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THE POTENTIAL FOR WATER DIFFUSE POLLUTION WITH HEAVY METALS IN ARIEŞ RIVER BASIN

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Abstract: The potential for water diffuse pollution with heavy metals in Arieș river basin**.** Arieș river basin is found mostly in the area of mining extractions from Apuseni Mountains. Its position causes a high vulnerability of water courses to pollution with heavy metals derived from mine waters. In this sutdy, in order to determine the potential for water diffuse pollution in Arieș river basin, two main factors were integrated in GIS software, respectively: the potential for surface runoff and the localization of the sources of water pollution with heavy metals (from quarries, mines, blank depositions, decantation ponds). The highlighting of the potential for water diffuse pollution was achieved by computing the DPPI index for each river sub-basin. The index was computed by multiplying the average values of the Flash-Flood Susceptibility Index for each river sub-basin by the number of difuse pollution sources (from quarries, mines, blank depositions, decantation ponds) within the sub-basin units. The results relieved that the most exposed areas to pollution correspond to water courses from Valea Șesei, Roșia Montană, Valea Buciumanilor river basins and implicitly Abrud river basin, which includes the last two mentioned river basins. The validation of the results was performed by consulting the official reports, which confirm the severe water pollution with heavy metals.

Keywords: *Arieș, FFSI, DPPI, diffuse pollution, GIS*

I. INTRODUCTION

Diffuse pollution of water courses is one of the most important issues of the areas with mining excavations, typically to metalliferous industry. Globally, the problem of diffuse pollution has been studied by: Chiew and McMahon (1999); Li and Zhang (1999); D'Arcy et al. (1998); Owen et al. (2012) etc. This type of pollution is caused by washing the metals from mine exploitation, due to rainfall. In this way, given the gravitational effect, water containing pollutants reaches the rivers, causing severe pollution. For this reason, it is very important to highlight the areas with high potential for surface runoff in mining areas. The issue of surface runoff has been studied both in national (Chendeș, 2007; Bilașco, 2008; Zoccatelli et al., 2010; Mătreață and Mătreață, 2010; Teodor and Mătreață, 2011; Minea, 2011; Domnița, 2012; Zaharia et al., 2012; Costea, 2013; Prăvălie and Costache, 2013) and international studies (Zhifeng, 2004; Sahoo et al., 2006; Barredo, 2007; Yu et al., 2009; Villarini et al., 2010; Zanon et al., 2010; Marchi et al., 2010)

Arieș river basin is one of the main heavy metals extraction areas in Romania. The presence of exploitation areas, like Roșia Montană, Roșia Poieni or Băișoara, related to specific physical-geographical characteristics, such as high slopes exceeding 25º (Bilașco et al, 2013), causes favorable conditions for severe pollution events and decrease of river water quality (Bătinaș, 2010).

The aim of this study is, firstly, to spatially model the DPPI (Diffuse Pollution Potential Index) values within each river sub-basin, and secondly, to identify the water courses with the highest potential for diffuse pollution. The spatial computation of DPPI values was performed by multiplying the average values of the potential for surface runoff index from each river basin with the number of polluting sources (quarries, mines, blank depositions, decantation ponds) from the river sub-basins. In the scientific literature, there are several similar approaches regarding water diffuse pollution: Onless (1995), Novotny (1999), De Wit et al. (2000), Nisbet (2001), Chiew et al. (1999), Heatwaite et al. (2005), Kim et al. (2007) etc.

II. STUDY AREA

Arieș river basin is located in the central-western part of Romania (Fig.1). Recording 3005 km² of draining surface, the river is the second major tributary to Mureș River (Bilașco et. al., 2013). The study area overlays several relief units: the mountain area: Apuseni Mountains (59% of the total area), the hilly area: Feleacului Hill (11.89 %), the plateau area: Transilvania Plateau (19.87%) and the depression area of Arieș on 9.96% (Bilașco et. al., 2013). The altitudes range between 250 m at the confluence with Mureș River and 1826 m (Fig.1) on the highest peaks of Apuseni Mountains. High slopes exceeding 15°, found mainly in the central part of the river basin (Fig.2a), where the most diffuse pollution sources are found (Fig.3d), cause the increase of the potential for runoff (Prăvălie and Costache, 2013; Fontanine and Costache, 2013; Costache and Prăvălie, 2013), and, subsequently, the increase of potential for metal washing from the surface. The slope values exceeding 15º occur on almost 40% of the study area. The high convergence within the valleys from Arieș river basin (Fig.2d) and the presence of profile curvature negative values on aproximately 48% of the area (Fig.3b) are also two indicators of the high potential for water runoff (Constantinescu, 2006).

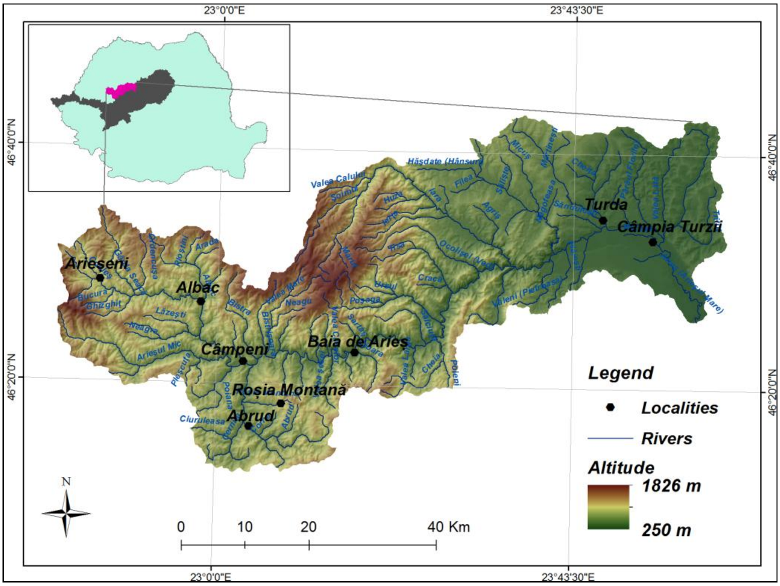

Fig.1 Study area location

Generally, the potential for surface runoff and diffuse pollution with heavy metals (Co, Cu, Cd, Ni, Pb) in Arieş river basin is favored by the low weight of lands under forestry (about 28%, according to Corine Land Cover, 2006). Heavy methals are mainly absorbed onto suspending particles and accumulate in the sediments, having an impact on living organisms that assimilate them, due to the high toxicity (Naimo, 1995).

III. METHODOLOGY

A proper methodolgy was used to highlight the the potential for water diffuse pollution with heavy metals within Arieş river basin. The methodology consists of the computation and spatially modeling of the DPPI. A similar methodology, based on GIS tools, which focused on the influence of surface runoff on diffuse pollution, was used by Heatwaite et al. (2005). Other approaches on the relationship between surface runoff and water diffuse pollution were made by Chiew and McMahon (1999), Kim et al. (2007) etc.

The study was realized in several stages. Firstly, the Flash-Flood Susceptibility Index (FFSI) was computed and spatially modeled. This index was calculated by integrating in ArcGIS 10.1 seven geographical factors that influence water flow on slopes (Fig.2 a.b.c.d. and 3a.b.c.). Factors as slope, LS Factor, profile curvature, convergence index and the shape of sub-basins were derived from the digital elevation model at a 20 m cell size, by interpolating the contours digitized from the Topographic Map at 1:25000 scale.

The slope (Fig.2a) is the indicator that reflects mostly the gravitational effect on runoff. The speed of water flow is directly proportional with slope values. LS factor (Fig. 2c), used in many hydrological studies (Hickey, 2000; Bilașco et al., 2009; Arghiuș and Arghiuș, 2012), represents the relation between the slope angle and length. Its values were computed after the formula:

$$LS = \; m+1 \; \cdot \left(\frac{As}{22.13}\right)^{m} \cdot \left(\frac{sin\beta}{0.0896}\right)^{n}$$

where As – surface of the basin, m=0,4 and n=1,3 (Constantinescu, 2006).

The convergence index (Fig.2d) allows separating the interfluve from valley bottoms. Values near -100 express high convergence, meanwhile positive values, near 100, correspond to highly divergent areas (Wilson et al., 2000).

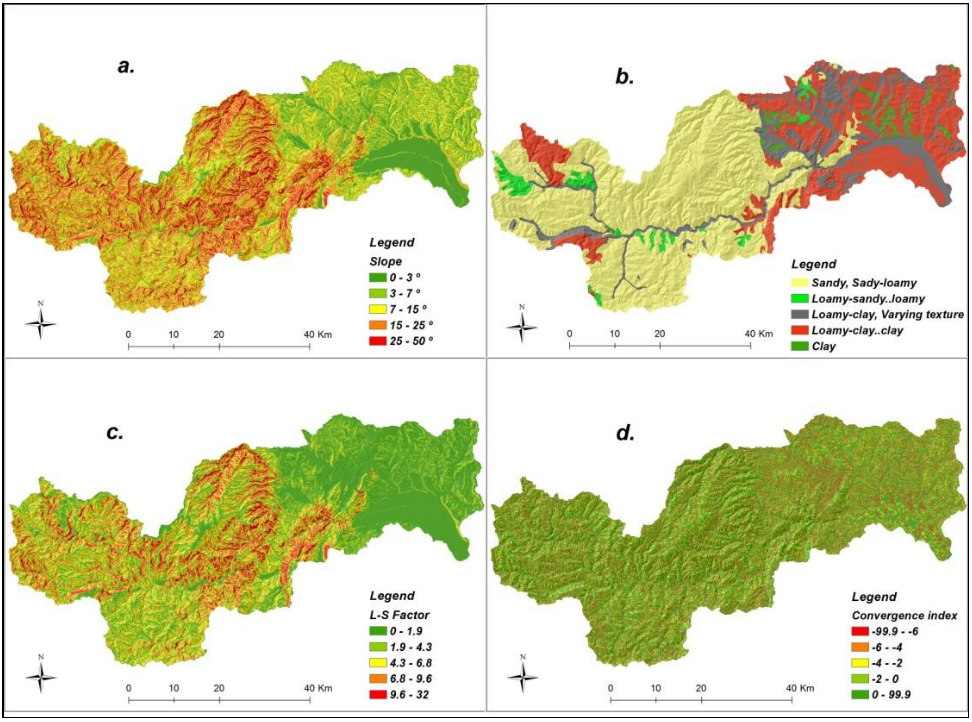

Fig. 2 The factors that influence runoff (a. slope; b. soil texture; c. LS factor; d. convergence index)

The profile curvature (Fig. 3a) differentiates convex surfaces (negative values), with accelerated flow and high potential for erosion, from concave areas (positive values) with limited flow (Constantinescu, 2006). The shape of the sub-basins (Fig.3c) is an important factor in determining the way of water accumulation. The shape of the sub-basins was computed by the formula $4\pi F/P^2$, where F – the basin surface and P – its perimeter. Whereas, closer values of the shape index to 1 reveals more circular basins, shorter time of water accumulation in the main collector and faster surface runoff.

The land use (Fig.3b) was obtained for the study area by extracting vectorial data from Corine Land Cover, 2006 database, while soil texture was obtained from the Map of Romania Soils, at 1:200000 scale (ICPA, 2002). Land use and soil texture were converted to raster data, at a 20 m cell size in order to be integrated in the computation of FFSI together with the other 5 indexes: profile curvature, catchment area shape, LS Factor, convergence index, slope.

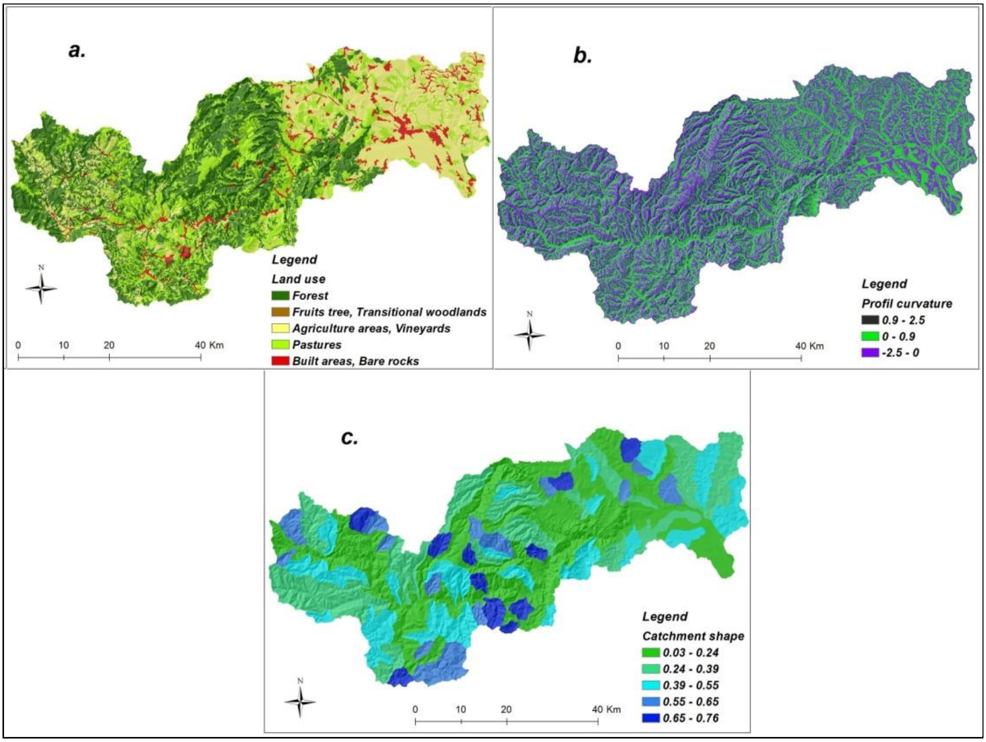

Fig. 3 The factors that influence runoff
(a. land use; b.profile curvature; c.catchment area shape)

In order to obtain the Flash-Flood Susceptibility Index, the characteristics of the seven factors were scored with marks between 1 and 5. The score 1 was given for those characteristics that diminish the hydric erosion processes, whereas the score 5 was given to classes of values that increase these processes (Table1). For example, the factors characteristics such as the highest values of the slope (>25º), negative profile curvature values and clay textures were assigned 5, meanwhile forests and very low slope values were assigned 1.

As the above mentioned factors have different contribution to surface runoff, they were weighted (Table1) using Weight module in Idrisi Selva software. After spatially modeling the FFSI, the average of the index values was calculated for each river sub-basin, by using Zonal Statistics tool in ArcGIS 10.1.

Table 1 The scores and weights of the factors that influence runoff

Parameters	*Types/Values*				
Slope (˚) – 20%	0 - 3	3.1 - 7	7.1 - 15	15.1 - 25	> 25
L-S Factor – 13%	0 – 1.93	1.93 – 4.37	4.37 – 6.82	6.82 – 9.65	9.65 – 32.83
Catchment area shape – 5%	0.03 – 0.24	0.25 – 0.39	0.40 – 0.55	0.56 – 0.65	0.66 – 0.76
Profile curvature – 20%			0.9 – 2.1	0 – 0.9	-2.1 - 0
Convergence Index – 10%	> 0	0 - (-2)	(-2) - (-4)	(-4) – (-6)	(-6) - (-100)
Soil texture – 12%	Sandy, Sandy-loamy...loamy-sandy	Loamy-sandy...loamy, Loamy-sandy	Loamy-clay, Varying texture, Loamy-sandy...loamy-clay	Loamy-clay... clay, l loamy... loamy-clay	Clay
Land use – 20%	Forest	Fruit trees, Transitional wood-lands	Agricultural areas,Vineyards	Pastures	Built areas, Bare rocks
Bonitation score	1	2	3	4	5
FFSI (classes)	Very Low 16 – 23.9	Low 23.9 – 27.6	Medium 27.6 – 31.3	High 31.3 – 35.3	Very High 35.3 – 45.7

The last stage of the study consists in the computation of DPPI for each river sub-basin. This calculation was performed by applying the following relation:

$$DPPI = FFSI_{AV} \cdot N$$

where $\mathbf{FFSI_{AV}}$ is the average of FFSI within each river sub-basin and N is the number of sources of water diffuse pollution within each river sub-basin. The sources of water diffuse pollution were digitized from several cartographical supports, like the topographic map 1:25000 and orthorectified aerial image, 2005. The largest number of diffuse pollution is recorded in Roșia Montană river basin (20) (Fig. 4).

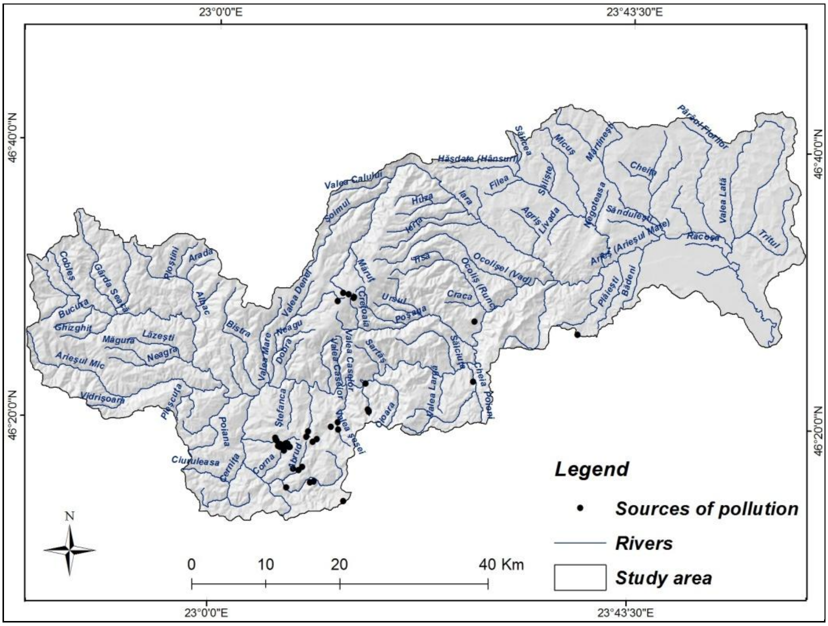

Fig. 4 The localisation of water diffuse pollution sources in Arieș river basin

IV. RESULTS

By applying the above described methodology, the FFSI values were firstly obtained and spatially modeled within the study area (Fig. 5). The values were grouped in fives classes of values, by *Natural Breaks* method in ArcGIS 10.1. The values of FFSI reveal high and very high potential for surface runoff, especially in the central part of Arieș river basin. These values overlay generally deforested slopes, with high slope values and fine soil texture which blocks water infiltration. The FFSI values between 31.3 and 45.7 occur on almost 31% of the study area (Fig.5), which means a high potential for water diffuse pollution in case of torential rainfall or sudden snow melting. The largest areas within Arieș river basin are characterised by FFSI values between 27.6 and 31.3. These values record 39% of the study area (Fig.5) and are distributed within all the area. Low and very low values of the FFSI occur mainly on deforested areas, but also with slopes beneath 3º located in the extremity of the mountain area and the plateau area before Arieș inflow to Mureș River. In these areas, the risk of water diffuse pollution is very low. The calculation of average FFSI values for each river sub-basin was performed by using *Zonal Statistic* tool in ArcGIS 10.1.

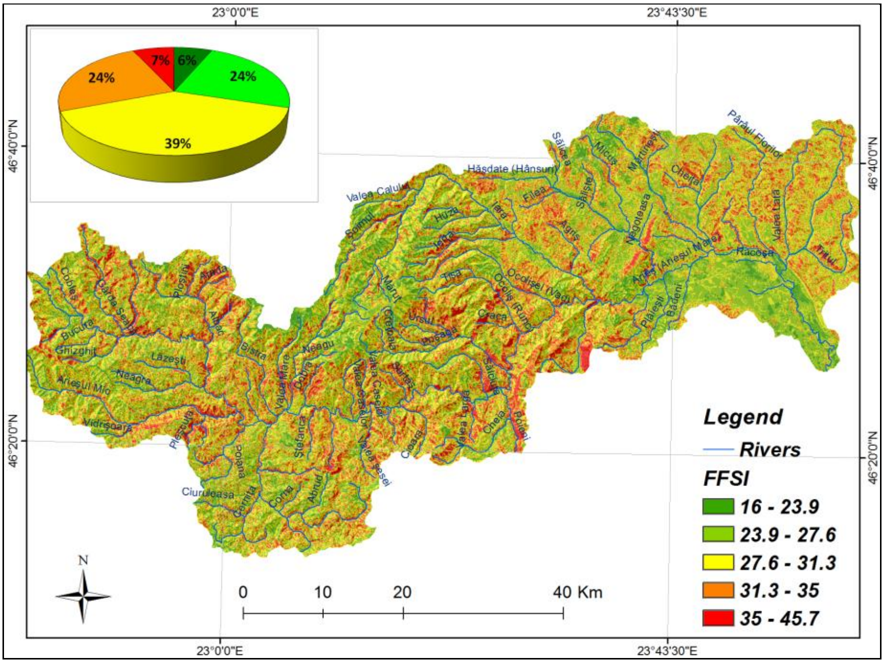

Fig. 5 The distribution of FFSI values within Arieș river basin

The values are generally between 26.9 and 32.3 (Fig. 6) and were grouped in five classes by *Natural Breaks* method. Very high average values of FFSI, between 31.24 and 32.3 are found within 12 sub-basins: Arada, Valea Largă, Sartăș, Lămășoaia, Rimetea etc. Medium average values of the FFSI occur in 18 sub-basins: Roșia Montană, Ocoliș, Săiciuța, Negoteasa, Cheile Băișoarei, Valea Sărată, Valea Lată, Ploștini, Valea Șesei, Valea Caselor, Cheița, Agriș, Pleșcuța, Ordencușa, Hermăneasa, Stefanca, Săgeaca și Becaș.

The DPPI was calculated for each river sub-basin, the results ranging between 0 and 607.76 were obtained (Fig.7). Generally, the sub-basins with high and very high average values of FFSI have a circular shape and small draining areas. Many of these are located in the mining areas were quarries, mines, blank depositions and decantation ponds are found.

The values were also grouped in five classes of values, by Natural Breaks method. Further, two sub-basins with very high potential for water diffuse pollution were identified: Șesei Valley, a direct tributary of Arieș river and Roșia Montană, a direct tributary of Abrud river (the most important tributary of Arieș river).

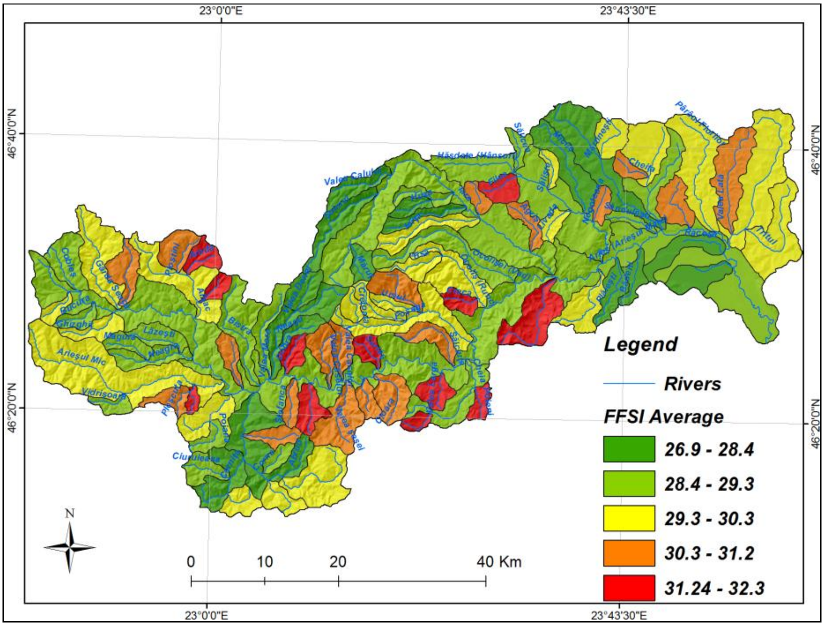

Fig. 6 Average values of the FFSI within river sub-basins

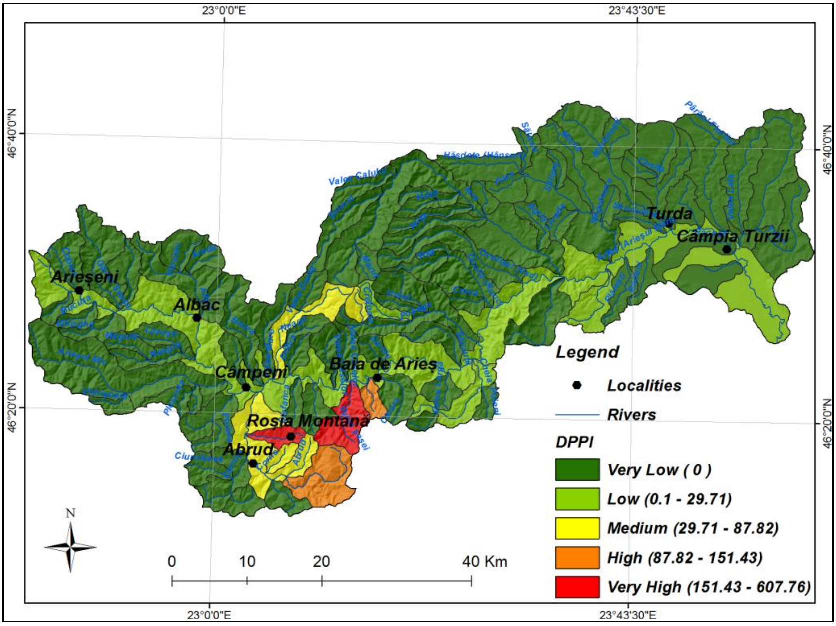

Fig.7. The values of the Diffuse Pollution Potential Index

The DPPI values within the two river sub-basins are between 151.43 and 607.76. High values of the DPPI, between 87.82 and 151.43 occur in Hermăneasa river basin, which is confluent to Arieș (at Baia de Arieș locality), and Buciumanilor Valley river basin, the most important tributary of Abrud river.

V. RESULTS VALIDATION

In order to validate the results of this study, the annual reports of the Agency for Environmental Protection from Alba County were consulted for the period 2004-2009. For the study area, water quality monitoring was performed by three monitoring control points. These are placed on Arieș River, upstream Baia de Arieș, Abrud and Șesei Valley rivers. In 2004 and 2005 water quality monitoring was performed only for Arieș and Abrud rivers (APM Alba, 2009). For Arieș River, the water quality was included in the IVth class of quality (bad quality) according to metal concentrations, whereas Abrud river's water quality was included in the Vth class of quality (unbecoming). In these cases, pollution was due to metals like: Cu, Co, Cd, Ni (APM Alba, 2009). As from the year 2006, Șesei Valley river's water quality has been also monitorized. Until 2009, the state of Arieș and Abrud rivers was similar to the previous period, meanwhile Șesei Valley river's water quality was also included in the Vth class of quality due to a large decantation pond (ortoforectified aerial image, 2005), managed by Cuprumin, which causes its pollution by mining water.

VI. CONCLUSIONS

The existence of many sources of water diffuse pollution with heavy metals and the high potential for surface runoff cause the increase of the risk of water pollution in mining areas. We consider that the methodology used in this study is useful and efficient for the identification of the main areas affected by water diffuse pollution and the methodology could be applied for any other mining areas.

In Arieș river basin, water diffuse pollution with heavy metals is very severe in the case of Șesei Valley, Roșia Montană and Abrud rivers, which leads to the conduction of pollutants to the main collector river of the study area. The contamination of surface water also causes the decrease of phreatic water quality, which is very harmfull to the area's inhabitants and potential consumers of polluted water.

In order to diminish the potential for surface runoff and, consequently, the potential for water diffuse pollution in Arieș river basin, besides performing a better management of pollution sources (quarries, mines, blank depositions, decantation ponds), measures regarding torrential systems development and torrential processes decrease must be considered, such as deforestation.

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