ISSN 1848-0071
543.26+519.2+669.14=111
Recieved: 2015-08-03
Accepted: 2015-11-04
Original scientific paper

APPLICATION OF MULTIDIMENSIONAL STATISTICAL METHODS FOR THE AIR QUALITY EVALUATION IN THE VICINITY OF A STRATEGIC PLANT

MIRIAM ANDREJIOVÁ, ZUZANA KIMÁKOVÁ, MIRIAMA PIŇOSOVÁ, RUŽENA KRÁLIKOVÁ

Faculty of Mechanical Engineering, Technical University of Kosice, Slovak Republic
e-mail: ruzena.kralikova@tuke.sk

The worsening condition of the environment on various levels of devastations in various regions negatively shares both the health of the population and the general quality of the entire ecosystem. The air pollution is the cause of hundred of thousands of deaths of Europeans per year and millions of people in the world. At present we are breathing the air polluted by the power industry, the traffic, the waste disposal or the agriculture. The monitoring of the environment is one of the important tools detecting the state of the environment. Only the complex monitoring of the environment system enables the objective knowledge of the state of the environment basic components influenced by human being as well as the real establishment of the development tendencies and the effective measures improving the state of the environment. This paper deals with the air quality assurance applied through the selected multidimensional statistical methods in the vicinity of the important plant in the East Slovakia. In the analysis of the air quality were applied methods: method of principal components analysis, cluster analysis and the multidimensional comparison methods. The level of the air quality was described by five contaminations substances: CO, SO_2, NO_2, O_3 and PM_{10}. The monitored areas have a low level of air polluted by air quality index. The results of the cluster analysis indicated that three monitored areas (Veľká Ida, Sokoľany and Seňa) have similar characteristics of selected air quality indicators and they are forming one cluster. The results of the multidimensional comparison methods pointed to the fact that localita Velka Ida is the area with the highest air pollution.
Key words: air quality, principal components analysis, cluster analysis, multidimensional comparison method.

Primjena višedimenzijskih statističkih metoda za ocjenu kvalitete zraka u blizini strateškog postrojenja. Pogoršanje stanja okoliša na različitim razinama te pustošenje različitim regijama negativno utječe na zdravlje stanovništva i na opću kvalitetu ekosustava. Zagađenje zraka je uzrok smrti stotine tisuća stanovnika Europe godišnje i milijuna ljudi u svijetu. Trenutno udišemo zrak zagađen proizvodnjom energije, prometom, odlaganjem otpada ili poljoprivrednom proizvodnjom. Praćenje okoliša jedan je od važnih alata za otkrivanje stanja okoliša. Jedino cjelovito praćenje sustava okoliša omogućava objektivne spoznaje o stanju osnovnih komponenata okoliša pod ljudskim utjecajem kao i realno uspostavljanje razvojnih tendencija i učinkovitog mjerenja poboljšanja stanja okoliša. Ovaj rad obrađuje osiguranje kvalitete zraka kroz primjenu odabranih višedimenzijskih statističkih metoda u blizini značajnog postrojenja u istočnoj Slovačkoj. U analizi kvalitete zraka primjenjene su sljedeće metode: metoda analize glavnih komponenata, klaster analiza i metoda višedimenzijske usporedbe. Razina kvalitete zraka opisana je pomoću pet polutanata: CO, SO_2, NO_2, O_3 and PM_{10}. Promatrana područja imaju nisku razinu zagađenja zraka izraženu indeksom kvalitete zraka. Rezultati klaster analize pokazuju da tri promatrana područja (Veľká Ida, Sokoľany i Seňa) imaju slične karakteristike odabranih indikatora kvalitete zraka i oni čine jedan klaster. Rezultati metode višedimenzijske usporedbe ukazuju na činjenica da je lokalitet Veľká Ida područje s najvećim onečišćenjem zraka.
Ključne riječi: riječi: kvaliteta zraka, analiza glavnih komponenti, klaster analiza, metoda višedimenzijske usporedbe.

INTRODUCTION

The state of the environment, the human health and the respective ecosystems are markedly influenced by the quality of the air. During tens of millions of years and especially in time of previous semi-century the stabilized balance of the air basic components was invaded by the emission activities of energetics, industry, traffic, the raw material exploitations, incompetently accelerated agriculture with coincidental accumulation of both industrial and the communal waste and the same the agricultural waste.

At present several hundreds of air contamination substances are known and identifiable. The most frequently monitored contamination substances are represented by the substances resulting from combustion of solid, liquid and gaseous fuels as the: carbon oxide, sulphur dioxide, oxides of nitrogen including nitrogen dioxide and nitrogen oxide, the dust components and the secondary pollution substances like the ozone, carbon dioxide and other.

The particulate matter (PM) represent the most important health risk involved in air contamination within EU [1, 2, 3]. In 2010, 21% of the city inhabitants were estimated as exposed to higher PM concentrations in comparison with the most severe specified EU day limits. Up to 30 % of the city inhabitants were exposed to softer $PM_{2.5}$ substances of the concentration exceeding (less severe) EU year limits. According to World Health Organization (WHO) reference values, more severe than EU legislative limits, 81% resp. 95 % of the cities inhabitants were exposed to PM concentrations exceeding the reference values specified with regard to the human health prevention. PM_{10} year limit applied from 2005 was most often exceeded in Poland, Italy, Slovakia and in the Balkan region. Up to 97% of EU cities inhabitants were exposed to ozone concentrations exceeding WHO reference values in 2010. The ozone may evoke the respiratory problems and may cause the premature death. 17 % of the inhabitants were exposed to the concentrations exceeding the EU target value of the ozone [1, 4, 5]. The formation of both the solid substances and the ozone is contributed by the **nitrogen oxide (**NO_2) mainly reasoning the eutrophication – the overgrowth of the water plants and sea-grass and the acidification. In the cities 7% of Europeans were exposed to NO_2 level exceeded EU limit values in 2010. In many countries of the Union the inland nitrogen oxides emissions remain over the upper levels specified in EU legal enactments and in the international agreements. A big success was reached regarding the **sulphur dioxide** (SO_2) – its emissions markedly decreased during the foregoing years. The EU legal enactments demand the application of the exhaust gas filtration technologies and the fuel of the lower sulphur volume. The year 2010 was the first year when the EU cities citizens were not exposed to SO_2 levels exceeding the EU limits. In EU the air concentrations of the **carbon monoxide, benzene and of the heavy metals** (arsenic, cadmium, nickel and plumbum) are generally low, local and sporadic. The cases of both the exceeded limits and the target values specified by EU legal enactments are rare.

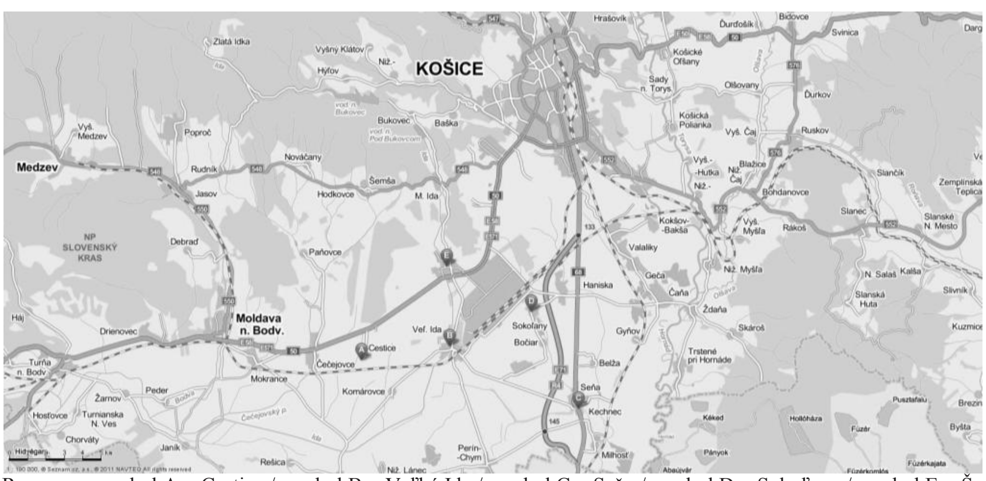
In Slovakia, several years of observations result in the investigation that the emissions of both the solid substances and the sulphur dioxide are continuously decreasing from 1990 and that it is caused also by the changed fuel basis in favour of the generous fuels, through the implementation of the separators technique and by improving its efficiency, through the application of the heating oils with low volume of the sulphur and by installation of the de-sulphurating equipment in big energetic sources. CO emissions are of the decreasing tendencies too. The nitrogen oxides emissions show slight decrease from 1990. In Slovakia the Vojany Power-plant denitrification positive resulted in nitrogen oxides emissions decrease in 2002-2004 [2].

The air prevention is one of the most monitored environmental components evidenced through a considerable progress of the development of the legislation. Now, in Slovakia the allowed level of air pollution is determined by Law No. 137/2010 Coll. of Laws on the Air [6] and by Ministry of Environment Regulation No. 360/2010 Coll. of Laws on the Air Quality Limit Values, tolerance limits, numbers of exceeded limit values [7]. Long term, within several spheres, Slovakia does not follow the limit values of dust particles (PM_{10}) specified through the European Parliament and Board Directive 2008/50/ES on Environment Air Quality and on Clean Air transposed to Ministry of Environment Regulation No. 360/2010 Coll. of Laws on Air Quality [8].

METHODS

Monithoring areas

One of many obligations of the air pollution sources operators is their responsibility to perform the regular monitoring of the particular polluting substances discharged from these sources. The purpose is to recognize the compliance with the specified emission limits. In addition, the operators of selected big sources of the contamination including the existing plant have to monitor the level of the air pollution (so called emission monitoring) within the production plants environment. The company performs also the regular air monitoring by the measuring vehicle in surrounding villages. In recent time period the most frequently monitored areas were the villages: Veľká Ida, Šaca, Sokoľany, Cestice and Seňa (Table 1). Every month is realized the distribution and the collection of the dust fall sample-cases within the localities near the company namely due to the long-term control of the spread and the evaluation of the soil dustiness intensity.



Response: symbol A = Cestice / symbol B = Veľká Ida / symbol C = Seňa / symbol D = Sokoľany / symbol E = Šaca

Figure 1. Companies in monitoring areas
Slika 1. Poduzeća u praćenom području

Table 1. Characteristics of monitored areas
Tablica 1. Karakteristike promatranih područja

Monitoring areas	Distance from contamination source	GPS co-ordinates
Cestice	8 km	48.59286°N, 21.10174°E
Veľká Ida	5.6 km	48.59766°N, 21.16739°E
Seňa	15.8 km	48.55885°N, 21.25726°E
Sokoľany	10.3 km	48.60889°N, 21.22845°E
Šaca	1 km	48.64242°N, 21.17046°E

Statistical methods

The multidimensional statistical methods were applied in the analysis of the air pollution state within the selected contamination source environment: method of principal components analysis, cluster analysis and the multidimensional comparison methods.

Principal Component Analysis

The aim of Principal Component Analysis (PCA) is to reduce the number of interrelated variables with as little information loss as possible [9]. New variables, so called components, are mutually independent and are ordered according to the portion of represented total original variability. The first principal component corresponds to the greatest input variability the other principal components contribute the variability with ever less share. PCA method may also be applied as the detection of the outlying values sometimes needed to be eliminated from subsequent analyses, and it is a useful method of cluster classification of the objects [10, 11, 12, 13].

Cluster analysis

Cluster analysis is the statistical method being the part of the multidimensional statistical methods. Its purpose is to cluster the monitored objects into specific similar, homogenous groups so called clusters [10, 11, 12, 14, 15, 16].

Multidimensional comparison methods

The purpose of a multidimensional comparison is to replace several indicators (variables) with a single integrating indicator according to which the objects can be compared and arranged with regard to achieved level of the monitored feature. The group of principal multidimensional comparison methods include the simple ordering method, the scoring method, the standardized variable method and the fictitious object distance method [17].

RESULT AND DISCUSSION

The level of the air quality of selected areas within the strategic plant environment was described by five contamination substances: carbon oxide CO, sulphur dioxide SO_2, nitrogen oxide NO_2, ozone O_3 and the particulate matter PM_{10}. The air quality assurance was based on the previous year data measured by the company. The Table 2 shows the basic features of selected air quality indicators within the respective areas. The values of CO and O_3 represent the maximum 8 hour day average. The values of SO_2 and PM_{10} show the 24 hour average and the values of NO_2 represent the maximum 1 hour average. Graphic presentation of measured indicators in respective monitoring areas is in the Figures 2 to 6.

Table 2. Basic characteristics of air quality indicators
Tablica 2. Osnovne karakteristike pokazatelja kvalitete zraka

Monitoring areas/ basic characteristics		**CO (mg/m^3)**	**SO_2 (μg/m^3)**	**NO_2 (μg/m^3)**	**O_3 (μg/m^3)**	**PM_{10} (μg/m^3)**
		Max. daily 8 hours average	24 hours average	Max.1 hours average	Max. daily 8 hours average	24 hours average
Cestice	Average	0.935	32.955	18.227	88.750	21.909
	Stand.deviation	0.388	16.102	16.142	5.560	10.034
	Max-min	1.4-0.1	55-1	59-1	94-83	39-5
Veľká Ida	Average	1.217	39.087	38.130	63.625	33.529
	Stand.deviation	0.402	15.719	18.013	21.974	14.803
	Max-min	1.9-0.1	65-14	72-7	94-41	60-6
Seňa	Average	1.184	33.429	31.611	60.222	32.273
	Stand.deviation	0.456	13.815	21.219	5.674	9.328
	Max-min	2.3-0.6	48-4	85-3	69-50	45-13
Sokoľany	Average	1.263	52.745	33.340	75.333	22.042
	Stand.deviation	0.539	33.966	21.379	24.055	7.850
	Max-min	2.5-0.3	230-8	85-5	91-27	43-12
Šaca	Average	0.981	27.714	30.434	28.250	27.375
	Stand.deviation	0.389	10.199	15.496	7.365	17.378
	Max-min	1.7-0.4	48-4	55-6	37-19	51-11
limit		**10 mg/m^3**	**125 μg/m^3**	**200 μmg/m^3**	**120 μg/m^3**	**50 μg/m^3**

CO concentrations found within the respective measuring areas result in the knowledge that the village Sokoľany is the most contaminated locality. The order of the areas of the highest average CO concentration is as follows: Sokoľany > Veľká Ida >Seňa > Šaca > Cestice.

The maximum daily 1-hour **SO_2** value was measured in the monitoring locality Sokoľany (230 μm/m^3). The order of the areas of the highest average of SO_2 concentrations is as follows: Sokoľany > Veľká Ida > Seňa > Cestice > Šaca.

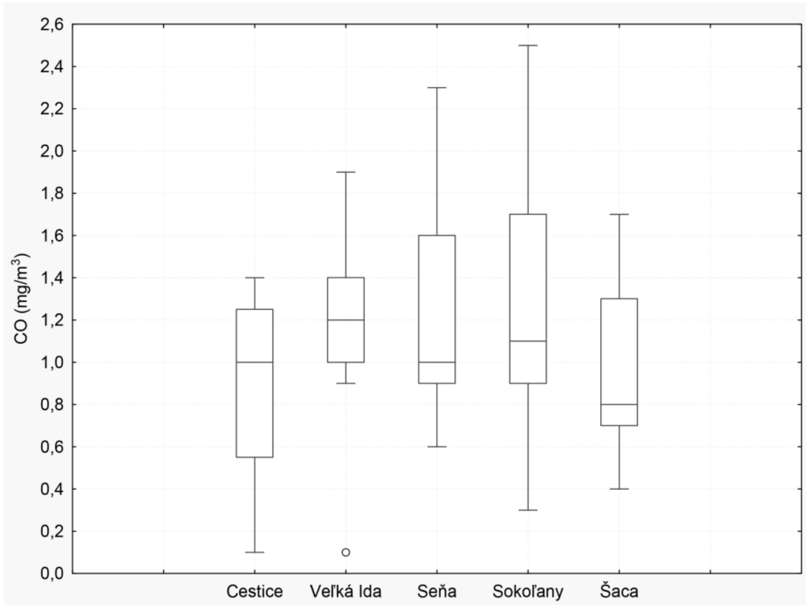


Figure 2. Carbon oxide
Slika 2. Ugljični monoksid

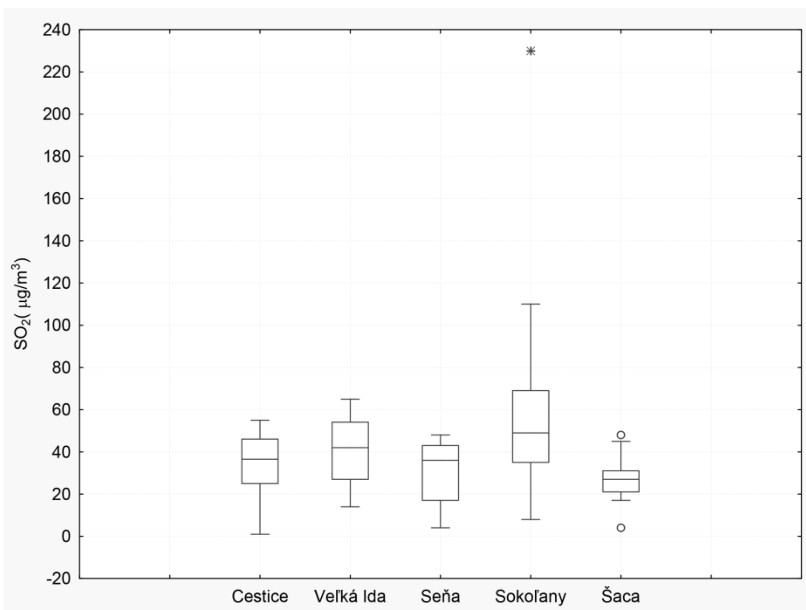


Figure 3. Sulphur okside
Slika 3. Sumporni dioksid

During the existing time period the highest average $\mathbf{NO_2}$ value was measured in the monitoring area Sokoľany. The order of the areas of the highest average NO_2 concentration is as follows: Veľká Ida > Sokoľany > Seňa > Šaca > Cestice.

In the monitoring area Cestice the highest average value of ozone $\mathbf{O_3}$, of allowed limit 120 μm/m^3, was measured during the time period of the monitoring. The order of the areas of the highest O_3 concentration is as follows: Cestice > Sokoľany >Veľká Ida > Seňa > Šaca.

The highest **PM_{10}** value was measured in the monitoring area Veľká Ida representing 1.2 multiple of allowed 50 µm/m^3 limit value. The order of the areas air pollution is as follows: Veľká Ida > Seňa > Šaca > Sokoľany > Cestice.

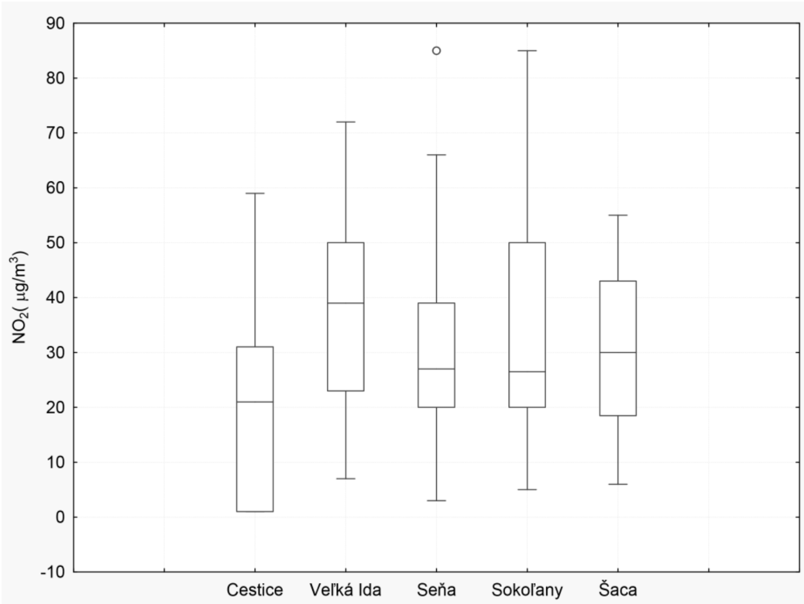


Figure 4. Nitrogen oxides
Slika 4. Dušikovi oksidi

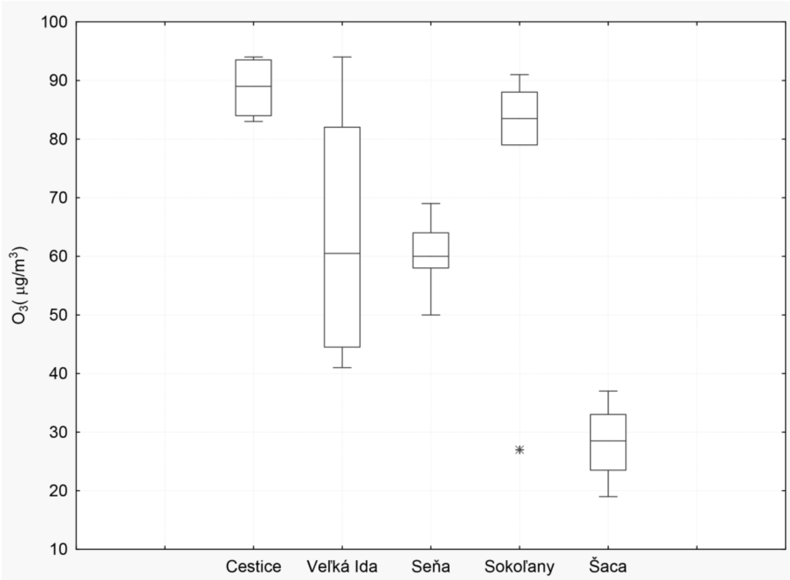


Figure 5. Ozone
Slika 5. Ozon

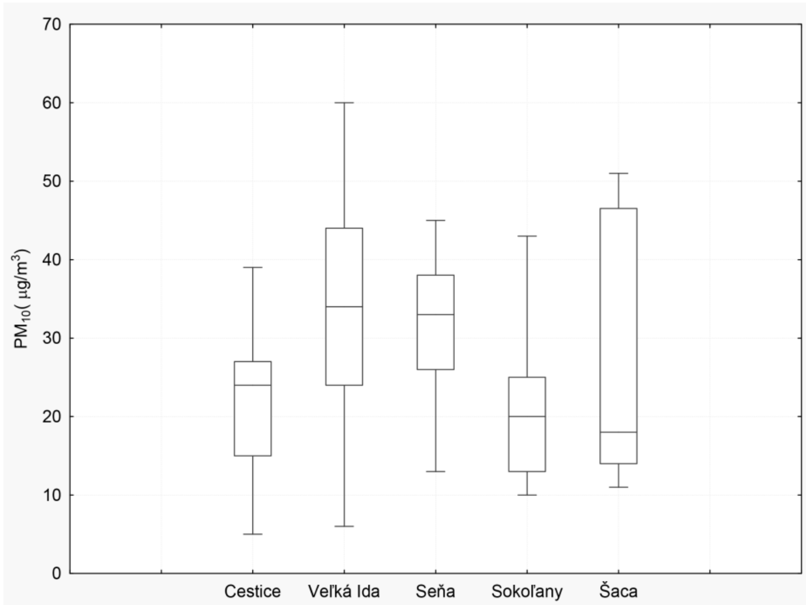


Figure 6. Dust particle
Slika 6. Čestica prašine

Air Quality Index (AQI) was applied in air quality assessment (Table 3).

Table 3. Breakpoints for the AQI (according to [18])
Tablica 3. Prijelomne točke za AQI (prema [18])

Pollution category	CO (8h) (mg/m^3)	SO_2(24 h) (µg/m^3)	NO_2(1 h) (µg/m^3)	O_3(8 h) (µg/m^3)	PM_{10}(24 h) (µg/m^3)
Unhealthy	15.5-30	500-1000	950-1900	223-500	238-500
Unhealthy for sensitive groups	11.6-15.5	250-500	400-950	180-223	144-238
Moderate pollution	10-11.6	125-500	200-400	120-180	50-144
Low pollution	4-10	20-125	40-200	65-120	20-50
Good quality	0-4	0-20	0-40	0-65	0-20

The measured data analysis most frequently shows the low level of air polluted by surveyed indicators in respective monitoring areas (Table 4).

Table 4. AQI of surveyed indicators in respective monitoring areas
Tablica 4. AQI istraživanih pokazatelja u promatranim područjima

Monitoring areas	CO (8h) (mg/m^3)	SO_2 (24 h) (µg/m^3)	NO_2 (1 h) (µg/m^3)	O_3 (8 h) (µg/m^3)	PM_{10} (24 h) (µg/m^3)
Cestice	Good quality	Low pollution	Low pollution	Low pollution	Low pollution
Veľká Ida	Good quality	Low pollution	Low pollution	Low pollution	Moderate pollution
Seňa	Good quality	Low pollution	Low pollution	Low pollution	Low pollution
Sokoľany	Good quality	Low pollution	Low pollution	Low pollution	Low pollution
Šaca	Good quality	Low pollution	Low pollution	Good quality	Low pollution

PCA method

The first step of the PCA method is to review the mutual relations among respective contamination indicators while the correlation matrix of input variables is the initial source (Table 5). The correlation coefficients indicate the contamination substance NO_2 showing a very high positive correlation with CO (r=0.800) and SO_2 and CO (r=0.752). A strong positive correlation is between the indicators NO_2 and PM_{10}(r=0.645). The indicator O_3 is in a slight negative correlation with NO_2 (r=-0.416) with PM_{10} (r=-0.438) and in slightly positive correlation with SO_2 (r=0.491).

Table 5. Correlation dependability of contamination substances
Tablica 5. Korelacijska ovisnost kontaminirajućih tvari

	CO	SO_2	NO_2	O_3	PM_{10}
CO	1				
SO_2	**0.752**	1			
NO_2	**0.800**	0.378	1		
O_3	0.129	**0.491**	**-0.416**	1	
PM_{10}	0.359	-0.317	**0.645**	**-0.438**	1

In determination of the principal components we apply our own figures (Table 6). PCA shows the first principle component accounting approximately 49.3% of total variability data and the second component 39.4%. The last two components together represent approximately 11.3% of total variability.

Table 6. PCA method results
Tablica 6. Rezultati PCA metode

	Comp.1	**Comp.2**	**Comp.3**	**Comp.4**
Eigenvalues	2.464	1.972	0.526	0.039
Standard deviation	1.569	1.404	0.725	0.196
Proportion of Variance (%)	49.27	39.43	10.51	0.78
Cumulative Proportion (%)	49.27	88.70	99.21	100

To specify the correspondent number of new variables we applied a Kaiser-Guttmann criterion according to what are regarding all own figures of the values higher than 1 [9, 12, 13]. Another rule recommends to take only so many principal components how many are representing 70 up to 90% of total variability [11, 13]. It results in knowledge that regarding the specification of new variables we took initial two principal components comprising together approximately 88.7% of total variability data.

The shapes of initial two principal components:

$$Comp.1 = 0.592\,Co + 0.341\,SO_2 + 0.613\,NO_2 - 0.121\,O_3 + 0.378\,PM_{10}$$

$$Comp.2 = 0.238\,Co + 0.584\,SO_2 - 0.146\,NO_2 + 0.600\,O_3 - 0.470\,PM_{10}$$

The first component is including two indicators (CO, NO_2) of approximately equal absolute value of the weight. The second component above all includes the indicators O_3, SO_2 and PM_{10}.

Cluster Analysis

The cluster method was applied to sort the monitoring areas of similar characteristics according to the level of air pollution. Stepwise were chosen the agglomerative hierarchical methods: the method of average binding, the method of nearest neighbour, the method of the farthest neighbour, Ward method, the method of centroids and meridians. The Euclidean distance, being the most common technique, was applied as the distance metric, and two principle components generated via PCA method were utilized as the input variables.

The cophenetic correlation coefficient CC was applied to verify the results and to determine the best clustering method. The closer to 1 is its value the more appropriate is the method of hierarchical and agglomerative clustering applied in analysed data structure definition [11, 16]. The results indicate that average-link clustering seems to be the most suitable clustering technique (CC=0.84).

The monitoring areas Veľká Ida, Sokoľany and Seňa are of similar characteristics and are forming one cluster. Another two monitoring areas Cestice and Šaca represent additional independent group (Figure 7).

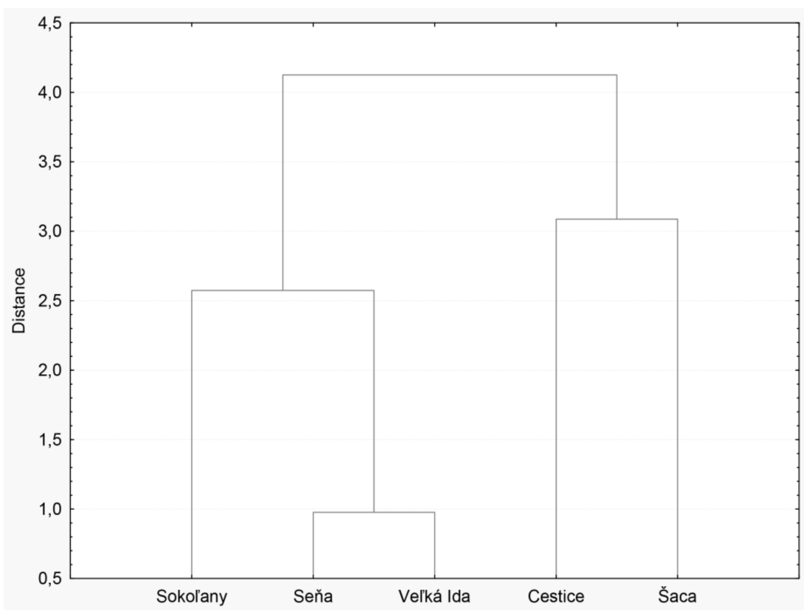


Figure 7. Dendogram
Slika 7. Dendogram

Multidimensional comparison methods

Our additional aim is to define the final order of the air pollution in selected monitoring localities based on the level of air polluted by surveyed contamination substances. In comparison of monitoring areas were chosen the methods: simple ordering method, the scoring method, the standardized variable method and the fictitious point distance method [17]. All variables are deemed as de-stimulating variables (its decrease is the positive effect).

A. Ordering method

Through the ordering method the area of the lowest average value of surveyed parameter was assigned with the highest value equal to 1. In case of the equal values the respective monitoring areas were assigned with average order. The final order of surveyed areas was determined based on the sum of the respective orders. The area of the lowest sum of orders is assigned with the lowest order.

The analysis indicates that Veľká Ida is the monitoring area of the highest concentration of air pollution substances and Šaca is the area of the lowest concentration. The final order is as follows: Veľká Ida > Sokoľany > Seňa > Cestice > Šaca.

B. Scoring method

With the scoring method the determined values of variables were replaced with the number of points. Maximum number of 100 points was assigned to the area of the lowest value of given parameter. Remaining monitoring areas were assigned with the number of points according to formula

$$z_{ij} = \frac{x_{\min,j}}{x_{ij}}.100\% \quad \text{where} \quad i = 1,2,...m,\ j = 1,2,...k, \tag{1}$$

where $m = 5$ is the number of monitoring areas, $k = 5$ is the number of variables, b_{ij} is the number of points of j variable in i measuring area, x_{ij} is the value of assigned variable appertaining to i area and $x_{min,j}$ is the minimum value of the respective variable. Based on the total score d_i is defined the order of the respective monitoring areas. The final order of the monitoring areas is as follows: Veľká Ida > Sokoľany > Seňa > Cestice > Šaca.

C. Standardized variable method

The values of de-stimulating variables are standardized according to the relation

$$z_{ij} = \frac{\bar{x}_j - x_{ij}}{s_j}, \quad i = 1,2,...5,\ j = 1,2,...5, \tag{2}$$

Where: $\bar{x}_j$ is arithmetic mean and s_j is standard deviation of j variable. Based on the arithmetic mean of $\bar{z}_i$ standardized values was determined the order of the monitoring areas depending on the air pollution. The final order of the monitoring areas is as follows: Veľká Ida > Sokoľany > Seňa > Cestice > Šaca.

D. Fictitious point distance method

First was defined the fictitious point with the co-ordinates depending on the type of the variable. With de-stimulating variables of

$$z_{oj} = \min_i \{z_{ij}\}, \quad \text{with} \quad i = 1,2,...5, \tag{3}$$

Where: z_{ij} are the standardized values of the variables.

The order of the areas was specified through the average Euclidian fictitious point distance d_i

$$d_i = \sqrt{\frac{1}{k}\sum_{i=1}^{k}\left(z_{ij} - z_{oj}\right)^2}, \quad i = 1,2,...5. \tag{4}$$

The final order of the monitoring areas is as follows: Veľká Ida > Sokoľany > Seňa > Šaca > Cestice.

Overall analysis of the air pollution assessment indicates the order of the monitoring areas as follows in Table 7.

Table 7. Final order of monitoring areas (from locality of the highest level of pollution)
Tablica 7. Konačni poredak praćenih područja (od lokaliteta najviše razine onečišćenja)

Order	Ordering method	Scoring method	Standardized variable	Fictitious point distance method
5.	Veľká Ida	Veľká Ida	Veľká Ida	Veľká Ida
4.	Sokoľany	Sokoľany	Sokoľany	Sokoľany
3.	Seňa	Seňa	Seňa	Seňa
2.	Cestice	Cestice	Cestice	Šaca
1.	Šaca	Šaca	Šaca	Cestice

Any applied method indicates that the village Veľká Ida is the area of the highest air pollution. Next are the villages Sokoľany, Seňa and Cestice. The monitoring area Šaca seems to be the location of the lowest level of the air pollution.

Equal orders were verified by *Kendall coefficient of concordance* W.

Regarding the concerned case the coefficient of concordance value is $W = 0.963$ and indicates a good concordance of the respective methods results. The statistical significance of Kendall coefficient of concordance was confirmed through the table of critical values of real distribution of parameter, made by M. Friedman [15].

CONCLUSION

In east Slovakia the air quality is to a great degree influenced by the activities of big industrial sources within both the metallurgical and the chemical industries and through the production of heat and electric energy.

The monitored areas are located near of the air pollution source. The level of the air quality of monitored areas was describe by five contaminations substances: CO, SO_2, NO_2, O_3 and PM_{10}. It follows from the correlation matrix that there is a very strong possitive correlation between SO_2 and CO (r=0.752), and CO and NO_2 (r=0.800).

The five original dependent variables were replaced with two independent input variables. These were determined according to PCA and cumulatively accounted for almost 89 percent of the total data variance. The results of the hierarchical agglomerative method of average-link clustering pointed to the fact that Veľká Ida, Sokoľany and Seňa are of similar characteristics and are forming one cluster. The statistical analysis indicates that Veľká Ida has the highest average concentrations of three of the five monitoring indicators (SO_2, NO_2 and PM_{10}). A similar result was obtained through the multidimensional comparison methods. Based on the comparison of the measuring areas within the plant environment we found that the highest pollution was in the locality Veľká Ida and the lowest pollution was in the locality Šaca. Surprising is that the pollution source nearest locality Šaca is the locality of the best air quality state. The reason regarding may be the appropriate meteorological conditions and especially the speed and the direction of the wind.

Acknowledgements

The work presented in this paper was supported by the Project KEGA 072TUKE-4/2014 and VEGA 1/1216/12. This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0432-12.

REFERENCES

[1] M. Demo, O. Hronec, M. Tóthová et al.: Sustainable development. Living within the carrying capacity of biosphere (in Slovak), SPU Nitra, 2007.

[2] R. Králiková, M. Badida, J. Halász: Environmental protection equipment (in Slovak), Elfa, Košice, 2007.

[3] M. C. Minguillón, E. Monfort, A. Escrig, I. Celades, L. Guerra, G. Busani, A. Sterni: Air quality comparison between two European ceramic tile clusters. Atmospheric Environment, Volume 74, 2013, pp. 311-319.

[4] Air quality in Europe - 2012 report. Accessed last on 22nd August 2013. http://www.eea.europa.eu/publications/air-quality-in-europe-2012.

[5] The air in Europe contains many harmful substances (in Slovak). Accessed last on 22nd August 2013. http://www.euractiv.sk.

[6] Law No. 137/2010 Coll. of Laws on the Air (in Slovak).

[7] Ministry of Environment Regulation No. 360/2010 Coll. of Laws on the Air Quality Limit Values (in Slovak).

[8] Directive 2008/50/EC on ambient air quality and cleaner air for Europe.

[9] I. T. Jollifte: Principal Component Analysis, Springer – Verlag, New Yourk, 2002.

[10] P. Hebák: Multivariate statistical methods 3 (in Slovak), Informatorium, Praha, 2007.

[11] M. Meloun, J. Militky: Computer analysis of multidimensional data in the examples (in Czech), Academia, Praha, 2005.

[12] M. Meloun, J. Militky: Compendium of statistical data processing (in Czech), Academia, Praha, 2006.

[13] I. Stankovičová, M. Vojtková: Multivariate statistical methods with application (in Slovak), IURA Edition, Bratislava, 2007.

[14] B. S. Everitt, S. Landau, M. Leese: Cluster Analysis, Wiley, London, 2001.

[15] A. Melka: Fundamentals of experimental psychoacoustics, Akademie muzickych umeni, Praha, 2005.

[16] H. Řezanková, D. Húsek, V. Snášej: Clusters analysis of data (in Czech), PB, Praha, 2009.

[17] M. Pažitná, V. Labudová: Methods of statistical comparisons (in Slovak), Ekonóm, Bratislava, 2007.

[18] A. Plaia, F. Di Salvo, M. Ruggieri, G. Agró: A multisite-Multipollutant air quality index, Atmospheric Environmnet, Volume 70, 2013, pp. 387-391.