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CLASSIFICATION SYSTEMS FOR THE HYDROGRAPHICAL NETWORK

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Abstract. The paper discusses the main systems of classification and codification starting from the mainstream to the smallest tributaries and the other way round, from the smallest tributaries to the mainstream systems. A new drainage basin coding system is developed based on the Horton-Strahler principles of classification. The new system is supposed to be useful both for scientific research and the management of water resources.
Key words: drainage network, codification.

Rezumat. Sisteme de clasificare a reţelei hidrografice. Lucrarea tratează sistemele principale de clasificare şi codificare începând de la cursul principal până la cei mai mici afluenţi şi invers, de la cei mai mici afluenţi la sistemele cursului principal. Un nou sistem de codificare al bazinului de drenaj s-a dezvoltat pe baza principiilor de clasificare Horton-Strahler. Noul sistem se presupune că este util atât pentru cercetarea ştiinţifică cât şi pentru managementul resurselor de apă.
Cuvinte cheie: reţea de drenaj, codificare

Introduction

Following the present technologic and social-economic development, the scientific researchers must find solutions for an accurate evaluation of the resources of the natural environment and their careful management in accordance with the demands for a sustainable development. Consequently, the issues related to the spatial distribution, formation and variation in time and space, evaluation, exploitation and management of the water resources are of major concern. At present, the research conducted for classifying the hydrographical network and basins follows two main directions. On the one hand, there is a global research for achieving a comprehensive view of the potential of the fresh water resources that can be found on the planet, starting from the global resources, to the continental and hydrographical basin of various sizes, which is considered the basic unit for the landscape.

On the other hand, some research is being done from local to global scale, from simple to complex, paying great attention to the phenomena at larger scale, which offer the fundamental knowledge about the elementary formation processes and variation in time and space of water resources, in order to elaborate a correct mathematic modelling and prognosis of the extreme hydrological phenomena with negative, sometime severe effects for the social and economic development. A larger scale research also implies the study and quantification of the interdependence relationships between the hydrological processes and the rest of the physical-geographical factors, in order to determine their influence on the quantity of water resources.

According to both directions of study, the hydrographical basin is the basic unit not only for the issues related to the modelling of hydrological processes, but also for those related to the monitoring and effective management of this resource, which, in certain circumstances, may be considered as a strategic resource.

Taking into consideration the water dynamics and its role in modelling the relief, it is highly necessary to have detailed knowledge about the physical environment, its morphometrical characteristics in order to be able to quantify them and to use the interdependence relationships between them. This is even more necessary as there is quite a small number of hydrological stations to measure the quantity and quality of water resources, and there are large areas where measurements are not performed; in this case, the evaluation is done based on some territorial generalization relations, which are already established.

Classification systems for the hydrographical network

Due to the large number of rivers and rivulets within a drainage system, including the entire hierarchy of basins and sub-basins, there has always been need of finding some criteria for their hierarchy and codification. This became more acute as the electronic methods for evaluation and determination have been perfected, adding numerous pieces of information, which must be arranged and systematized in order to be most efficient.

Among the used classification and codification methods, starting from large to small, from general to particular, it is worth mentioning the ones below.

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According to ***the classification proposed by Gravelius*** (1914), the first order is given to the main river of a drainage system that flows into a sea, lake or ocean. All the tributaries that flow directly into the first order water-course are considered to be second order and so on, to the tiniest water-courses, which will have the highest order (Zăvoianu, 1985). This way, the order depends only on the position the river segment has within a given hydrographical basin. For the Danube for instance, which is a first order river, tributaries such as the Siret, the Calmatui, the Ialomita or the Olt are second order water-courses, and their tributaries are of third order and so on.

If we analyse water courses that have the same order according to this classification system, it becomes obvious that rivers like the Siret, the Călmățui, the Olt and the Drincea, which are all second order rivers, are not similar from the hydrological or morphometrical point of view but for the position towards the main river. Consequently, the flows and catchment areas of hydrographical basins of the same order may greatly vary, and basins covering approximately similar areas may be given quite different orders (Fig. 1a). This classification system was used in many cases; the survey of Romania's waters was carried on based on this classification system. The survey has been used since 1962. The codification system for Romania disregarded the Danube as the first order river; every water course, considered to be more important, was seen as a first order river. These rivers bear a name and Roman figures (Tisa I), counter clockwise up to the Prut, XIII. The Danube's smaller tributaries bear the code Danube XIV, while those in Dobrogea, which flow directly into the Black Sea, are named Littoral XV.

Beside this first part of the codification, there are also some figures, beginning with 1 for the main course, followed by those with 2, from the mouth to the springs. However, this system includes only those water courses, the basins of which cover an area of more than 10 sq km and have a minimum length of 5 km. Using the above mentioned system, there were codified water courses for the first to the sixth order. The numeric code given to every order is separated from the upper and the lower ones by a dot, the figures assembly having no numeric significance (1.28.3.15.2).

This way, in Romania there were codified 4,864 water courses varying from the first to the sixth order, the hydrographical network being 78,905 km long. The 1962, the survey was the starting point for various editions of the Atlas, this principle being still valid.

The classification proposed by Pfafstetter (1989) is also widely used for dividing the drainage area both at the continental and at the basin level in sub-basins, complying with the following principles (Furnas, 2001; Zhang, 2007):

- the main water course with code 4 in Fig. 1 b drains the largest area of the basin;
- the first four tributaries having the largest areas of the basin, are given the codes 2, 4, 6 and 8 respectively from downstream to upstream; these figures come next to the code of the main river, becoming 42, 44, 46 and 48 respectively;
- the remaining area is divided into 5 inter-basin areas, codified from downstream to upstream with 1, 3, 5, 7 and 9, which are added, in their turn, to the code of the main water course, becoming 41, 43, 45, 47 and 49;
- then, the three conditions apply to the tributaries and inter-basin areas that were previously codified, leading to a second codification level. For instance, the sub-basins within the sixth basin area, are given, according to the size of their area, the codes 2, 4, 6 and even 8, which are added to the previous code; there results 462, 464, 466 and even 468. For the inter-basin areas, there are the codes 1, 3, 5, 7 and even 9 added to the previous code, leading to 461, 463, 465, 467 and 469 (Fig. 1 b);
- the action is repeated to the smallest sub-basins and inter-basin areas. Passing from one level to another depends on the surface of the drainage area. The endoreic areas within a basin or sub-basin bear the code 0 (Furnas, 2001). The number of digits equals the number of subordination levels that were used.

Such a code given to a particular area takes into consideration the code of the main water course and, at the same time, identifies the topological position within the system (Vogt, 2007).

The system is quite detailed and may be used for a thorough analysis, but the areas between the sub-basins are sometimes difficult to compare due to the difficulties posed by the basin dividing, that sometimes, catchment areas of the same size bear very different codes. The limited number of digits for every level requires that some sub-basins should not be included into the corresponding category.

The binary codification method proposed by Li et. all (2006) topologically characterizes the relationships of the river networks using the following conditions (Zhang, 2007):

- for every knot there is only one tributary that flows into the main river;
- between two knots there is only one river segment;

- for this codification system, 0 is given to the main river;
- along the river, upstream, it is noted "1" at the right of the code of the main course for the last sector of the first tributary and "0" for the upstream sector and then, the operation is applied for the entire system.

Although useful for determinations and topological location, sometimes there are numerous symbols (0 or 1) when there are many tributaries within the upper sector of the river (Fig. 1 c).

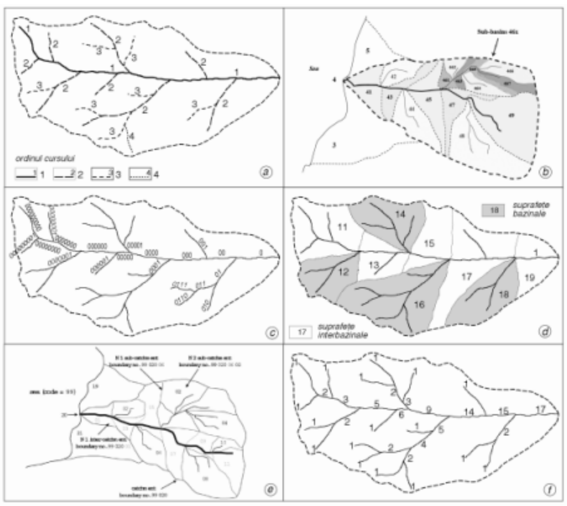

Fig. 1 Classification systems for the hydrographical network : a – Gravelius; b – Pfafstetter (after Voght, J. & Foisneau, S., 2007); c – Li; d – LAWA; e – ERICA (after Arakelyan, S., Mkrtchyan, A. 2007); f – Shreve

LAWA German classification system is almost identical with the one proposed by Pfafstetter, but in this case the codification starts from the springs towards the mouth of the river and not from the mouth (Fig. 1d).

ERICA codification system was proposed after the evaluation of two previous systems – the Norwegian one – REGINE – and the German one – LAWA (Flavin et al., 1998). This system codifies the sea basins where the rivers flow into, the sea shoreline, the inter-basin areas that are drained towards the sea and the afferent basins. The code includes 2 digits for the sea code, 3 for the shoreline code, 8 for the four detailing levels of the basin and inter-basin areas and 1 digit for the littoral strip. This system allows the codification of 49 tributaries with their catchment area using odd numbers, from 2 to 98, while for the inter-basin areas there are even numbers, from 1 to 99. Thus, there are codified all the main water courses and inter-basin areas, starting from the river mouth towards the springs (Fig. 1e).

The system also has its inconveniences, because although the codification potential is great, it is rather difficult to identify 49 tributaries, especially within the small sized catchment areas.

The second category of classification systems refer to those that start from simple to complex, from small to big, i.e. from the tiniest water courses, which begin with a spring, and end at the first confluence; they are considered to be the first order. Then, by cumulating the catchment areas and water flows, their size gradually increases.

According to ***Shreve classification method,*** a river network includes outer segments of rivers, that begin with a spring and end at the first confluence, and inner segments, between the confluences. The number of outer segments in this system equals the number of river segments of the first order in the Horton-Strahler system. From the union of two segments of the first order, there results one of the second order, and continuously, by adding new segments, the size order of the network and implicitly that of the basin increases (Fig. 1 f). Consequently, if two segments of the size n_1 and n_2 unite, the resulting segment will have the size n_1+n_2 (Zăvoianu, 1985).

The classification method proposed by Horton in 1945 and modified by Strahler in 1952 is based on the following rules:

- the river segments that start with a spring, end at the first confluence and between the two points have no tributaries, are considered to be of 1st order;
- the union of two segments of the 1st order leads to a segment of the 2nd order;
- the union of two segments of the 2nd order leads to a segment of the 3rd order and so on;
- a river segment of a given order may have lower order tributaries, without changing its order. Passing to an upper order takes place only when there is a confluence between two segments of the same order (Horton, 1945).

This method, which was applied in numerous regions, has proved to be a useful research instrument, its results proving that the morphometry of the hydrographical networks and basins comply with some probability laws that may be acknowledged through the morphometrical analysis.

The research that was done has clearly testified that most of the morphometrical elements analysed depending on the size order form direct or indirect geometric progressions, their coefficients and constants being easily determined from the quantitative point of view (Zăvoianu, 1985).

Network and basins codification in Horton-Strahler system

The detailed analysis of the morphometrical characteristics of the physical and hydric environment using this classification system also implies the introduction of a system for network codification that should meet the following demands:

- to allow the individualization, spatial positioning and access of the data base for every river segment, irrespective of the size order;
- to ensure the data base for quantitative evaluation of the morphometrical elements of the hydrographical network at different order confluences and at the chosen points along the longitudinal profile of the main rivers and hydrometric stations;
- to allow the grouping of morphometrical characteristics on size orders;
- to function even if a hydrographical system is not so evolved as to include the basin of the highest order, and has only some sub-basins.

This system is very useful for the detailed studies and can be achieved either by direct digitization on maps at the scale 1:25,000, or by processing the information from the Numeric Model of the Terrain, having a very good resolution.

If the digitization is done manually, using the maps at the scale 1:25,000, it is highly recommended that the tiniest highlighted and measured basin units be of the second order; when necessary, the characteristics of those of the first order are easily calculated. The digitization should start from the second order because it is very easy to highlight the starting point at the confluence of two segments of the first order, well figured on the maps. In case the digitization starts from the first order, then the starting point would be somewhat arbitrarily chosen, and the length of the segments, as well as the other morphometrical elements would have quite significant errors, not to mention the work to be done. The end of a second order segment is always fixed at the confluence with another segment of the same order, or a higher one, even if downstream it has other segments of the first order. When the digitization process of a river segment is over, the data base also includes the size order, its name and code. The digitization always begins from upstream to downstream, paying great attention to the configuration of level curves. When two segments of the second order merge, there results a third order segment and the digitization of the rivers segments continues up to the highest order segments, which usually ends with a confluence or to a lake, sea or ocean that it flows into.

After the digitization of the hydrographical network was carried on from upstream to downstream, there should be individualized the water courses of every order, this time beginning with the highest orders. At the same time, the hydrographical network is codified in the data base.

Thus, the fifth order river is delineated. In the case given as example, it is the highest order and will bear the code 5(1) in the data base. This part of the general code will accompany all the rivers and their corresponding basins, of lower order, within the main basin. As for the fourth order basins, they are delineated from the spring to the mouth of the river and codified, starting from the first basin of the fourth order, which will bear the code 5(1)4(1). The second will be 5(1)4(2), up to the last basin of this order; by its code, it gives information about the number of basins of the fourth order.

There follows the codification of third order river segments, which are found in all the basins of the fourth order or as direct tributaries of the main water course, using the same codification procedure. For instance, the first basin of the third order within the basin 5(1)4(1) will bear the code 5(1)4(1)3(1); the first part of the code – 5(1)4(1) is common for all the sub-basins of the first basin of the fourth order (Fig. 2).

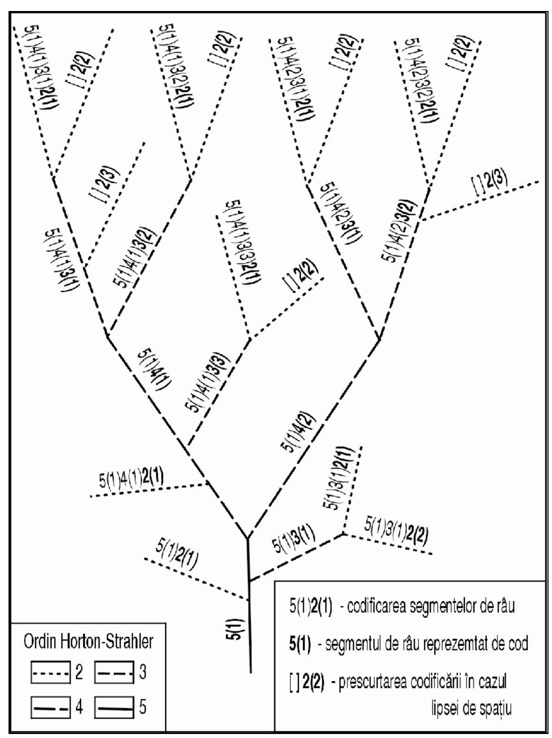

Fig. 2 The codification of hydrographical network based on Horton- Strahler classification

When a river segment of the third order is a direct tributary of the main river, its code will not include the indicative for the fourth order and the code will be only 5(1)3(1). The action of delineation continues, as well as the one of codification of the third order water courses within the upper basin of the order 5(1)4(1)3(1). In this case, the codification follows the same rule for keeping the same label, to which there will be added the second order basins within the third order one. The first basin of the second order will bear the code 5(1) 4(1) 3(1) 2(1). When coming to the next rivers of the fourth order, the same rule for demarcation and codification applies; the code for the second basin will be 5(1) 4(2), to which there are added the codes of the lower order basins.

Within this system, a water course of a given order may have direct tributaries of lower order, without changing the size order. For a fifth order basin, it may have, besides the fourth order tributaries, third and second tributaries, without changing its size order. In this case, for the third order segments, labelled from the spring to the water mouth, when setting the code there must be taken into consideration the fact that the fourth order is missing; consequently, the code of the first basin of the third order that flows directly into the fifth order will be 5(1) 3(1). Forwards, for the lower orders within this sub-basin bear the same code, followed by the numbers for the second order codes.

The first tributary of the third order that flows directly in the fifth order river will bear the code 5(1) 3(1), and the first river of the second order will have the code 5(1) 2(1), without the intermediate orders that may have 4(0) 3(0), but in order to be simpler, they are not used. This way, the code offers information about the fact that the basin 5(1) 2(1) flows directly into the main river. This is also true for the fourth order basins that have direct tributaries of the second order. Thus, the first basin of the third order that flows directly into 5 will have the code 5(1) 3(1), and the first water course of the second order that flows directly into 5 will be 5(1) 2(1). The number between brackets always gives information about the number of segments of each category, and may have different values. All these codes are given and registered in the data base; they can be obtained only by interrogation, without loading the image (but for larger scales, they may be shown). If some of the water courses have their own names, they may be given to the main river or the basin in the database and used accordingly.

The data base made up of points, lines and polygons offer enough possibilities of gathering the necessary data for the detailed morphometrical analyses of the environment as support of water resources. By using the points that mark the start and the end of each segment and the Numeric Model of the Terrain, we can find out their height and the relief intensity of each segment, no matter its size. Then, they also offer the possibility for each point marking a confluence to be the bearer of the entire data base for the basin upstream. Along the main water course, there may be various points at the confluences or at the hydrometric stations, which have all the characteristics of the basin situated upstream of this particular station. In all the cases, the data base also offers the necessary information to highlight the law of level differences for river segments of ever increasing orders.

With respect to the lines, the interrogation of the data base gives information for pointing out the law of river number, average lengths and average perimeters (Zăvoianu, 1985). Knowing the relief intensity and the lengths of all river segments of different orders, there can be determined the slope law for all the river segments, and then an average slope for the entire hydrographical network within the analysed basin.

The present system of codification may also identify the points based on the geographical coordinates.

In case the digitization could not be achieved and there was stopped at a sub-basin or along the main river, the process may be stopped by establishing an ending point on the main river that should gather the entire information. When the digitization begins again, the rest of the basin will be integrated into the data base, keeping the codification rules.

If a particular basin of any order was given a wrong code, it may be corrected in the data base, but following the implications of the new correct code.

Since the system is conceived for detailed studies and the work carried on for small areas, it is necessary that for a codification, they be analysed independently, but also to offer the possibility for being integrated. In this case, assuming that the basin 6(1) is part of a larger basin, having the position 6(2), only this part of the code will be modified, the remaining tributaries codes being the same. Thus, they are integrated into a higher order basin.

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