METHODOLOGY TO IDENTIFY THE LEADING FACTORS OF RIVERS' ELECTRICAL CONDUCTIVITY. CASE STUDY: JIU CATCHMENT (ROMANIA)

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ABSTRACT. - Methodology to Identify the Leading Factors of Rivers' Electrical Conductivity. Case Study: Jiu Catchment, Romania. The river's conductivity is the capacity of the water to transport electricity and depends on the physical and anthropogenic characteristics of the catchment. This paper aims to investigate the spatial variation of the rivers' electrical conductivity in order to identify the role of its main predictors, by using multivariate analysis and GIS methods. The study area, Jiu River basin, is located in the SW of Romania. It covers 10,000 km^2 and has a high diversity of geographical features, which could explain the variations in conductivity. The paper is based mainly on field measurements on electrical conductivity and turbidity, in 19 sites on Jiu River and some tributaries. The recorded conductivity values ranged from 61 μS/cm to 1201 μS/cm. This wide variation may be caused by several factors, such as turbidity, lithology, soils, as well as land use. The Principal Components Analysis (PCA) highlighted that the chief variables which determine the increase of river conductivity are the geological substrate and the soil textures across the catchments (particularly marls). The results also show a close relationship between the dominantly clayey textures and the high values of conductivity. Additionally, anthropogenic disturbances (reflected by the extent of the agricultural and urbanized areas) are also likely to play a role in the local increase of electrical conductivity.

Keywords: electrical conductivity, turbidity, Jiu Watershed, multivariate analysis, geographical factors.

1. INTRODUCTION

Electrical conductivity (EC) is an important parameter which indirectly analyzes the rivers' quality (Patel & Parikh, 2013; Braul et al., 2011). According to Niekerk et al. (2014), EC is interchangeable with total dissolved solids (TDS), which is a function of it. Both parameters can be easily measured in the field and they reflect the influence of the upstream catchment geographical features on rivers' water quality (Anhwange et al., 2012).

In the literature, several categories of conductivity drivers are mentioned, such as geology, soils and anthropogenic activities (Shabalala et al., 2013).

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Generally, the electrical conductivity is related to the dissolved ions in water, which are more likely to occur when the river flows over limestones, marls and clayey soils (Braul et al., 2011). Many studies have reported that EC in rivers not only varies according to one or another reach-scale determinant, but suffers significant changes due to variations in characteristics affecting the upstream basin (Goransson et al., 2013; Némery et al., 2013; Stewardson et al., 2016).

The aim of this paper is to examine, by using GIS and multivariate analysis, the spatial variation of the electrical conductivity of Jiu River and some of its tributaries, in order to assess the role of the responsible geographical drivers. It is an innovative study for this area, where such analysis has not been achieved by now, showing the interest, both scientifically and methodologically, of this work.

2. STUDY AREA

The Jiu River catchment (~10,000 km^2) is located in south-western Romania, between the Southern Carpathians and the Danube River (Fig. 1). In this area, the Carpathian Mountains occupy 35%, the Subarpathians Hills and Getic Plateau around 65% and the Oltenia Plain, only 10%.

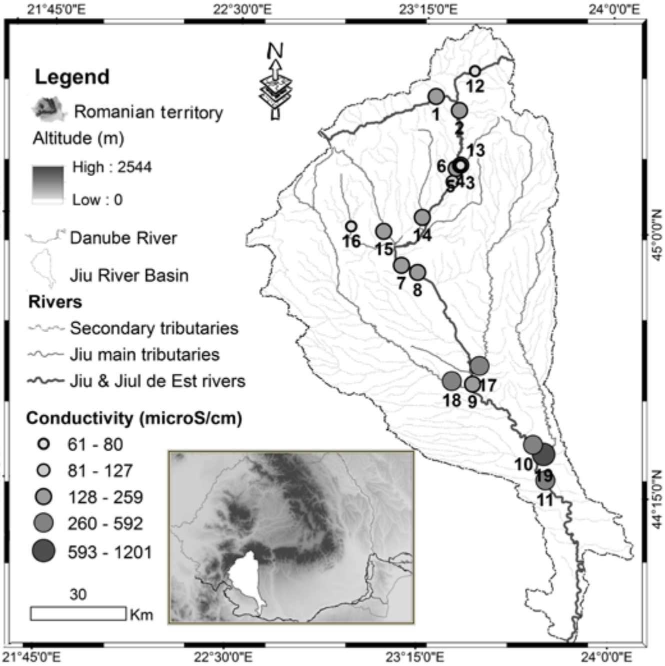

Fig. 1. ***Jiu River basin location and measuring points according to the conductivity values (numbers on the map correspond to those from Table 1)***

It is characterized by a large variety of geographical features (physical and anthropogenic). The altitude of the catchment varies between 2159 m in the north and 24.1 m at the river mouth into Danube, reflecting the diversity of landforms, geology (siliceous rocks - metamorphic or Miocene, Pliocene and Quaternary sedimentary shale; limestone in the upper mountainous and plateau area from north and north-west), soils (with predominance of the clay and loamy textures) and land cover (dominantly arable – 49%).

In terms of streamflow, the mean annual discharge at hydrometric stations (h.s.) increases downstreamward as follows: 2.36 m^3/s at Lonea h.s. (in the upper basin), 21.7 m^3/s at Sadu h.s. (at the exit from the Carpathians), 46 m^3/s at Rovinari h.s., 63.3 m^3/s at Filiasi h.s. (both in the middle sector) and 85 m^3/s at Zăval h.s. at the exutory. On the tributary rivers, there are differences depending mainly of the drainage area: 4.63 m^3/s on Bistrița at Telești h.s., 12.6 m^3/s on Motru at Fața Motrului h.s. and only 2.5 m^3/s on Amaradia at Albești h.s.

Table. 1. ***Data on the studied sites (Site numbers refer to Fig.1)***

No.	Name of the measuring point	River	Area of the catchments upstream the measuring points (km^2)	Conductivity (µs)
1	Vulcan	Western Jiu	277.5	198
2	Gorge	Jiu	2936.5	191
3	Upstream confluence Sadu	Jiu	1866.8	184
4	Downstram confluence Sadu	Jiu	453.0	108
5	Bumbești	Jiu	1269.6	189
6	Sâmbotin	Jiu	1012.2	127
7	Rovinari	Jiu	7723.9	220
8	Fărcășești	Jiu	1319.0	190
9	Filiași	Jiu	1170.3	259
10	Ișalnița	Jiu	1342.7	592
11	Bucovăț	Jiu	9233.5	461
12	Lonea	Eastern Jiu	1264.0	80
13	Upstream confluence with Jiu	Sadu	3013.6	80
14	Vaidei	Susita	883.9	231
15	Telești	Bistrita	208.0	187
16	Godinești	Tismana	129.2	61
17	Confluence Jiu	Gilort	94.1	394
18	Butoiești	Motru	5281.6	451
19	Albesti	Amaradia	99.6	1201

3. DATA AND METHODS

The methodology relies on two major types of data: field measured and spatial data. In total, 19 conductivity and turbidity measurements were made in the period 5 - 7 August 2016, during low flow conditions, in 12 sites on Jiu River and in 7 sites on some of its main tributaries (Fig. 1). The main criteria for choosing our sampling points were watershed surface and the issue of accessibility. In the process, we respected the indications concerning water temperature constancy by performing the measurements on three summer days with similar atmospheric conditions (Anhwange et al., 2012). The EC measurements [μS/cm] and turbidity [FNU - Formazin Nephelometric Unit] were performed using the EC/TDS/Temperature Hand-held Tester and the portable HI 98713 turbidimeter.

Apart from turbidity, the conductivity variations at different measurement points could be explained by several upstream catchment characteristics: lithology, hydro-geological structures that interact with the rivers, soil texture, as well as anthropic influences (Stewardson et al., 2016). For this, we also used spatial data from cartographic documents (maps) and land cover database, processed in the GIS environment (vectorization, selection, classification and spatial statistics analysis):

- Geology maps (1:200,000) - explaining the electrical charge on different ions, typically released from carbonate rocks, marls and facies with clay;
- Soil map (1:200,000) – for identifying the soil texture; areas with clayey soils tend to have higher conductivity (Braul et al., 2011);
- Data on human influences (based on CLC 2012): industrial and mineral extraction areas, irrigated lands, urbanized areas, non-point pollution sources.

In the next stage, the simple and multiple regressions, as well as the principal component analysis (PCA), were applied in order to assess the relationships between the main drivers and the conductivity values.

4. RESULTS AND DISCUSSION

4.1. Spatial variation of conductivity

The spatial differences in conductivity were identified and shown in Fig. 1 and Table 1. Over the whole study area, the measured values varied from a minimum of 61 μS/cm (Tismana River at Godinești) to a maximum of 1201 μS/cm (Amaradia river at Albești). On the Jiu River itself, conductivity values are between 80 μS/cm (point 4) and 592 μS/cm (point 10).

4.2. Statistical analysis of the sensitivity of rivers' conductivity to upstream catchment-scale drivers

4.2.1. Simple and Multiple Linear Regressions

Based on field measurements and spatial data, the simple and multiple linear regressions were conducted to check the predictability of the variables controlling the conductivity. Although not mutually related to each other, this set of analysis could be regarded as a pre-step of the PCA.

For the input variables, we considered the conductivity values (dependent variable) and a set of 6 independent variables including the turbidity and some geographical features of catchment upstream of each measurement point: the coverage area (in %) of the geology units (limestones, clay rocks; marls, the total coverage of all erodible rock types), soils (clayey and clayey-loamy textures) and the spatial extent of the anthropic activities (some land uses from which easily ionizable substances may reach the rivers, such as mines or industrial areas, irrigated agricultural land, impermeabilized surfaces).

To bring all the dependent and independent variables in proportion to each other, the data were prepared for the statistical analysis by means of normalization, resulting comparable values from 0 to 1 (lowest to highest conductivity/ turbidity and smallest to biggest coverage of the catchment factors). As shown in the Fig. 2 (with real values), the best correlations were established between EC and marls.

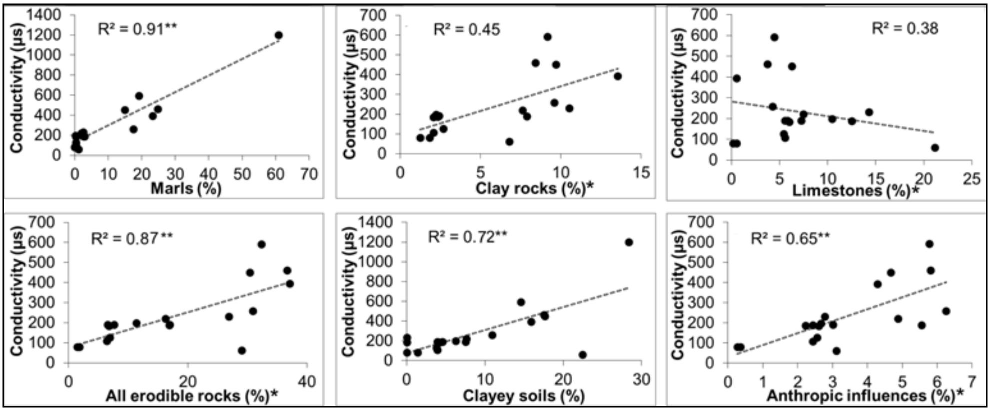

Fig. 2. ***Best simple regressions for each of the 6 upstream catchment variables used as predictors for conductivity variation: * - Without accounting for Amaradia value (outlier) and ** - Correlation is significant at the 0.01 level (2-tailed)***

In order to find the significantly correlated variables, we used the stepwise method. The best correlation was obtained for the coverage of the upstream basin with marls ($R^2 = 0.91$), which may be interpreted as a unique contribution of this factor to the multiple regressions between conductivity and its independent variables. For this single determinant, the Durbin-Watson factor of the multiple regression was between 1.5 and 2.5, which means that we achieved one statistically significant serial correlation (marls and conductivity), with $R^2 = 0.91$ at a $p<0.01$. In the simple regressions, other good correlations were obtained between conductivity, erodible rocks ($R^2 = 0.87$), clayey soils ($R^2 = 0.72$) and anthropic influences ($R^2 = 0.65$).

4.2.2. Principal Components Analysis

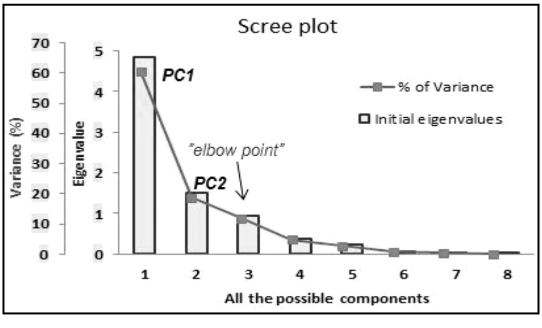

Fig. 3. *Scree plot of the PCA*

Principal Components Analysis (PCA) turns original variables into new ones, which are referred to as the principal components and are the result of a linear combination on the original variables. The resulting axis illustrates the directions of maximum variance (Smith, 2003, Shretsa & Kazama, 2006).

Thus, PCA was employed to reduce the contribution of less significant variables in order to simplify the causality relationship between electrical EC values and its geographical drivers. In order to find out how many components to extract, we approached the Monte Carlo simulation for estimating the significantly statistical eigenvalues by looking at the scree plot (Fig. 3).

This chart shows how many principal components can be taken into account in the correlation. We were then able to note the high scores of the first two in terms of eigenvalues and variance accounted to perform the PCA (%).

As only the first two components could explain most of the variance, they were further retained for the interpretation (Fig. 4).

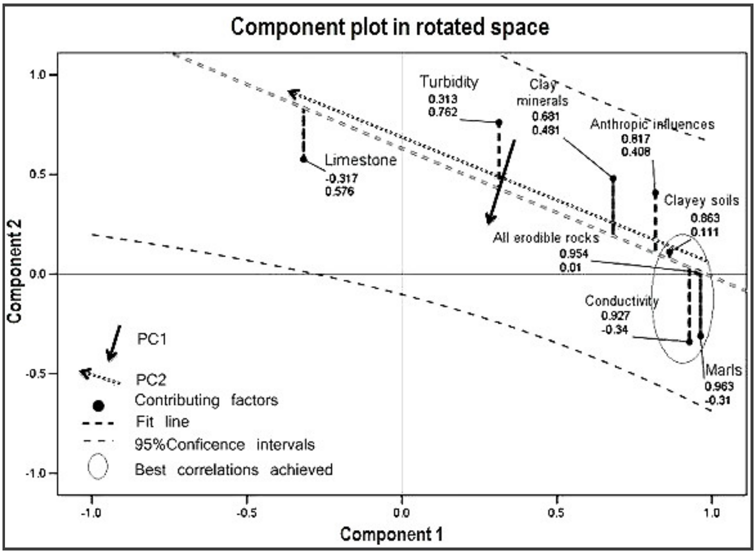

Fig. 4. ***Rotated values of the contribution of each variable to the principal components. Some variables made up both of them (marls) and others only one component (turbidity)***

A first remark is that all the variables had at least one correlation R^2 above 0.3, which means that even if some of the considered factors are poorly predictable for EC variation; they are nevertheless not negligible, contributing to the principal components. There are three main determinants which best correlate with the conductivity values and contribute the most to the first component retained: marls (r = 0.95), all types of erodible rocks (r = 0.86) and clayey soils (r = 0.72).

Yet, this statistical analysis was not enough to prove a significant influence of turbidity and limestones on the conductivity, unlike what was reported in other studies (Goransson et al., 2013; Némery et al., 2013; Patel & Parikh, 2013).

4.3. DISCUSSION

The implications for this kind of combined methodology consist in the investigation of a large number of driving factors for sensitive water quality parameters, such as conductivity and total dissolved solids or other parameters.

However, from a methodological and researcher - side perspective, the present research has a number of limitations that will be addressed in a future study. The methodology used suffers from the lack of an adequate validation, through its application to other river basins, and is affected by the weight assigned to each spatial factor used in the analysis. It is possible that the variations in conductivity are also due to local conditions that were not accounted for as preexisting factors in our study, which is a consequence of the absence of previous similar studies and of the novelty of our approach (the use of GIS and statistical analysis for explaining conductivity).

5. CONCLUSIONS

In this paper, GIS and multivariate analysis were used to examine the spatial variation of electrical conductivity in Jiu River catchment. The study is based on field data on conductivity and turbidity measured in 19 sites, as well as on cartographic data extracted from maps (geology and soils) and land cover database.

The methodology allowed for the delineation of the most important explanatory variables. Thus, the lithology consisting in erodible rocks (particularly the presence of marls with $r = 0.95$ at 0.01 significance level) and clayey textures of soils have the greatest influence on the conductivity in both statistical approaches. The importance of their coverage is well seen in small and homogeneous river basins, such as Amaradia and Gilort. The second contributing factor is the anthropogenic influence on the rivers.

In this way, through the proposed methodology, it was ascertained that the regressions and principal component analysis that we applied on data gathered from the field and also on data provided by cartographic documents represent useful approaches for the understanding of spatial variations of conductivity.

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