Environmental Risk Assessment in Sediments from Jiu River, Romania

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The aim of this paper is to assess the heavy metal pollution and ecological risk in sediments of the Jiu River, Romania, upstream and downstream of mining: Vulcan, Lupeni, Uricani, Petrila, Rovinari and Turceni Energy Complexes. Contamination factor (CF), geoaccumulation index (Igeo), pollution load index (PLI), Nemerow pollution index (PI), potential ecological risk index (RI), were used to evaluate the quality of the Jiu River sediments. In sediments of the Jiu River there is low environmental risk upstream and downstream of Bumbeşti Jiu, a moderate ecological risk downstream of Petrila, a strong environmental risk downstream of Vulcan Mining, downstream of Uricani, downstream of Livezeni, upstream and downstream of Rovinari Energy Complex and downstream of Turceni Energy Complex, and a strong ecological risk downstream of Lupeni Mining, upstream of Uricani and upstream of Petrila.

Keywords: heavy metals, sediment, pollution index, assessment risk

Aquatic ecosystems have been affected by various types of contaminations around the globe in the recent few years. Traces metals are one of the most common pollutants which have severely deteriorated aquatic ecosystems [1-2].

Heavy metals in aquatic environment are distributed among aqueous phase, suspended particles and sediments. Suspended particles play an important role controlling the reactivity, transport and biological impacts of metals and other substances in aquatic environment and provide a crucial link for chemical constituents between water column, bed sediments and food chain [3].

Heavy metals are among the most persistent of pollutants in the ecosystem such as water, sediments and biota because of their resistance to decomposition in natural condition. Metal have low solubility in water, get adsorbed and accumulated on bottom sediments [4].

The increase the heavy metal content in the reservoirs is shown notably by increasing their concentration in bottom sediments. Accumulation of heavy metals in the environment results primarily from human activity. In addition, an important role in the "enrichment" heavy metal reservoirs they have natural processes, such as the disintegration of rocks and volcanic activities. Sediment is the ultimate destination for heavy metals discharged into the environment. The accumulation of heavy metals in sediment through physical and chemical mechanisms complexes of the adsorption, depending on the nature of the matrix of the sediment and the adsorption properties of the compounds [5 -6].

The lake sediments are basic components of our environments as they provide nutrients for living organism. Lake bottom sediments are sensitive indicators for monitoring contaminants as they can act as a sink and a carrier for pollutants in the aquatic environment. Thus, the lake sediment analysis plays an important role in evaluating pollution status in aquatic environment [7].

Sediment has widely been studied for anthropogenic impacts on the aquatic environment [8]. Various studies have reported sediment quality assessments, distribution and contamination of heavy metals and quantification of pollution load in sediments of different rivers such as the Haihe River, China [9], the Jialu River, China [10], the Lancang River, China [11], the Turag River, Banglades [12], the Hindon River, India [13], the Chao Phraya River, Thailanda [14], the Kurang River, Pakistan [8], the Euphrates River, Turcia [15], the Euphrates River, Iraq [16], the Olt River, Romania [17], the Danube River [18-19], water reservoirs Bakomi, Rozgrund, and Vindsachta, Slovakia [20].

The main aspects of the present work are to: determine to content and spatial distribution of heavy metals (Cd, Cu, Ni, Zn, Pb, Cr, Hg) in the Jiu River surface sediments; calculating the contamination factor (CF), the geo-accumulation index (Igeo), the pollution load index (PLI), the Nemerow pollution index (PI) and potential ecological risk (RI) in order to asses toxicity of the sediments.

Experimental part

Areas studied

Jiu River is formed by the union of the two streams, West Jiu and East Jiu, in the Petrosani Depression.

West Jiu has a length of 51km and a hydrographic basin area of 534 km^2, rises in the Retezat Mic at an altitude of 1760m, the glacial bucket to Scorota. West Jiu is bordered on the right the Vîlcan massif and left of Retezat. Due to the fact that during its limestone rocks are present, the river and its tributaries have dug impressive gorges and waterfalls. The most important tributaries on the right are Oslea, Gîrbovul and Valea of Peşti stooping over, and on the left Buta, Crevedia and Aninoasa.

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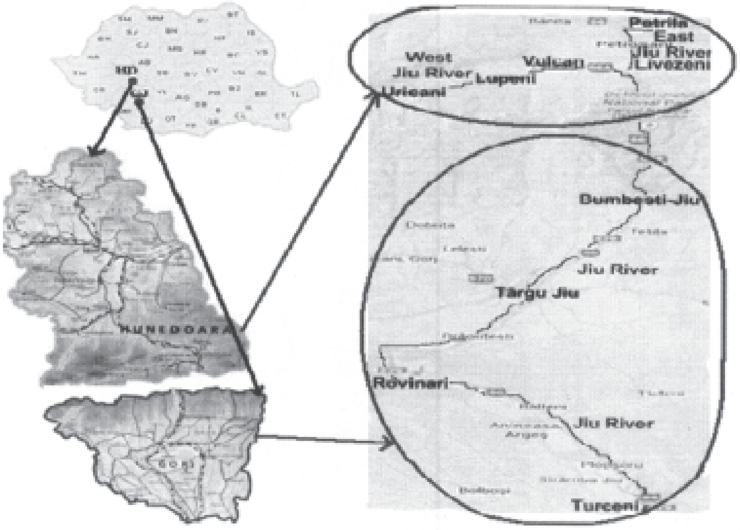

Fig. 1. Localization points

Table 1
SEDIMENT SAMPLING POINTS

Sample designation		Water samples - sampling point
S_1	Jiu River	sediment samples were harvested from the Jiu River, downstream of Bumbesti Jiu and upstream of Tg. Jiu
S_2		sediment samples were harvested from the Jiu River, upstream of Bumbesti Jiu and Downstream of Jiu Valley
S_3	West Jiu River	sediment samples were harvested from the West Jiu River, downstream of Mining Vulcan
S_4		sediment samples were harvested from the West Jiu River, upstream of Mining Vulcan and downstream of Mining Lupeni (Dam Paroseni)
S_5		sediment samples were harvested from the West Jiu River, upstream of Mining Lupeni and downstream of locality Uricani
S_6		sediment samples were harvested from the West Jiu River, upstream of locality Uricani
S_7	East Jiu River	sediment samples were harvested from the East Jiu River, downstream of locality Livezeni
S_8		sediment samples were harvested from the East Jiu River, downstream of locality Petrila and upstream of locality Livezeni
S_9		sediment samples were harvested from the East Jiu River, upstream of locality Petrila
S_{10}	Jiu River	sediment samples were harvested from the Jiu River, upstream of Rovinari Energy Complex
S_{11}		sediment samples were harvested from the Jiu River, downstream of Rovinari Energy Complex and upstream of Turceni Energy Complex
S_{12}		sediment samples were harvested from the Jiu River, downstream of Turceni Energy Complex

East Jiu has a length of 28 km and basin covers an area of 479 km^2. The river is born in the eastern part of the Petrosani Depression between Şureanul and Paring. Tributaries on the right are Răscoala, Voievodul, Bilele and Taia.

Jiu River flow regime is characterized by high waters in spring and early summer, when there are frequent floods, fed from the snowmelt and high rainfall, sometimes torrential. Jiu waters are used in the Petrosani Depression washing coal coke needed in the preparation and the Rogojelu, Turceni, Isalnita for power plants and chemical plant. Quarrying of lignite deposits in Rovinari imposed Ceauru Dam construction, the lake formed with the purpose to retain water and to prevent floods.

Sediment samples were collected in Mai 2014 from 12 sites distributed along the study area (fig.1) and (table 1).

Methods of analysis

Determination of metals

Sediments samples were collected into plastic bags, and preserved by adding a small amount of concentrated nitric acid. Samples were air-dried. The samples were mixed thoroughly to achieve homogeneity and were sieved (< 0.2 mm), as the case. For each digestion procedure, about 2 g of sample (dry weight) was transferred in to a digestion vessel, followed by addition of mixture consist in 5 mL HNO_3 (65%) and 15 mL HCl (38%). The sample is kept for 16 h at room temperature to permit slow oxidation of the organic matter from the sediment. Reaction mixture temperature is increased slightly until it reaches boiling point and is maintained for 2 h, then let cool. The resulted mixture is passed through filter paper and collected in a 100 mL flask. The filter paper was washed with HNO_3 0.5 M acid aqueous solutions. 100 mL flask is filled up to the mark with distilled water. Determination of the heavy metals in sediments was performed according to ISO 11466/1999 and ISO 11047/1999.

Quantification of sediment pollution

For assessment of the pollution degree with heavy metals in sediment four parameters have been used: Contamination factor (CF), Geo-accumulation index (I_{geo}), Pollution load index (PLI), Nemerow pollution index (PI) and the Ecological risk index (RI).

Contamination factor (CF)

The contamination factor (CF) was used to determine the contamination status of sediments and it is calculated as the ratio obtaind by dividing the concentration of each heavy metal in the sediment (C_{metal}) by the concentration in background (*Bn*) (eq.1). The concentrations in background for Cd, Ni, Cu, Pb, Zn, Cr and Hg are 0.1, 1.0, 1.0, 1.0, 23.6, 13.6, and 1.21 mg / kg, average of the samples S1, S2 and S10. Depending on its value, the sediment pollution degree is classified as shown in table 2.

$$CF = \frac{C_{metal}}{Bn} \qquad (1)$$

Table 2
CONTAMINATION LEVELS OF SEDIMENTS ACCORDING TO VALUES OF CONTAMINATION FACTOR

Contamination factor (CF)	Contamination level
CF<1	Low
1≤CF<3	Moderate
3≤CF<6	Considerable
CF>6	Very high

Table 3
RELATION BETWEEN I_{GEO} AND POLLUTION LEVEL

I_{geo} value	Class relative to I_{geo}	Pollution level
≤0	0	No polluted
0-1	1	No polluted to moderate polluted
1-2	2	Moderate polluted
2-3	3	Moderate to strong polluted
3-4	4	Strong polluted
4-5	5	Strong to very strong polluted
>5	6	Very strong polluted

Table 4
NEMEROW POLLUTION INDEX SEDIMENT QUALITY INDICATORS

PI value Qualification of sediment	PI value Qualification of sediment
PI < 0.7	Non-polluted sediment
0.7 < PI < 1	Nearly polluted sediment
1 < PI < 2	Lightly polluted sediment
2 < PI < 3	Moderately polluted sediment
3 < PI	Seriously polluted sediment

Table 5
GRADE STANDARD OF (Ef) AND (RI) [7]

Pollution coefficient (Ef)	Pollution index (RI)	Pollution level
<40	<150	Light ecological risk
40-79	150-299	Middle ecological risk
80-159	300-600	Strong ecological risk
160-320	>600	Very strong ecological risk
>320	-	Extremely strong ecological risk

Geo-accumulation index (Igeo)

Geo-accumulation index to determine metals contamination in sediments and can be calculated using the following formula (2):

$$I_{geo} = \log_2\left[\frac{C_n}{1.5B_n}\right] \qquad (2)$$

where:

C_n is the concentration of element „n";
B_n is the background value in sediment.

Pollution load index (PLI)

Pollution load index (PLI) is calculated as the following equation (3):

$$PLI = (CF1\times CF2\times CF3\times ....CFn)^{1/n} \qquad (3)$$

where, „n" is the number of metals, *CF* is contamination factor.

The PLI provides simple bat comparative means for assessing a site quality, where a value of PLI < 1 denotes perfection; PLI = 1 presents that only baseline levels of pollutants are presented and PLI > 1 would indicate deterioration of site quality.

Nemerow pollution index (PI)

The Nemerow pollution index [21], (PI; eq. 4) was used to determine whether or not sampling sites were polluted in comparison with the criteria given in table 4.

$$PI = \sqrt{\frac{(\overline{CF})^2 + (CF\max)^2}{2}} \qquad (4)$$

(5)

Potential ecological risk (RI)

In 1980, Lars Hakanson reported an ecological risk index for aquatic pollution control; therefore, Hakanson' method has been often used in ecological risk assessment as a diagnostic tool to penetrate one of many possible avenues towards a potential ecological risk index, *i.e.*, to sort out which drainage area, reservoir, and substances should be given special attention (tables 5- 6) [1, 9, 12, 22].

The index is calculated as the following equations (5) - (9):

$$CF = \frac{C_{metal}}{Bn} \qquad (5)$$

$$CH = \sum_{i=1}^{n} CF \qquad (6)$$

$$mCH = \frac{\sum_{i=1}^{n} CF}{n} \qquad (7)$$

$$Ef = Tf \times CF \qquad (8)$$

$$RI = \sum_{i=1}^{n} Ef \qquad (9)$$

where:

CF is the contamination factor;
C_H is the polluted coefficient of many metals;
mC_H is the modified degree of contamination factors;
E_f is the potential ecological risk factor of single metal;
T_F is the biological toxicity factor of individual metals, which are defined as Cd=30, Cr=2, Cu=Ni=Pb=5, Zn=1, Hg=40 [14, 21].

Results and discussions

Heavy metal concentration in sediments

To assess the contamination degree of sediments in the studied area, samples were collected from the upper layer of sediment, in twelve points.

Table 6 shows the concentrations of heavy metals in sediments of the Jiu River, West Jiu River and East Jiu River. The results were compared with the national legislation regulations (table 7) [23].

The concentration range of metals in sediments is: 17.53 to 89.43 mg/kg d.w. for Ni, 2.35 to 34.34 mg/kg d.w. for Cu, 8.73 to 49.06 mg/kg d.w. for Cr, 16.93 to 145.05 mg/kg d.w., 0.42 to 10.64 mg/kg d.w. for Hg and 1.59 to 1.84 mg/kg d.w. for Cd. Higher concentrations of Ni were found in sediments of the points S5 (downstream of locality Uricani), S6 (upstream of locality Uricani) and S9 (upstream of locality Petrila) while higher concentrations of Cd was found in sediments of the points S4 (downstream of Mining Lupeni), S5 (downstream of locality Uricani) and S6 (upstream of locality Uricani). Hg was found in higher concentrations than the limit imposed by legislation, in all points analyzed.

Assessment of sediment contamination

For assess the heavy metal pollution of sediments were used parameters: the contamination factor (CF), the

Sample designation		pH	Cr	Ni	Cu	Zn	Cd	Hg	Pb
		Quality indicators analyzed							
S1	Jiu River	8.07	10.56	<1.0*	<1.0*	24.9	<0.1*	**0.42**	<1.0*
S2		8.14	20.35	<1.0*	<1.0*	25.9	<0.1*	**2.22**	<1.0*
S3	West Jiu River	8.43	8.73	<1.0*	20.6	46.5	<0.1*	**5.18**	<1.0*
S4		6.05	10.1	31.93	13.0	23.72	**1.79**	**6.34**	29.84
S5		7.88	9.0	**53.0**	<1.0*	24.10	**1.59**	**0.86**	<0.1*
S6		7.82	10.36	**89.43**	<1.0*	31.23	**1.84**	**10.64**	<0.1*
S7	East Jiu River	7.75	33.25	18.6	13.3	65.23	<0.1*	**1.97**	30.56
S8		7.8	31.33	17.53	22.95	145.05	<0.1*	**1.06**	<0.1*
S9		7.68	49.06	**35.88**	2.35	124.0	<0.1*	**1.3**	64.0
S10	Jiu River	7.89	9.9	<1.0*	<1.0*	20.0	<0.1*	**1.0**	<1.0*
S11		7.92	21.11	<1.0*	34.34	16.93	<0.1*	**1.16**	<1.0*
S12		7.86	10.26	18.49	24.2	34.3	<0.1*	**1.18**	<1.0*

Table 6
THE CONTENT OF METALS IN SEDIMENTS OF THE JIU RIVER, WEST JIU RIVER AND EAST JIU RIVER (mg/kg d.w.)

Indicators analyzed	U.M.	Standard limit value
Ni	mg/kg d.w.	35
Cd	mg/kg d.w.	0.8
Cu	mg/kg d.w.	40
Pb	mg/kg d.w.	85
Zn	mg/kg d.w.	150
Cr	mg/kg d.w.	100
Hg	mg/kg d.w.	0.3

Table 7
STANDARD LIMIT VALUES IMPOSED BY ORDER NO. 161/2006

Table 8
CONTAMINATION FACTOR (CF) FOR HEAVY METALS IN SEDIMENTS OF THE JIU RIVER

Sample designation	Cr		Ni		Cu		Zn		Cd		Hg		Pb	
	CF	Level	CF	Level	CF	Level	CF	Level	CF	Level	CF	Level	CF	Level
S1	0.77	<1	1.0	1<CF<3	1.0	1<CF<3	1.05	1<CF<3	1.0	1<CF<3	0.35	<1	1.0	1<CF<3
S2	1.5	1<CF<3	1.0	1<CF<3	1.0	1<CF<3	1.1	1<CF<3	1.0	1<CF<3	1.8	1<CF<3	1.0	1<CF<3
S3	0.64	<1	1.0	<1	20.6	CF>6	1.97	1<CF<3	1.0	1<CF<3	4.28	3<CF<6	1.0	1<CF<3
S4	0.74	<1	31.93	CF>6	13.0	CF>6	1	<1	17.9	CF>6	5.24	3<CF<6	29.8	CF>6
S5	0.66	<1	53	CF>6	1	<1	1.02	1<CF<3	15.9	CF>6	0.71	<1	1	1<CF<3
S6	0.76	<1	89.43	CF>6	1	<1	1.32	1<CF<3	18.4	CF>6	8.79	CF>6	1	1<CF<3
S7	2.44	1<CF<3	18.6	CF>6	13.3	CF>6	2.76	1<CF<3	1	<1	1.63	1<CF<3	30.5	CF>6
S8	2.3	1<CF<3	17.53	CF>6	22.9	CF>6	6.15	CF>6	1	<1	0.87	<1	1	1<CF<3
S9	3.61	3<CF<6	35.88	CF>6	2.35	1<CF<3	5.25	3<CF<6	7.48	CF>6	1.1	1<CF<3	64	CF>6
S10	0.73	<1	1	<1	1	<1	0.85	<1	11.3	CF>6	0.83	<1	1	1<CF<3
S11	1.55	1<CF<3	1	<1	34.3	CF>6	0.72	<1	7.5	CF>6	0.96	<1	1	1<CF<3
S12	0.75	<1	18.49	<1	24.2	CF>6	1.45	1<CF<3	9.9	CF>6	0.98	<1	1	1<CF<3

geoacumulation Index (Igeo), the ecological risk index (RI), the pollution load index (PLI) and Nemerow pollution index (PI).

Contamination factor (CF)

In sediments from the Jiu River, there was a moderate contamination with Ni, upstream and downstream of Bumbeşti Jiu (S1 and S2), with Zn upstream and downstream of Bumbeşti Jiu (S1 and S2), downstream of Vulcan Mining (S3), upstream of Uricani (S6), downstream of Livezeni (S7) and downstream of Turceni Energy Complex (S12), with Cd in upstream and downstream of Bumbeşti Jiu (S1 and S2), downstream of Vulcan Mining (S3), with Hg upstream of Bumbeşti Jiu (S1) and downstream of Livezeni (S7), with Cr upstream of Bumbeşti Jiu (S1), upstream and downstream of Livezeni (S7 and S8) and downstream of Rovinari Energy Complex, with Pb upstream and downstream of Bumbeşti Jiu (S1 and S2), downstream of Vulcan Mining (S3), upstream and downstream of Uricani (S6 and S5), downstream of Petrila (S8), upstream and downstream of Energy Complex Rovinari (S10 and S11) and downstream Energy Complex Turceni (S12). A considerable contamination with Hg was found downstream of Mining Vulcan and Lupeni (S3 and S4), with Cr and Zn upstream of Petrila (S9). A very high contamination with Ni was found upstream and downstream of Lupeni (S4 and S5), upstream of Uricani (S6), upstream and downstream of Petrila (S8 and S9) and downstream of Livezeni (S7), with Cu downstream of Vulcan and Lupeni Mining (S3 and S4), downstream of Livezeni and Petrila (S7 and S8), with Zn downstream of Petrila (S8), with Cd upstream and downstream of Lupeni (S4 and S5), upstream of Uricani (S6), upstream of Petrila, upstream and downstream of Rovinari Energy Complex (S10 and S11) and downstream of Turceni Energy Complex (S12), with Hg upstream of Uricani (S6), with Pb downstream of Lupeni (S4), downstream of Livezeni (S7) and upstream of Petrila (S9) (table 8).

Geo-accumulation index (Igeo)

From the calculation of Geo-accumulation index (Igeo), in the sediments of Jiu River, Cr ranged from Class 0-2 with a level of pollution from unpolluted to moderately polluted, Ni with pollution levels unpolluted (Class 0) in the upstream and downstream Bumbeşti Jiu, downstream of Vulcan Mining, upstream and downstream of Rovinari Energy Complex, a strong polluted levels (Class 4) downstream of Livezeni and downstream of Petrila, a strong to very strong polluted (Class 5) downstream of Lupeni Mining and upstream of Petrila, a very strong polluted (Class 6) upstream and downstream of Uricani. Cu with a level of pollution polluted (Class 0) upstream and downstream of Bumbeşti Jiu, upstream and downstream of Uricani, upstream of Petrila and upstream of Rovinari Energy Complex, a strong polluted levels (Class 4) downstream of Lupeni and Vulcan Mining, downstream of Livezeni, downstream of Petrila and downstream of Energy Complex Rovinari and a strong to very strong polluted (Class 5) downstream of Turceni Energy Complex. Zn with pollution levels in unpolluted (Class 0) at moderate to strong polluted (Class 3) downstream of Petrila, Cd pollution levels in unpolluted (Class 0) to a strong polluted levels (Class 4) downstream of Lupeni Mining, upstream and downstream of Uricani, Hg with a moderate polluted (Class 2), downstream of Vulcan and Lupeni Mining and a moderate to strong polluted (Class 3) upstream of Uricani and downstream of Turceni Energy Complex while Pb a strong to very strong polluted (Class 5) downstream of Lupeni

Table 9
GEO-ACCUMULATION INDEX (I_{GEO}) FOR HEAVY METALS IN SEDIMENTS OF THE JIU RIVER

Sample designation	Cr		Ni		Cu		Zn		Cd		Hg		Pb	
	I_{geo}	Class	I_{geo}	Class	I_{geo}	Class	I_{geo}	Class	I_{geo}	Class	I_{geo}	Class	I_{geo}	Class
S1	-0.9	0	-0.58	0	-0.58	0	-0.51	0	-0.58	0	-2.11	0	-0.58	0
S2	-0.003	0	-0.58	0	-0.58	0	-0.45	0	-0.58	0	0.29	**1**	-0.58	0
S3	-1.22	0	-0.58	0	3.77	**4**	0.39	0	-0.58	0	1.51	**2**	-0.58	0
S4	-1.01	0	4.41	**5**	3.11	**4**	-0.57	0	3.57	**4**	1.8	**2**	4.3	**5**
S5	-1.18	0	5.14	**6**	-0.58	0	-0.55	0	3.4	**4**	-1.07	**1**	-0.58	0
S6	-0.97	0	5.9	**6**	-0.58	0	-0.18	0	3.61	**4**	2.55	**3**	-0.58	0
S7	0.7	**1**	3.63	**4**	3.15	**4**	0.88	**1**	-0.58	0	0.118	**1**	4.35	**5**
S8	0.62	**1**	3.55	**4**	3.93	**4**	2.03	**3**	-0.58	0	-0.77	0	-0.58	0
S9	1.27	**2**	4.58	5	0.65	0	1.8	**2**	2.32	0	-0.48	0	5.41	**6**
S10	-1.04	0	-0.58	0	-0.58	0	-0.82	0	2.91	0	-0.86	0	-0.58	0
S11	-2.8	0	-0.58	0	4.52	**5**	-1.1	0	2.32	0	-0.64	0	-0.58	0
S12	-0.99	0	3.63	**4**	4.0	**4**	0.455	**1**	-0.04	0	2.72	**3**	-0.58	0

Sample designation	PLI	Pollution level	PI	Pollution level
S1	0.83	Unpolluted	0.97	Unpolluted
S2	**1.16**	**Polluted**	1.55	Lightly polluted
S3	**1.93**	**Polluted**	**14.88**	**Seriously polluted**
S4	**6.78**	**Polluted**	**24.72**	**Seriously polluted**
S5	**2.31**	**Polluted**	**38.2**	**Seriously polluted**
S6	**3.83**	**Polluted**	**64.4**	**Seriously polluted**
S7	**4.88**	**Polluted**	**22.74**	**Seriously polluted**
S8	**3.29**	**Polluted**	**17.05**	**Seriously polluted**
S9	**6.73**	**Polluted**	**46.8**	**Seriously polluted**
S10	**1.28**	**Polluted**	**8.16**	**Seriously polluted**
S11	**2.2**	**Polluted**	**24.74**	**Seriously polluted**
S12	**3.27**	**Polluted**	**18.04**	**Seriously polluted**

Table 10
POLLUTION LOAD INDEX (PLI) AND NEMEROW INDEX (PI) FOR HEAVY METALS FROM SEDIMENTS OF THE JIU RIVER

Sample designation	Cr	Cu	Zn	Cd	Hg	Pb	RI	Grade Hakanson pollution level
	E_f	E_f	E_f	E_f	E_f	E_f		
S1	1.55	5	1.05	30	13.88	5.0	56.5	Light ecological risk
S2	2.99	5	1.09	30	73.4	5.0	117.5	Light ecological risk
S3	1.28	**103**	1.97	30	**171.23**	5.0	**312.5**	**Strong ecological risk**
S4	1.49	65	1.0	**537**	**209.6**	**149.2**	**963.3**	**Very strong ecological risk**
S5	1.32	5	1.02	**477**	28.45	5.0	**517.7**	**Strong ecological risk**
S6	1.52	5	1.32	**552**	**351.7**	5.0	**916.58**	**Very strong ecological risk**
S7	4.88	66.5	2.76	30	**65.12**	**152.8**	**322.1**	**Strong ecological risk**
S8	4.6	**114.75**	6.15	30	35.0	5.0	195.54	**Middle ecological risk**
S9	7.21	11.75	5.25	**224.4**	42.97	**320.0**	**611.0**	**Very strong ecological risk**
S10	1.45	5	0.85	**339.0**	33.05	5.0	**384.4**	**Strong ecological risk**
S11	3.1	**171.7**	0.17	**225.0**	38.35	5.0	**443.4**	**Strong ecological risk**
S12	1.5	**121.0**	1.45	**297.0**	39.1	5.0	**465.0**	**Strong ecological risk**

Table 11
ECOLOGICAL RISK INDEX FOR HEAVY METALS FROM SEDIMENTS OF THE JIU RIVER

SEDIMENT	CR	NI	CU	ZN	CD	HG	PB
Cr	1						
Ni	-0.03194	1					
Cu	0.051625	-0.35709	1				
Zn	**0.79352**	0.056605	0.128387	1			
Cd	-0.40804	**0.80393**	-0.31487	-0.31103	1		
Hg	-0.31069	**0.63829**	-0.12704	-0.19495	**0.66969**	1	
Pb	**0.73107**	0.167371	-0.17486	0.48251	-0.00629	-0.0209	1

Table 12
METAL-TO-METAL CORRELATION COEFFICIENT MATRIX FOR METALS IN SEDIMENT SAMPLES

Mining and downstream of Livezeni and a *very strong polluted* (Class 6) upstream of Petrila (table 9).

Pollution load index (PLI)

Regarding of pollution load index (PLI), PLI >1, in the most of the points, indicating polluted sediments, except in the downstream of Bumbeşti Jiu, value are less than 1 (PLI< 1), indicating no pollution (table 10).

Nemerow pollution index (PI)

From the calculation the Nemerow index (PI) was found a level of pollution "unpolluted" downstream of Bumbeşti Jiu, pollution levels "lightly contaminated" upstream of Bumbeşti Jiu and pollution levels "seriously polluted" downstream of Lupeni and Vulcan Mining, upstream and downstream of Uricani, downstream of Livezeni, upstream and downstream of Petrila, upstream and downstream of Rovinari Energy Complex and downstream of Turceni Energy Complex (table 10).

Potential ecological risk (RI)

In sediments from the Jiu River it was found a *small ecological risk* upstream and downstream of Bumbeşti Jiu, *a moderate ecological risk* downstream of Petrila, *a strong ecological risk* downstream of Vulcan Mining, downstream of Uricani, downstream of Livezeni, upstream and downstream of Rovinari Energy Complex and downstream of Turceni Energy Complex and a *strong ecological risk* downstream of Lupeni Mining, upstream of Uricani and upstream of Petrila (table 11).

Correlation of metals

Pearson's correlation coefficients for the investigated metals are depicted in table 12. In sediment samples the best correlations were found for the following pairs of metals: Zn-Cr (r=0.79352), Cd-Ni (r=0.80393), Hg-Ni (r=0.63829), Hg-Cd (r=0.669069), Pb-Cr (r=0.73107). These correlations among metal-metal pair may be an indication of common sources of these metals as well as similar geochemical characteristics. It is observed a positive correlation Cd - Ni, Cd - Hg and negative correlation Cd - Cr, Cd - Cu, Cd - Zn and Cd - Pb, and a positive correlation Hg - Ni, Hg - Cd and negative correlation Hg - Cr, Hg - Cu, Hg - Zn and Hg - Pb.

Conclusions

In sediments of the Jiu River from the calculation of pollution load index (PLI) was found a heavy metal pollution in most points, except point downstream of Bumbesti Jiu where the PLI < 1 where no was found pollution with heavy metals analyzed. From the calculation the Nemerow index (PI) was found a level of pollution "unpolluted" downstream of Bumbeşti Jiu, pollution levels "lightly contaminated" upstream of Bumbesti Jiu and pollution levels "seriously polluted" downstream of Lupeni and Vulcan Mining, upstream and downstream of Uricani, downstream of Livezeni, upstream and downstream of Petrila, upstream and downstream of Rovinari Energy Complex and downstream of Turceni Energy Complex. In sediments of the Jiu River there is low environmental risk upstream and downstream of Bumbeşti Jiu, a moderate ecological risk downstream of Petrila, a strong environmental risk downstream of Vulcan Mining, downstream of Uricani, downstream of Livezeni, upstream and downstream of Rovinari Energy Complex and downstream of Turceni Energy Complex, and a strong ecological risk downstream of Lupeni Mining, upstream of Uricani and upstream of Petrila.

Acknowledgements: The authors acknowledge the financial support from the Ministry of Education- State Authority for Research Scientific, technological development and innovation through the Proiect PN 09-13 02 17, "The environmental risk assessment with the pollution indices" and the sectoral Operational Programme Human Resources Development (SOP HRD), financed from European Social Fund and the Romanian Government under the contract number POSDRU/159/1.5/S/137390.

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Manuscript received: 12.11.2014