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Application Factor Analysis for the Evaluation Surface Water and Sediment Quality

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Water quality monitoring has one of the highest priorities in environmental protection policy. The main objectives are to control and minimise the incidence of pollutant-oriented problems, and to provide water of appropriate quality to serve various purposes such as drinking water supply, irrigation water, etc. Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable. In the present study, factor analysis is applied to physico-chemical parameters of Smolnik creek, Slovakia, with the aim classification and data summation as well as segmentation of large heterogeneous data sets into smaller homogeneous subsets that can be easily managed, separately modelled and analysed.
The paper deals with evaluation of the surface water and sediment quality relate to acid mine drainage (AMD) producing from abandoned sulphide mine in Smolnik (Slovak Republic) by factor analysis. This study underscores the value of multivariate statistical analysis for evaluation and interpretation of the data with a view to stimulating better policy outcomes and decision-making that positively impacts water quality and thus prospectively diminishes the pollution caused by hazardous toxic elements in mining environments.

1. Introduction

Acid mine drainage (AMD) is considered as one of the worst environmental problems associated with mining activity. Overflowed mine Smolnik produces AMD with high metal concentrations and low value of the pH (about 3-4) as a result of chemical oxidation of sulphides and other chemical processes.
Runoff from mining operations can have negative impacts on the surrounding aquatic environment including heavy loads of suspended solids, decreased pH levels and increased levels of heavy metals.
In Slovak republic there are some localities with existing AMD generation conditions. The most critical values were observed in the abandoned deposit Smolnik (Petriláková and Bálintová, 2011).
This was the reason for starting a systematic monitoring of geochemical development in acid mine drainage in 2004 in order to prepare a prognosis in terms of environmental risk and use of these waters as an atypical source of a wide range of elements (Šlesárová et al.,2007). Multivariate statistical methods including factor analysis, cluster analysis, principal components method etc., have been used successfully in hydrochemistry for many years. Surface water, groundwater quality assessment and environmental research employing multi-component techniques are well described in the literature. Multivariate statistical approaches allow deriving hidden information from the data set about the possible influences of the environment on water quality.

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2. Materials and methods

2.1 Study area

Smolnik is situated in the south eastern Slovakia between villages Smolnik and Smolnicka Huta in the valley of Smolnik creek (Figure 1), 11 km south–west of the village Mnisek nad Hnilcom. Geomorphologically, the locality is situated in the area of Slovenske Rudohorie (Slovak Ore Mountains - West Carpathians). It is a historical Cu, Fe, Ag, Au mining area that was exploited from the 14-th century to 1990. The mine-system represents partly opened geochemical system into which rain and surface water drain. The Smolnik mine was definitely closed and flooded from 1990 till 1994 (Špaldon et.al., 2006; Luptáková, et.al., 2007). More than 6 Mt of pyrite ores of various qualities have been abandoned in this mine. The analysis of water in the deserted mine and in the broader area surrounding this mine was made after the ecological accident in the Smolnik creek in 1995. Waters and sediments from the earth surface penetrated the mine and they were enriched with metals and their pH values decreased (Šotník et al., 2002). Acidity is caused mainly by the oxidation of sulphide minerals. The whole mine complex produces large amounts of AMD, discharging from the flooded mine that acidified and contaminated the Smolnik creek water which transported pollution into the Hnilec River catchment (Luptáková and Kušnierova, 2005; Luptáková, et.al., 2008).

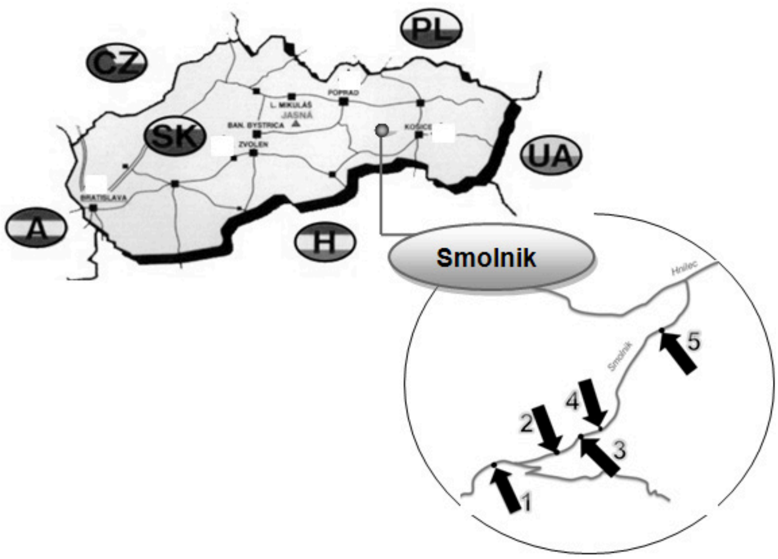

Figure 1: Location of Smolnik creek on the map of the Slovak Republic

2.2 Sampling and preparation

Water and sediment sampling localities are shown in Figure 1. Two localities were in the upper part of the Smolnik creek without contamination by acid mine waters from shaft Pech (1 – outside the Smolnik village, 2 - small bridge - crossing to the shaft Pech) and another two sampling localities were located under the shaft (4 - 200 m under the shaft Pech, 5 – inflow to the Hnilec river). The outflow of AMD from shaft Pech (Smolnik mine) has number 3. Twenty water and sediment samples were collected from Smolnik creek during years 2006-2009. The chosen physical and chemical parameters were determined by multifunctional equipment METTLER TOLEDO in situ and chemical analyses of water and sediment samples were realized by AAS-ICP (Varian Vista – MPX).

The results of chemical analysis of water samples in the Smolnik creek in 2006 - 2009 are presented in Table 1. Results of chemical analyses of the water were compared with the limited values according to the Regulation of the Government of the Slovak Republic No. 269/2010 Coll. Results of chemical analyses of the sediments were compared with the limited values according to the Slovak Act No. 188/2003 Coll. of Laws on the application of treated sludge and bottom sediments to fields.

Table 1: Analytical data of surface water and sediment in Smolnik creek

No.	pH	Cu- w	Cu -s	Fe - w	Fe- s	Mn-w	Mn- s	Zn-w	Zn-s	Al-w	Al-s
	-	mg/L	mg/kg	mg/L	%	mg/L	%	µg/L	mg/kg	mg/L	%
	5.4	4	176	0.05	3.96	0.01	0.108	2	171	0.02	7.02
	6	2	103	0.07	3.88	0.01	0.044	6	123	0.05	7.14
S1	5.45	2	114	0.06	3.49	0.01	0.062	5	140	0.12	6.88
	5.46	2	128	0.7	4.01	0.01	0.116	3	157	0.2	7.67
	5.52	2	111	0.06	4.57	0.01	0.09	3	143	0.02	7.68
	5.57	12	234	1.72	6.76	0.3	0.04	134	183	0.03	7.32
	6.58	12	282	0.79	5.7	0.09	0.051	25	186	0.28	6.76
S2	5.18	14	252	3.00	4.13	0.28	0.073	82	196	0.18	6.43
	5.58	9	237	0.62	7.27	0.12	0.051	38	180	0.12	7.21
	5.76	34	196	1.34	4.63	0.27	0.04	93	131	0.74	6.63
	3.88	3263	448	463	23.6	36,5	0.096	12600	313	107	2.52
	4.11	1379	215	433	29.7	32.2	0.012	8958	58	79.8	0.46
S3	4.01	1311	689	291	34.6	22.5	0.022	6750	150	53.9	4.01
	3.98	1642	663	392	26.6	28.5	0.024	7665	168	69.7	4.65
	3.94	1740	143	351	37.4	28.4	0.01	7250	45	67.6	0.74
	4.98	203	445	31.8	13.8	2.7	0.051	923	172	2.03	6.09
	5.76	14	903	108	12.3	0.96	0.084	187	328	0.61	6.46
S4	4.92	384	365	4.93	4.97	0.78	0.067	338	214	4,41	6.16
	5.26	50	295	16.8	8.9	1.32	0.048	383	172	0.13	6.84
	5.19	97	281	18.8	5.07	1.84	0.05	379	165	4,15	6.91
	493	207	506	17.8	7.84	2.22	0.044	757	250	2.46	6.55
	6.17	7	661	5.38	8.82	0.73	0.057	176	320	0.12	6.29
S5	5.34	14	404	2.52	6.24	0.3	0.068	68	193	0.32	6.39
	5.2	42	527	1.11	13.2	1.21	0.045	349	192	0.02	7.26
	5.4	31	836	10.5	31.7	1.3	0.03	280	200	0.43	2.62
Lim.	6-8.5	20	1000	2	-	0.3	-	100	2500	0.2	-

3. Data management and multivariate statistical techniques

Multivariate statistical methods including factor analysis have been used successfully in hydrochemistry for many years. Surface water, groundwater quality assessment and environmental research employing multi-component techniques are well described in the literature (Praus, 2005). Multivariate statistical approaches allow deriving hidden information from the data set about the possible influences of the environment on water quality (Spanos et al., 2003).

Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable (Yu et al., 2003). There are three stages in factor analysis (Gupta et al., 2005): for all the variables a correlation matrix is generated, factors are extracted from the correlation matrix based on the correlation coefficients of the variables, to maximize the relationship between some of the factors and variables, the factors are rotated.

A first step is the determination of the parameter correlation matrix. It is used to account for the degree of mutually shared variability between individual pairs of water quality variables. Then, eigenvalues and factor loadings for the correlation matrix are determined. Eigenvalues correspond to an eigenfactor which identifies the groups of variables that are highly correlated among them. Lower eigenvalues may contribute little to the explanatory ability of the data. Only the first few factors are needed to account for

much of the parameter variability. Once the correlation matrix and eigenvalues are obtained, factor loadings are used to measure the correlation between the variables and factors. Factor rotation is used to facilitate interpretation by providing a simpler factor structure (Zeng and Rasmussen, 2005).
Multivariate analysis of surface water data was subjected through Factor analysis (FA) (Yidana et. al, 2007; Johnson and Wichern, 1998, Millard and Neerchal, 2001). The data sets were first summarized (Table 2). From Table 2 results that the smallest range were for Mn in sediment, pH, Mn in water and Fe in sediment. The pH of surface water and sediments varies from 4.9 to 6.6 with an average 5.5. All the mathematical and statistical computations were made using the Statistical Package for Social Sciences version 7.

Table 2: Statistical data of surface water and sediment of selected chemical elements in Smolnik creek

	Mean	Minimum	Maximum	Range
pH	5.18	3.88	6.58	2.70
Cu-w, mg/L	419.08	2.00	3263.00	3261.00
Cu-s, mg/L	368.56	103.00	903.00	800.00
Fe- w, mg/L	86.24	0.05	463.00	462.95
Fe-s, mg/L	12.53	3.49	37.40	33.91
Mn- w, mg/L	6.50	0.01	36.50	36.49
Mn-s, mg/L	0.06	0.01	0.12	0.11
Zn- w, mg/L	1898.16	2.00	12600.00	12598.00
Zn-s, mg/L	182.00	45.00	328.00	283.00
Al- w, mg/L	15.78	0.02	107.00	106.98
Al-s, mg/L	5.79	0.46	7.68	7.22

4. Results and discussion

Initial information about the correlation structure of the data set was obtained from the implementation of the selection correlation matrix 11 variables (Table 3, w- water, s- sediment). Correlations fluctuate from – 0.13 (for Cu-s and pH) to 0.99 (correlation between the Mn-w and Al-w), respectively. Correlation coefficients in Table 3 between the evaluated elements larger than 0.5 indicate that there exist high mutual correlation, correlation coefficients less than – 0.5 indicate high indirect mutual correlation. The correlation matrix of variables was generated and factors extracted using the varimax rotation. Factor loadings are given in Table 4.

Table 3: Implementation of selective correlation matrix

	pH	Cu-w	Cu -s	Fe -w	Fe- s	Mn-w	Mn-s	Zn-w	Zn-s	Al-w	Al-s
pH	1.00										
Cu-w	-0.82	1.00									
Cu –s	-0.13	0.13	1.00								
Fe – w	-0.83	0.93	0.18	1.00							
Fe- s	-0.73	0.70	0.43	0.79	1.00						
Mn-w	-0.85	0.95	0.13	0.99	0.80	1.00					
Mn- s	0.31	-0.19	-0.17	-0.33	-0.58	-0.36	1.00				
Zn-w	-0.84	0.98	0.14	0.98	0.77	0.99	-0.29	1.00			
Zn-s	0.24	-0.02	0.62	-0.15	-0.22	-0.19	0.45	-0.12	1.00		
Al-w	-0.83	0.97	0.11	0.98	0.76	0.99	-0.29	0.99	-0.15	1.00	
Al-s	0.71	-0.75	-0.21	-0.82	-0.89	-0.83	0.50	-0.80	0.26	-0.81	1.00

w- water, s -sediment

Table 4: Factor analysis of surface water and sediments for selected chemical elements in Smolnik creek

Element	Factor 1	Factor 2	Factor 3
pH	-0.858903	0.042517	-0.223254
Cu-w	0.981072	0.056773	0.007076
Cu-s	0.095615	0.945661	0.254039
Fe- w	0.960981	0.038808	0.200596
Fe-s	0.710905	0.210436	0.611022
Mn-w	0.970511	-0.017778	0.214136
Mn-s	-0.150001	0.051551	-0.925678
Zn-w	0.985093	0.020480	0.125060
Zn-s	-0.084218	0.839128	-0.487834
Al-w	0.985280	-0.013762	0.128304
Al-s	-0.773441	-0.045765	-0.493144
% Totl.var	66.44	15.45	11.27
Eigen	7.309	1.699	1.239
% Cum.totl.var.	66.44	81.89	93.6

The factor analysis generated three significant factors which explained 93.16 % of the variance in data sets. The first factor correlates with Cu-w, Fe-w, Mn-w, Zn-w and Al-w and indirect with pH. The second factor correlates with Cu-s and Zn-s and the last factor weakly correlates with Fe-s and indirect with Mn-s. After rotation the first factor of the total variance in the 11 considered variables is 66.44 %. The second factor of the total variance represents 15.45 % and the third factor of the total variance represents 11.27 %. The following factors were indicated considering the hydro chemical aspects of the surface water and sediment:

Factor 1 can be interpreted as a high indirect dependence of metals concentration (Cu, Fe, Mn, Zn and Al) dissolved in water on pH. This result is in accordance with data from the literature (Balintova and Petrilaková, 2011). High correlation among concentration of dissolved metals means that increasing of concentration of one metal in surface water is connected with increasing of concentration of another metals.

Factor 2 can be interpreted as influence of sorption on the increasing of Cu and Zn in sediment. This was confirmed in literature (Petrilakova and Balintova, 2011).

Factor 3 can be interpreted as a factor of metals that are precipitated at pH > 8 (Calmano et. al, 1993).

5. Conclusion

The above analysis demonstrates the use of multivariate statistical techniques to study the source/genesis of chemical parameters in surface water systems and sediments. Eleven parameters including the trace elements (Cu-w, Cu-s, Fe-w, Fe-s, Mn-w, Mn-s, Zn-w, Zn-s, Al-w, Al-s) and the physicochemical parameters (pH) have been monitored on 5 sampling points from a survey conducted in surface within the Smolnik mining area in Slovakia. Data set was analysed using factor analysis (FA). FA identified three factors responsible for data structure explaining 93.16 % of total variance. Based on Factor analysis on surface water and sediments, Factor 1 characterises the influence of pH on metal precipitation in the interval of pH (3.94-6.58), Factor 2 is the sorption of Cu and Fe and Factor 3 represents metals (Fe^{2+} and Mn) which the pH of precipitation is more than 8. This study shows that factor analysis is a useful method that could assist decision makers in determining the extent of pollution via practical pollution indicators. It could also provide a crude guideline for selecting the priorities of possible preventative measures in the proper management of the surface water.

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