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Evaluation of heavy metals pollution in recent sediments of Zoubia Wadi, W-Skikda (NE of Algeria)

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Summary

This study aims to evaluate the level of metallic pollution in the recent sediments of the Zoubia area (Aïn Kechera) in north-east of Algeria. The method used for this assessment involves sediments sampling and the determination of heavy metal concentrations. The study estimated the level of metallic pollution in the sediments by calculating several pollution indexes, including the contamination factor (CF), the enrichment factor (FE), the geo-accumulation index (I_{geo}), the individual ecological risk index (), the potential ecological risk (RI) and statistical analysis of the data. The study monitored seven trace metals: cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn) and copper (Cu). The results indicate an enrichment of Cd, Pb, Zn, and Cu in all samples. However, Ni, Co, and Cr levels are below those of the continental crust (background). The geo-accumulation index values for Co, Ni, and Cr are negative in all samples. On the other hand, positive geo-accumulation index values were observed for Cd, Pb, Zn, and some Cu samples (B1, B2, B3, and B4) with individual ecological risks of less than 40 for Cd, (94.48–119.21) for Zn, and (80.23–135.4) for Cu, respectively. This indicates low risk for Cd and high risk for Zn and Cu. The results indicate that Pb poses a significant ecological risk (537.4–842.05) and may have adverse effects on human health. The most significant pollutants, in order of increasing risk, are Pb, Cu, Zn, and Cd.

Keywords

Zoubia • Northeast Algeria • recent sediments • heavy metals • pollution indexes

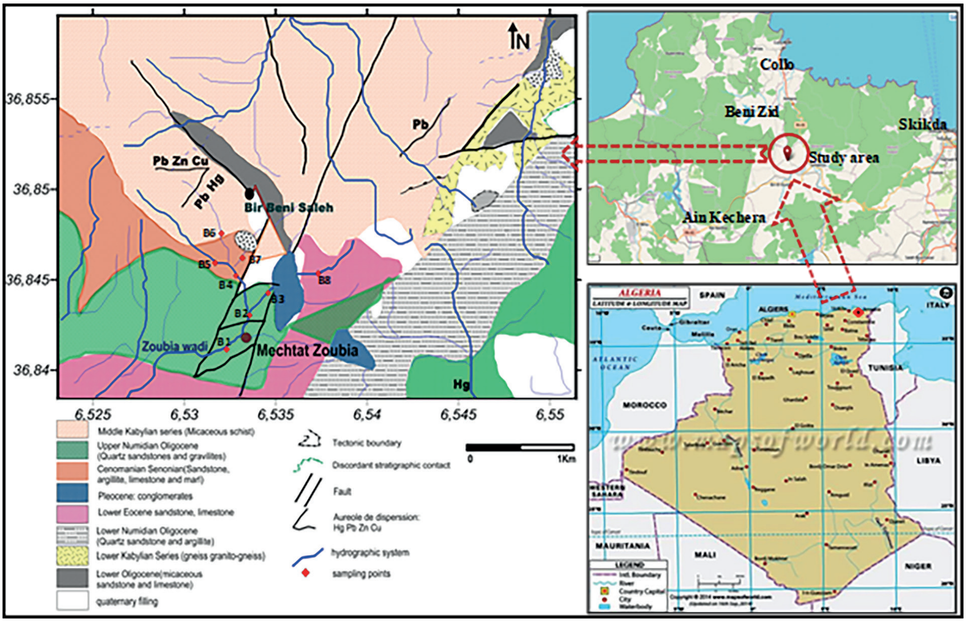
1. Introduction

The study area is located within the Kabylie metallogenic zone of Collo and El Milia [Bolfa 1942], which contains several metalliferous deposits and showings, such as the Zoubia, Boudoukha, Sidi Kambar, and Aïn Sedma mines. The Bir Beni Salah polymetallic mine was discovered in 1877 and operated until 1942, when only the mercury (Hg)-rich parts of the mine were mined and four veins were exploited. After 1942, the mine was completely abandoned, leaving behind ore processing waste that remained on site for decades. This waste can contaminate sediments and water with heavy metals, which can enter in the human food chain and cause health problems [Sin et al. 2001, Yuan et al. 2011, Zhu et al. 2013, Ahmed et al. 2015, Suresh et al. 2015, Malvandi 2017, Chatterjee et al. 2007, Boucenna et al. 2023]. Cancerous diseases have started to spread in this area and neighbouring regions. One possible cause is the presence of the open-pit mine. Heavy metals in running water are periodically redistributed and can accumulate in sediments, potentially becoming pollutants [Ghrefat and Yusuf 2006]. The increase in population in the study area, along with the expansion of agricultural land into the mine area and the intensification of fertilizer and pesticide use, may worsen the condition of sediment and water resources. This study aims to evaluate sediment contamination by trace metals resulting from the weathering of ores exposed to the open air for several years and to estimate the ecological risk posed by these sediments. The elements monitored in this study are Cd, Cr, Co, Ni, Pb, Zn, and Cu. Although the Bir Beni Salah mine was used to extract mercury (Hg), its levels found in some samples are quite low, in the order of 10–5 ppm. However, there is still work to be done in the region, particularly downstream (Zoubia zone) where the flat terrain facilitates the accumulation of heavy metals. It is important to note that the population density is higher in the downstream part of the study area.

2. Presentation of the study area

The study area is situated 16 km south of Collo and 12 km northeast of Aïn Kechera town (W/Skikda). It is bounded to the north by the El Guebli wadi and to the west by the El Kabir wadi. The region has a Mediterranean climate, with a hot, dry summer and an average temperature of 25°C, and a rainy winter with abundant, very irregular rainfall of 1200 mm/year. Furthermore, the area is distinguished by its rugged mountainous terrain and dense, diverse vegetation. The total population of the region exceeds 8000 and is scattered in small settlements around the mine. The primary occupations of the inhabitants are agriculture and animal husbandry.

The study area is located inside the metamorphic formations of the Beni-Ferguène edifice (Fig. 1), which extends from the Sidi Abd El Aziz and Beni Bel Aïd regions in the west to the Kerkera region (south of Collo) in the east. The edifice is composed of three sub-units arranged from bottom to top. The upper sub-unit is paragneissic and contains feldspathic mica schist or fine gneiss that is intersected by amphibolite sils. The intermediate sub-unit is metapelitic and contains multi-metric blades of eyed orthogneiss and sillimanite granite. The lower sub-unit is formed by alternating light and dark metapelites, pyroxenite lenses, and fine-grained granite. This edifice has a unique characteristic of having two metamorphisms, M1 (BP) and M2 (HP), and two major deformations, D1 and D2 [Mahdjoub 1991]. The sedimentary facies consists of two strata. The upper stratum, formed of quartz sandstones, gravilites, argillites, marls, and limestones of Cenomanian-Senonian age, is of Oligocene age. The lower stratum consists of argillites, quartz sandstones of Oligocene age, and limestones of Lower Eocene age. The Zoubia region geology is dominated by two facies: a sedimentary facies (cover) and a metamorphic facies. The metamorphic facies consists of gneiss, granito-gneiss, and micaceous schists. The study area is affected by several thrust-type tectonic movements and NW-SE and NE-SW faults (Fig. 1).



Source: Authors' own study

Fig. 1. The geographical situation and geological formations of the study area

Geologically, the study area is located in the metamorphic formations of the Beni-Ferguène edifice (Fig. 1). From bottom to top, this building is composed of a stack of three sub-units: (a) an upper paragneissic sub-unit (feldspathic mica schist or fine gneiss) cut by amphibolite sills, (b) an intermediate metapelitic sub-unit interspersed with multi-metric blades of eyed orthogneiss and sillimanite granite, (c) a lower sub-unit formed by alternating light and dark metapelites, pyroxenite lenses and fine-grained granite. A special feature of this structure is the superposition of two metamorphisms, M1 (BP) and M2 (HP), and two major deformations, D1 and D2 [Mahdjoub 1991]. The geology of the Zoubia mine is dominated by two facies, a sedimentary facies (cover) consisting of two strata: an upper Oligocene stratum consisting of quartz sandstones, gravilites and argillites, marls and limestones of Cenomanian-Senonian age, and a lower stratum consisting of argillites, Oligocene quartz sandstones and Lower Eocene limestones. The metamorphic facies consists of gneisses, granitic gneisses and micaceous schists. The study area is affected by numerous thrust-type tectonic movements and NW-SE and NE-SW faults (Fig. 1).

3. Materials and methods

This study is based on samples taken at a depth of 10 cm. Eight representative samples were selected for analysis. Prior to chemical analysis, the samples were physically prepared in the laboratory. This involved oven-drying the samples at 40°C for 24 hours, gently hand-grinding them with an agate mortar, homogenizing, and finally dry-sieving. The fraction retained for chemical analysis was (Ø < 63 μm).

Chemical analyses of heavy metals were conducted using a ThermoFisher X7 ICP/MS (Inductively Coupled Plasma-Mass Spectrometry) following the SARM (Service d'Analyse des Roches et Minéraux) instructions. Sample preparation included fine grinding, filtration at 0.2 μm, and acidification with 2% nitric acid. A minimum quantity of 1g was used.

4. Results and discussion

Table 1 displays the concentrations of heavy metals in sediments from the Zoubia region. The results indicate significant levels of certain heavy metals, which are considered to be polluting elements in relation to the reference (UCC).

Table 1. Concentration of heavy elements in each sample (ppm)

Sample	B1	B2	B3	B4	B5	B6	B7	B8
Cd	0.36	0.33	0.25	0.29	0.2	0.19	0.17	0.12
Co	1.32	1.41	1.28	1.77	1.75	1.68	1.74	2.08
Cr	21.70	20.75	19.03	20.14	19.62	18.87	19.58	18.02
Ni	7.03	8.14	9.28	7.92	6.78	6.27	7.09	6.32
Pb	168.41	113.56	147.08	132.15	118.37	107.48	127.22	116.3
Zn	119.21	111.65	116.01	107.14	101.46	98.35	94.48	102.68
Cu	27.08	23.78	25.94	21.66	18.95	17.01	15.89	16.04

4.1. Assessment of heavy metals contamination

The study area's sediment contamination by heavy metals was assessed using various indices, including contamination factor (CF), enrichment factor (EF), geo-accumulation index (I_{geo}), and potential ecological risk index (RI). To estimate the level of sediment contamination in the study area (Table 2), this study used the continental crust values (UCC) from Wedepohl [1995].

4.1.1. Contamination factor (CF)

The contamination factor (CF) is a tool used to determine the degree of pollution in an environment. In this study, we use the contamination factor proposed by Wedepohl in 1997 to assess the degree of pollution in the sediment near the Bir Beni Salah mine caused by Cd, Co, Cr, Pb, Zn and Cu. The contamination factor is calculated using formula (1):

$$CF = Cm / Bm \tag{1}$$

The contamination factor (CF) is calculated using the concentration of metal in the sample (Cm) and the concentration of metal in the ground crust (Bm) (background), as described by Hakanson in 1980.

The CF is classified into four categories:

1) $CF < 1$ indicates low contamination,
2) $1 \leq CF \leq 3$ indicates moderate contamination,
3) $3 \leq CF \leq 6$ indicates high contamination,
4) $CF \geq 6$ indicates very high contamination.

Table 2 shows the results of the contamination factor (CF). The results indicate low levels of Ni, Co, and Cr contamination in all samples (CF < 1). However, Cd contamination varies across samples, with moderately high levels in samples B3, B4, B5, B6, B7, and B8 (CF values ranging between 1.2 and 2.9) and very high levels in samples B1 and B2 (CF values ranging between 3.3 and 3.6). Pb contamination is classified as very high in all samples, with FC values greater than 6. Cu and Zn are considered moderate contaminants, with FC values ranging from (1.11 to 1.89) and (1.81 to 2.29) respectively.

Table 2. Contamination factor (CF) values in sediments of the study area

Sample	B1	B2	B3	B4	B5	B6	B7	B8
Cd	3.6	3.3	2.5	2.9	2.0	1.9	1.7	1.2
Co	0.11	0.12	0.11	0.15	0.15	0.14	0.15	0.18
Cr	0.62	0.59	0.54	0.57	0.56	0.53	0.55	0.51
Ni	0.37	0.43	0.49	0.42	0.36	0.33	0.38	0.34
Pb	9.91	6.68	8.65	7.77	6.96	6.32	7.48	6.84
Zn	2.29	2.14	2.23	2.06	1.95	1.89	1.81	1.97
Cu	1.89	1.66	1.81	1.52	1.32	1.19	1.11	1.12

4.1.2. Enrichment factor (EF)

Enrichment factor (EF) is used to evaluate the increase in the concentration of metallic chemical elements in the sediment of the study area. Iron is used as the normalizing element for calculating the enrichment factor. It is calculated using the formula (2) from Kartal et al. [2006] and Grygar and Popelka [2016].

$$EF = (M/Fe)_{sample} / (M/Fe)_{background} \tag{2}$$

Sutherland [2000] identified five classes of FE:

1) non-existent or weak enrichment for FE values less than 2,
2) moderate enrichment for FE values between 2 and 5,
3) significant enrichment for FE values between 5 and 20,
4) very strong enrichment for FE values between 20 and 40,
5) extreme enrichment for FE values greater than 40.

Table 3 shows the results of the enrichment factor (EF). The data indicates that the sediments are not enriched in Co, but are moderately enriched in Cr for all samples. Ni enrichment was moderate in samples B1, B2, B3, B4 and B5, but significant in samples B6, B7 and B8 ($5 < EF < 20$). For Cd, enrichment varies between very high enrichment for samples B1 and B2 ($20.1 \leq FE \leq 23.33$) and significant enrichment for the rest of the samples (B3, B4, B5, B6, B7 and B8). Pb was highly enriched in most samples ($EF > 40$), with B2, B3, and B8 showing lower or close to 40 enrichment ($36.87 > EF < 39.93$), indicating very high enrichment. For Zn and Cu, the enrichment factor values are ($9.31 \leq FE \leq 14.61$) and ($5.36 \leq FE \leq 11.54$) respectively, indicating significant enrichment. The origin of lead, zinc, and copper in this region is mixed, with both anthropogenic and natural sources. The Zoubia mine is responsible for the anthropogenic source, while the natural source is due to the alteration of rocks containing these ores. However, the natural origin dominates in this metalliferous zone.

Table 3. Enrichment factor (EF) values in sediments of study area

Sample	B1	B2	B3	B4	B5	B6	B7	B8
Cd	23.33	20.1	13.33	16.33	10.0	6.66	10.66	6.0
Co	0.68	0.68	0.51	0.69	0.75	0.69	0.88	0.86
Cr	3.81	3.37	2.59	2.61	2.83	2.60	3.36	2.52
Ni	2.33	2.42	2.31	1.89	1.79	8.63	12.2	8.83
Pb	60.0	36.87	39.93	41.04	40.84	35.4	52.18	38.89
Zn	14.61	12.46	10.82	9.56	10.08	9.31	11.14	9.87
Cu	11.54	9.23	8.41	6.72	6.53	5.61	6.51	5.36

4.1.3. Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) was introduced by Müller in 1981 to assess the intensity of sediment pollution. Table 4 summarizes the I_{geo} classes, ranging from natural concentrations (absence of pollution) to highly polluted sediments. Formula 3 is used to calculate the geo-accumulation index.

$$I_{geo} = \log_2 Cn / 1.5 \cdot Bn \tag{3}$$

where:
I_{geo} – geo-accumulation index,
Cn – concentration of the element in the sediment,
Bn – reference concentration (geochemical background) for the element,
1.5 – background exaggeration constant.

Table 4. Classification of Geo-accumulation index

Class	Geo-accumulation index	Intensity of contamination
0	$I_{geo} \leq 0$	No contamination
1	$0 < I_{geo} < 1$	Not contaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Slightly contaminated
3	$2 < I_{geo} < 3$	Moderately to highly contaminated
4	$3 < I_{geo} < 4$	Highly contaminated
5	$4 < I_{geo} < 5$	Highly to extremely contaminated
6	$I_{geo} < 5$	Extremely contaminated

Source: Müller [1969]

Table 5 shows the results of the geo-accumulation index calculations. The I_{geo} values for Ni, Cr, and Co are consistently below zero, indicating no sediment contamination by any of these metals ($I_{geo} < 0$). Cu also has I_{geo} values below zero, but only for samples B5, B6, B7, and B8, indicating no Cu sediment pollution. For samples B1, B2, B3, and B4, I_{geo} values range from 0.01 to 0.27, classifying them as non-contaminated to moderately contaminated. The I_{geo} values for Pb range from 0.58 to 2.52, indicating moderate to high contamination for most samples. However, sample B1 is classified as uncontaminated to moderately contaminated. Cd levels fluctuated, with I_{geo} values indicating moderate contamination for samples B3, B4, B5, B6, and B7, and uncontaminated to moderately contaminated for samples B1 and B2. Sample B8 was not contaminated. Zn levels were classified as uncontaminated to moderately contaminated for all samples.

Table 5. Index values (I_{geo}) for the various samples and for each heavy metal

Geo-accumulation index (GEO) values							
Sample	**Cd**	**Co**	**Cr**	**Ni**	**Pb**	**Zn**	**Cu**
B1	1.23	−0.9	−0.22	−0.42	0.58	0.09	0.07
B2	1.11	**−3.62**	−1.33	−1.77	2.15	0.51	0.14
B3	0.71	**−3.76**	−1.46	−1.58	2.52	0.57	0.27
B4	0.92	**−3.29**	−1.81	−1.81	2.37	0.45	0.01
B5	0.39	**−3.31**	−1.41	−2.04	2.21	0.37	−0.17
B6	0.31	**−3.37**	−1.47	−2.07	2.07	0.33	−0.33
B7	0.15	**−3.32**	−1.42	−1.97	2.31	0.27	−0.43
B8	−0.35	**−3.06**	−1.54	−2.14	2.18	0.39	−0.41

4.1.4. Index of potential ecological risk

The index (RI) is used to examine the degree of heavy metal contamination [Li et al. 2013]. This index is calculated using the following formulas (4, 5 and 6):

$$C_f^M = C_s^M / C_n^M \tag{4}$$

$$E_r^M = \left(T_r^M\right) * \left(C_f^M\right) \tag{5}$$

$$RI = \sum_{M=1}^{n} \left(E_r^M\right) \tag{6}$$

where:

RI – risk index,

E_r^M – individual risk index,

C_s^M – measured concentration,

C_n^M – reference concentration (background),

T_r – toxicity factor.

The (T_r) values used in this study are: Cd = 30; Pb = 5; Zn = 1; Cu =5; Cu =5; Ni =5; Cr = 2 and Co = 5 [Chai et al. 2016 and Zhang et al. 2018]. RI, evaluation criteria are presented in Table 6.

Table 6. E_r^M and RI evaluation criteria

E_r^M **of every heavy metal**	**Risk level**	**RI of several heavy metals**	**Risk level**
$E < 40$	Weak	$RI < 150$	Weak
$40 \leq E < 80$	Medium	$150 \leq RI < 300$	Medium
$80 \leq E < 160$	Strong	$300 \leq RI < 600$	Strong
$160 \leq E < 320$	Very strong	$RI \geq 600$	Very strong
$E \geq 320$	Extremely strong	–	–

Source: Chai et al. [2016] and [Zhang et al. 2018]

Table 7 summarizes the results for RI and E_r^M. The ecological risk of each metal is ranked in descending order as follows: Co < Ni < Cr < Cd < Zn < Cu < Pb. Cd and Co present a low risk (below 40), while Cu and Zn present a high risk (ranging from 80.23 to 135.4 and from 94.48 to 119.21, respectively). The study area presents an extreme lead risk to the environment due to individual lead risks with values well above ($E_r^M > 320$) and ($RI > 600$). The high concentrations of lead, zinc, and copper in the sediments of the study area make these sediments a source of endogenous pollution and represent a potential risk. These metal pollutants can pass into the water table and springs, affecting the quality of drinking water and human health. This is particularly concerning as the population relies on wells and springs for drinking water.

Table 7. Values of (E_r^M) and (RI) per sample in the study area

Individual ecological risk index (E_r^M)								**Potential ecological hazard (RI)**
Sample	**Cd**	**Co**	**Cr**	**Ni**	**Pb**	**Zn**	**Cu**	
B1	10.8	6.6	43.4	35.15	**842.05**	**119.21**	**135.4**	1193
B2	9.9	7.05	41.5	40.7	**567.8**	**111.65**	**118.9**	898
B3	7.5	6.4	38.06	**46.4**	**735.4**	**116.01**	**129.7**	1079
B4	8.7	8.85	40.28	39.6	**660.75**	**107.14**	**108.3**	974
B5	6.0	8.75	39.24	33.9	**591.85**	**101.46**	**94.75**	876
B6	5.7	8.4	37.74	31.35	**537.4**	**98.35**	**85.05**	804
B7	5.1	8.7	39.16	35.45	**636.1**	**94.48**	**80.45**	898
B8	3.5	10.4	36.04	31.6	**581.5**	**102.68**	**80.23**	846

4.2. Statistical analysis

4.2.1. Correlation analysis

Multivariate statistical methods were used to determine the relationship between the variables studied. Specifically, Pearson's correlation matrix and principal component analysis (PCA) were employed.

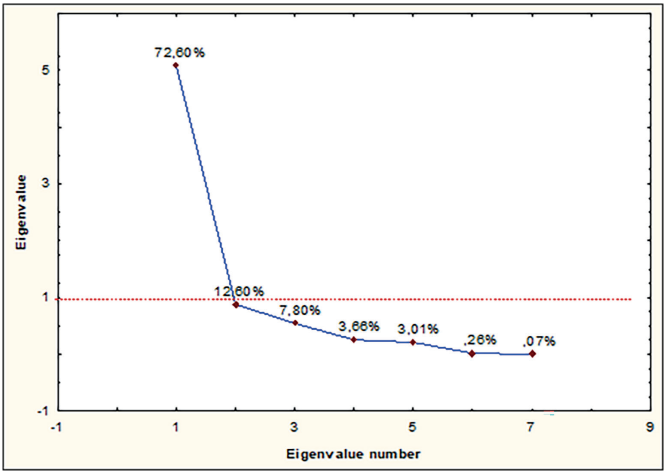
The correlation coefficient (Table 8) provided valuable information on the links between the heavy metals studied. The correlation between two elements reflects the degree of relationship between them. Table 9 shows the Pearson correlation matrix for the various metals studied. The results indicate a highly significant positive correlation between the pairs of elements Cd-Cu (0.90) and Cd-Cr (0.88). There are also significantly average positive correlations between the element pairs Cd-Pb (0.57); Cd-Zn (0.57); Cr-Pb (0.56); Cr-Zn (0.67); Ni-Zn (0.58) and Ni-Cu (0.58). The high correlation between heavy metals could be an indicator of the common source of these elements, whether natural or anthropogenic. This study investigates the incorporation of Cd, Cr, and Ni as impurities in several mineral phases, such as blende and galena, or in copper-bearing minerals, such as chalcopyrite or gruzdevite. As these minerals degrade, heavy metals are released into the sediment and transported by the hydrographic network that drains the region. The study found a negative correlation between Co and the other metals: Co-Cr (–0.62), Co-Ni (–0.62), Co-Pb (–0.59), Co-Zn (0.74), and Co-Cu (–0.86). This negative correlation suggests that Co has a different source than Pb, Zn, Cd, and Cu, which is likely to be terrigenous.

Table 8. Correlation matrix of variables

	Cd	**Co**	**Cr**	**Ni**	**Pb**	**Zn**	**Cu**
Cd	1.000						
Co	−0.772	1.000					
Cr	**0.901**	−0.627	1.000				
Ni	**0.499**	−0.627	0.223	1.000			
Pb	**0.578**	−0.595	**0.564**	0.375	1.000		
Zn	**0.578**	−0.746	**0.567**	**0.598**	**0.725**	1.000	
Cu	**0.880**	−0.865	**0.679**	**0.598**	**0.737**	**0.962**	1.000

4.2.2. Eigenvalues

Eigenvalues were calculated for the covariance matrix. The data were then transformed into factors. The decreasing curve of the percentage of all the factors (Fig. 2) is a graphical representation that also makes it possible to discern the number of factors required for a better visualization of the results. The eigenvalues are presented in (Fig. 2) and Table 10.



Source: Authors' own study

Fig. 2. Eigenvalues of correlation matrix

Table 9. Calculated eigenvalues for the covariance matrix

	Eigenvalue	% Total	Cumulative
1	5.081875	**72.59822**	72.5982
2	0.882151	**12.60215**	**85.2004**
3	0.546142	7.80202	93.0024
4	0.256354	3.66220	96.6646
5	0.210773	3.01104	99.6756
6	0.017882	0.25546	99.9311
7	0.004824	0.06891	100.0000

According to the table and the graphical representation of the eigenvalues of the correlation matrix, we have stopped the calculation at two factorial planes (F1 and F2) which represent more than 84% of the total variance.

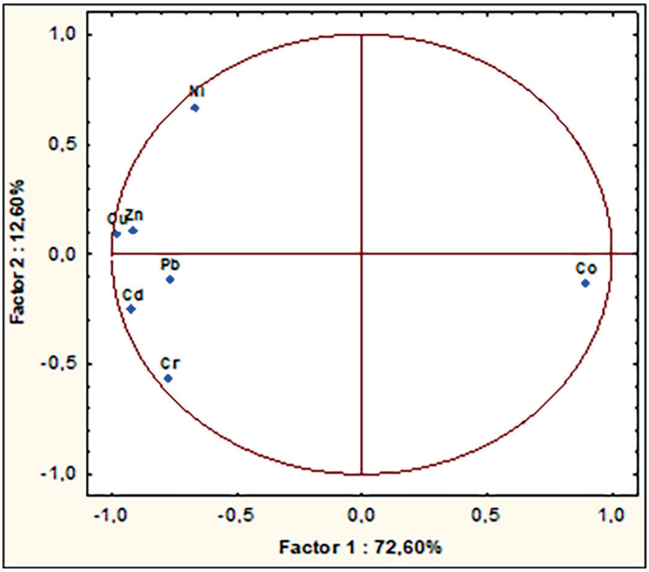
4.2.3. Principal component analysis

Principal component analysis (PCA) was conducted to establish relationships between the chemical elements (Cd, Co, Cr, Ni, Pb, Zn and Cu). To determine the number of factorial axes to retain, we followed the rules of normalized PCA and focused only on axes with an eigenvalues greater than 1 [Kaiser 1958]. The first axes were selected to achieve a given percentage of explained inertia (> 75%). The 'minimum inertia rule' is demonstrated in Figure 3 through the results of the PCA. These results reveal two principal components that represent 85.20% of the total variance, indicating a continuous structuring of the variance. The F1 factor accounts for 72.6% of the total variance and contrasts the chemical elements (Cr and Ni), explaining the different origins of these elements. The F2 factor accounts for 12.60% of the total variance.

The calculation was based on two axes, F1 and F2. The F1 factor is negatively correlated with all elements except cobalt, suggesting a different source from the other elements, which is likely to be terrigenous. The F2 factor is weakly correlated with Ni and Cr.

Table 10. Coordination factors for geochemical data in the Zoubia area

	Factor 1	**Factor 2**
Cd	–0.92053	–0.25094
Co	0.88916	–0.13308
Cr	–0.77417	–0.56469
Ni	–0.66840	0.67025
Pb	–0.76944	–0.11457
Zn	–0.91578	0.10739
Cu	–0.98339	0.09319

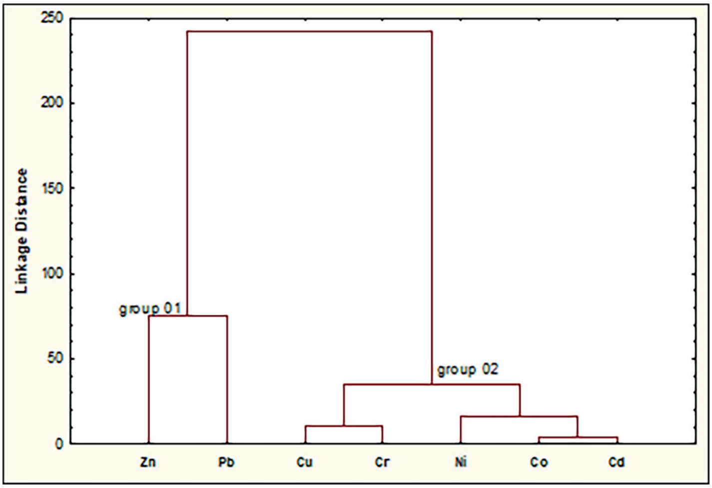


Source: Authors' own study

Fig. 3. Projection of the variables on the factor plane (1–2).

4.2.4. Ascending hierarchical classification

Using Ward's method and Euclidean distance for hierarchical classification, the dendrogram of the study area's samples (Fig. 4) shows two main groups. The second group comprises the remaining elements (Cu, Cr, Ni, Co and Cd). The first group consists of (Zn-Pb), which are the main components of the polymetallic ore (blende and galena). The second group consists of two sub-groups. The first sub-group comprises elements (Cu-Cr) that are closely clustered, indicating that Cr is incorporated into the chalcopyrite. The second sub-group, consisting of (Ni, Co and Cd), indicates an identical origin, probably due to the alteration of the gruzdevite.



Source: Authors' own study

Fig. 4. Tree diagram for variables

The multivariate statistical analysis helps to identify the common origin of the two contaminants, Zn and Pb, which may result from the alteration of galena and blende, and Ni, Co, and Cd, which originate from the alteration of gruzdevite formation.

5. Conclusions

The study was conducted due to a significant increase in certain types of cancer, particularly in older men, which has never been observed before in the region. This study aims to determine the level of contamination of sediments in the Zoubia region by heavy metals (Pb, Zn, Cu, Ni, Co, Cr and Cd) and their risk to human health. The region contains a formerly exploited polymetallic mine.

Based on the results of pollution indices such as CF, EF, I_{geo}, E_r^M, and RI, as well as multivariate statistical analysis, it can be concluded that the sediments in the Zoubia region are moderately to severely contaminated with Pb, and uncontaminated to moderately contaminated with Cu, Zn, and Cd. Additionally, the sediments are uncontaminated by other metals such as Ni, Co, and Cr. It is important to note that the concentrations of Co, Ni, and Cr are well below the reference levels and do not pose a risk of pollution. Although Cd is present in the region's sediment, it does not pose a medium-term risk. However, lead is a very high ecological risk factor that may pose a potential threat to both human health and the ecosystem of the region. The source of pollution in the region was determined using multivariate statistical analysis. Natural pollution is caused by geological processes such as the alteration of rocks and polymetallic ores. Anthropogenic pollution is caused by the intense use of chemical fertilisers and pesticides in agriculture, and the former operation of the Zoubia mine. To maintain the ecological integrity of the region and reduce potential threats, we recommend monitoring the sediment contamination load in the medium and long term. Additionally, we suggest replacing chemical fertilisers with animal fertilisers, especially since in animal life is abundant in the region. According to this study, the pollution sequence is as follows: Pb > Cu > Zn.

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