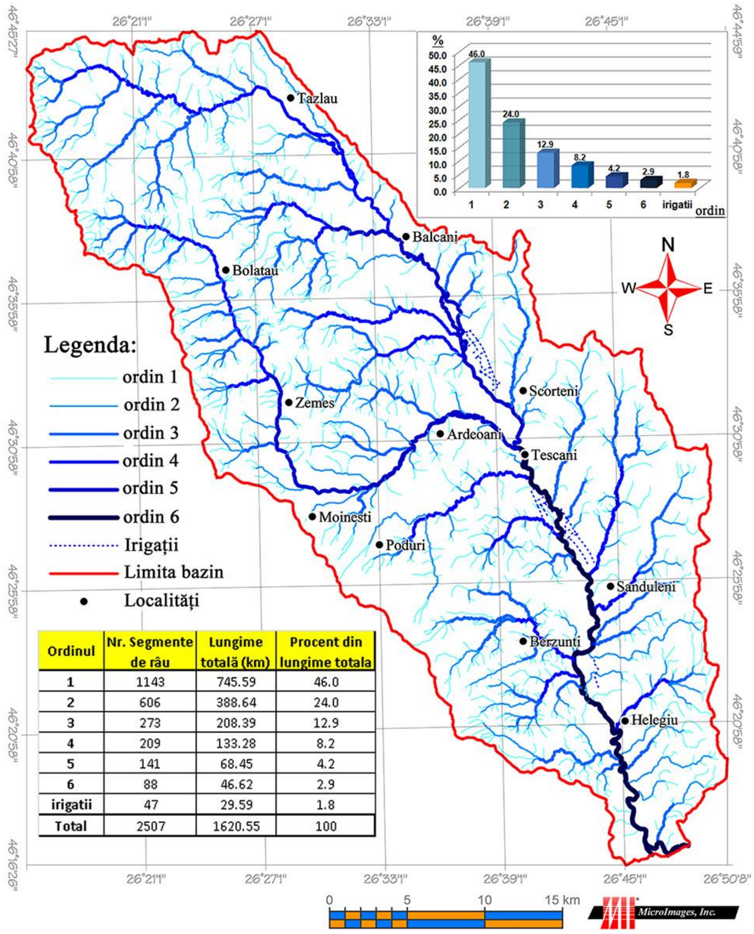
Figure 3. Slope of the Tazlău drainage basin, classified by quadratic progression, for filters of 3,5 and 7 cells

The last stage of processing the generated layers was to execute the layouts, to obtain cartographic materials representative for each layer, after which the graphs corresponding to the morphometric values tables of the rivers were made. The software utilised in the current analysis were Microimages TNTMips, the LibreOffice suite, for text formatting and table manipulation, but also graphs and design, and GIMP, used to finalise the cartographic material.

3. RESULTS

The drainage basin of Tazlău river, according to the working scale of this study, of 1:25.000, reveals a dense enough hydrological network, distributed in a relatively uniform manner, with the main valley of Tazlău, oriented mostly on a NNV - SSE direction, and its main tributaries form acute angles with Tazlău river, the ones on the left side being oriented on a N-S direction (mostly in the middle sector), or even NE-SV (in the downstream sector). The right side tributaries have a main flow direction on a V-E axis, excepting the upstream sector of the main tributary (Tazlăul Sărat), which flows parallel to the main Tazlău valley, in this sector. According to the Horton-Strahler hierarchisation, at this scale, at the outlet, Tazlău river records the 6^{th} order. 1143 river segments corresponding to the 1^{st} order were identified, representing 46% of the total cumulated length of all the rivers which form the hydrological network (at a 1:25.000 scale) from the Tazlău basin. Note the fact that only the hydrological network from the topographical maps was traced, and not the entire drainage network, for which it would have been necessary to add the river segments from all the inflections of the contour lines at this work scale. All the river segments of the 2^{nd} order add up to 388,6 km and represent 24% of the basin's hydrological network. When cumulated, orders 3 to 6, represent 456.7 km (a slightly larger value, than the 2^{nd} order, taken separately). The irrigation channels found, have a total length of 30 km, but the present working state is unknown. The most probable scenario is that these irrigation channels have been taken out of service for many years, following the 18/1991 law, which dictated the reallotment of the people with arable land. This law was followed by the fragmentation of the land and the lack of centralised management, with irrigation systems controlled at a large, efficient scale.

To emphasise the distribution of the hydrological network hierarchised according to Horton-Strahler (Fig. 4), on hypsometry classes, as correct as possible, the most appropriate class limits had to be identified for the given situation. The histogram and the extreme values were analysed and a conventional number of 5 classes was assigned, after which the 3 main types of statistical analysis were carried out, to identify the optimum class limit numbers, depending on the values from the histogram. The 3 types of analysis were based on arithmetic, geometric and quadratic progressions. The arithmetic progression generates an equal division, meaning that the class limit numbers would compile classes with an equal interval value, without compensating for the irregular (but significant) distribution of the values extracted from the histogram.



Ordinul	Nr. Segmente de râu	Lungime totală (km)	Procent din lungime totala
1	1143	745.59	46.0
2	606	388.64	24.0
3	273	208.39	12.9
4	209	133.28	8.2
5	141	68.45	4.2
6	88	46.62	2.9
irigatii	47	29.59	1.8
Total	2507	1620.55	100

Figure 4 The river network for Tazlău basin, classified according to the Horton-Strahler hierarchisation system

Taking this into consideration, this type of classification is not an effective one, because it does not count for the real field situation, such a division being easily applicable to any type of terrain, regardless of the histogram congestion tendency, and by definition, the arithmetic progression details mostly the extreme values in a row of given data, where usually, there are few or limited values. The geometric and quadratic progressions do not apply for negative values, but this aspect is not a drawback, knowing the altitude amplitude of the hydrographic basin, which extends from 183 to 1420 meters. The geometric progression, despite considered to be disadvantageous through the fact that it excessively details the lower values in a row, was used in the case of Tazlău basin precisely because, according to the histogram, the dominant values were small and needed to be divised into representative classes, as uniformly as possible (Fig. 5).

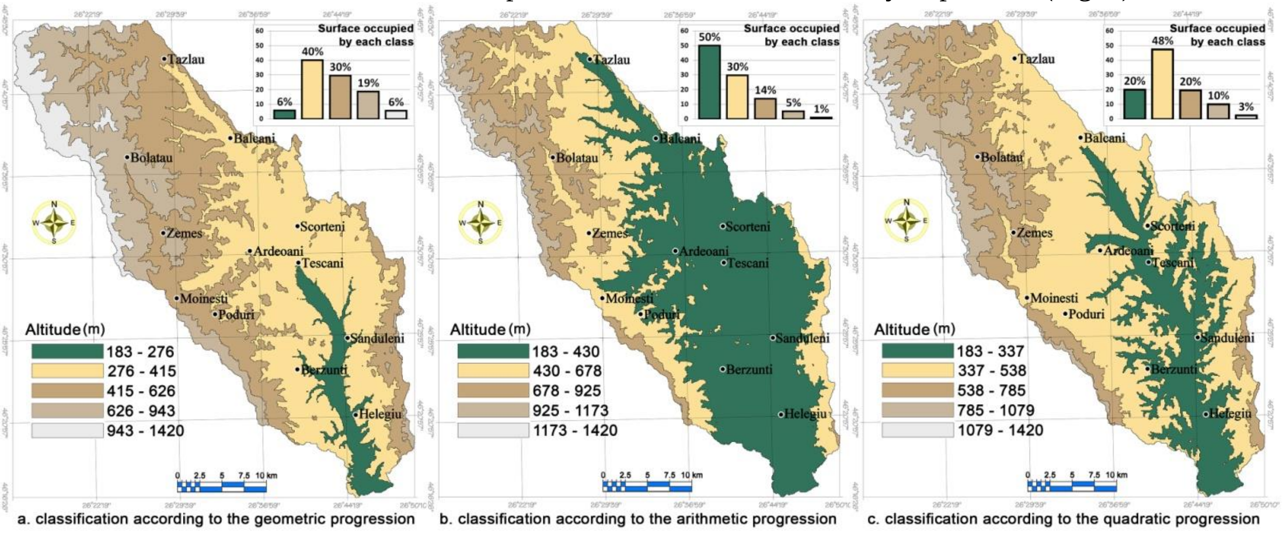
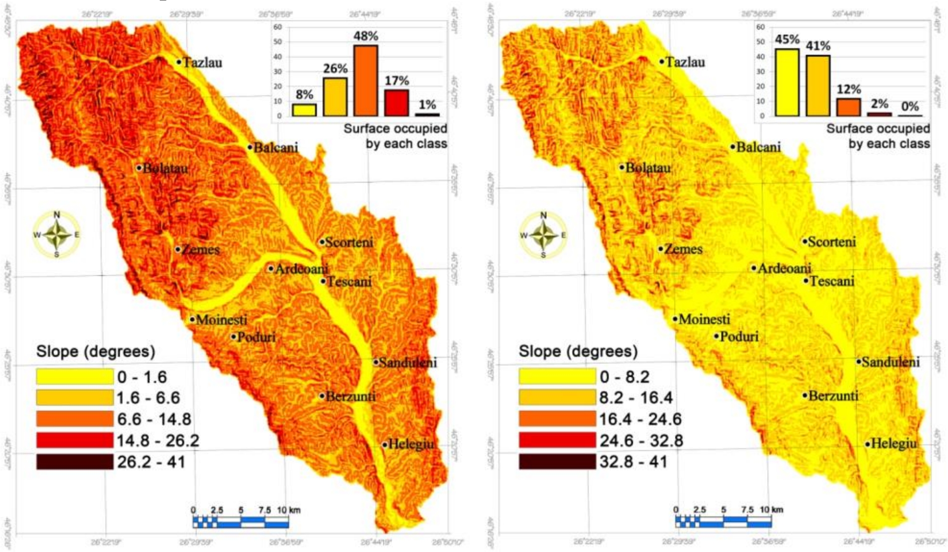


Figure 5 The hypsometry of Tazlău basin, classified according to the 3 statistical progressions

For the slope parameter, the "0" value had to be taken into account, which is frequent on the histogram, even if in real life, at the given scale, the value of absolute "0" might not exist, but have a value slightly over "0", by a few decimals. The issue comes from the fact that the minimum slope can not be accurately found, at a decimal level, because the terrain model used has a resolution of 80 x 80 meters for pixel, therefore the relatively coarse generalisation of the reality combines different slope values and the errors add up, the more decimals we are dealing with. While not being able to exactly calculate to which decimal the minimum slope value extends, it was conventionally set that the minimum slope value would be considered to be absolute "0". The difference between one or two decimals drastically changes the class limit values, according to different progressions, therefore an approximate value of the miminum slope could not be given by default, because the following classification would just be approximated after uncertain values. After accepting the existence of absolute "0", the geometric progression could not be applied, because the coefficient that is used in the calculus of the class limits has to be divided to the minimum slope value. But taking into consideration that the minimum slope value is "0" and the division by "0" is impossible, the geometric progression could not be applied in the case of the slope parameter. Therefore, only the arithmetic and quadratic progressions were applied (Fig. 6), out of which the map generated according to the quadratic method was used, because it efficently details the values in the lower half of the histogram, were most of the slope values are, in the first place.



a. classification according to quadratic progression b. classification according to arithmetic progression

Figure 6 The slope of the Tazlău basin, classified according to the statistical progressions

After identifying the most efficient progressions, according to which the class limits obtained best emphasise the distribution of the histogram values for the hypsometry and slope parameters of the Tazlău drainage basin, the vector extractions were made, for each class, in order to reveal the distribution of the rivers in the classes associated to these two parameters. By doing this, the cumulated river lengths of each stream order could be identified, for every slope or hypsometry class.

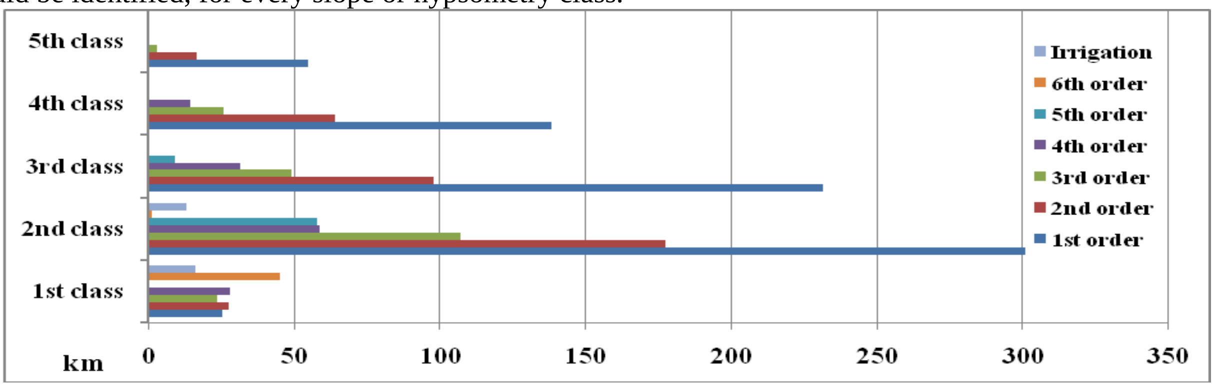


Figure 7 The distribution of the river network (classified according to Horton-Strahler system) on hypsometric classes

In the case of hypsometry (Fig. 7), an asymmetrical distribution can be observed, most river segments being part of the 2nd and 3rd hypsometry (an altitude difference of 276-626m). The 2nd hypsometry class alone, contains 44,3% of all the rivers in the basin. The 1st order rivers prevail, from a quantitative point of view, in all the hypsometric classes, except for the first class, where the dominant order is the 6th hierarchical one. This is the order represented by rivers which only reach the 415 meters altitude level, specific the the 2nd hypsometric class, but the rivers from this order in the 2nd class only extend for only 1,2 km (0.07% of the entire hydrological network), having a negligible value. The irrigations are found in equal proportions, in the 1st and 2nd class, with an average of 15 km, cumulated in each class. This accentuates the fact that large scale agricultural activities in the basin, have been done in the lower, floodplain area, where the access for the water was easier (either from the groundwater, or from the rivers).

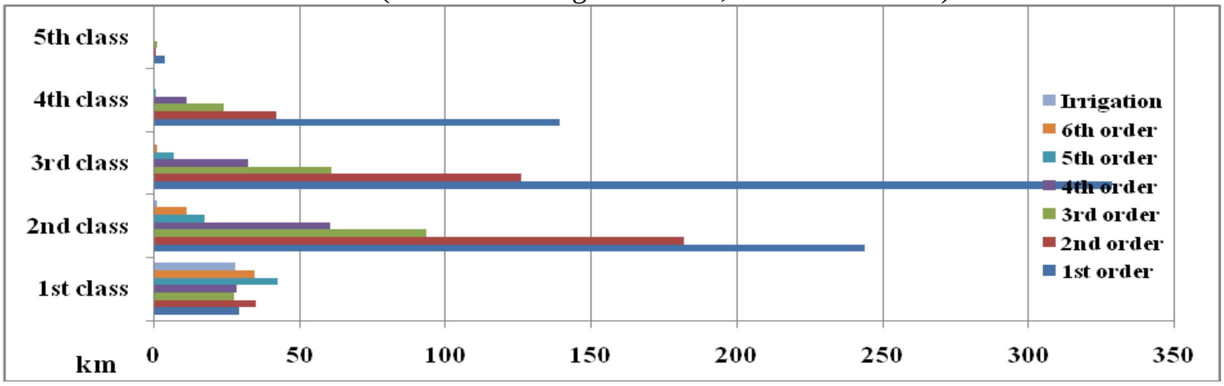


Figure 8 The distribution of the river network (classified according to Horton-Strahler system) on slope classes

Unlike hypsometry, for which the classification has revealed a zonal character, the slope parameter (Fig. 8) has an azonal character, varying on the entire basin surface. The irrigation network has also been grouped in the first two classes (even though in the second class, there are only 1,5 km of irrigation channels), which confirms the fact that the large scale agricultural practices were organised in the lower slope fields (up to a maximum of 6.6. degrees). The 1st order rivers, in this case, ar not dominant in the 2nd class, but most of them are actually located in the steeper slope areas, up to 15 degrees. In the last slope class, where values exceed 26 degrees, all the river oders, added up, barely exceed 6 km, this class having the lowestt representativity, precisely because of the fast water evacuation, that is caused by the high potential energy of the steep-sloped landscape. The distribution of the cumulated lengths, according to the slope classes is characterised by a more proeminent asymmetry, because of this reason. On the cvasi-horizontal surfaces (slopes under 1,6 degrees), even if high order, slow flowing strems should dominate, a very uniform distribution of all the stream orders can be observed, including irrigations, the cumulated values of the rivers oscillating between 28 and 42 km for each stream order.

4. CONCLUSIONS

The Tazlău river drainage basin is characterised by an altitude difference of 1237 meters, being situated between the 183 and 1420 meters levels, and slopes varying in values from 0, up to a maximum of 41 degrees. The cumulated length of the river network (at a 1:25.000 scale) has a value of 1620 km, and according to the Horton-Strahler hierarchisation system, there are 6 stream orders in the entire basin.

To identify the most relevant slope and hypsometry classes of the drainage basin, three major types of statistical classifications have been applied, corresponding to the following progressions: arithmetic, geometric and quadratic. After analysing the altitude and slope value distribution on the histograms, the geometric and quadratic progressions were chosen, for hypsometry and slope respectively.

The low values recorded for slope and altitude, favour the existence of a larger number of rivers in the corresponding classes (and also a larger cumulated length), because there are no high slope and hypsometry values, that would lead to a rapid evacuation of the water resources, and implicitly, to a low number (or inexistent) of water courses, representative for those levels.

This model can be used to analyse the distribution of the hydrological network, classified according to the Horton-Strahler system (or a similar one), on slope and hypsometry classes.

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