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Environmetric expertise of the water quality of the urban section of Banshtitsa River

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The goal of the present study is to demonstrate the power of the environmetric expertise of river water quality . Using cluster analysis and principal components analysis to interpret monitoring data collected in the urban sector of the stream of Banshtitsa river during summer period it has been shown that at least four major anthropogenic pollution sources are responsible for the water quality: illegal dumping sites, construction material, water acidity, waste water inlets. Specific markers for each one of the sources were found and, respectively, interpreted.

Keywords: environmetrics; in-situ monitoring; river water quality

Introduction

Banshtitsa River is located in Western Bulgaria being a tributary to Struma River near to Town of Kyustendil. Its length is about 22 km and collects the waters from the northern parts of Osogovo mountain as well as the southern parts of Lisets mountain.

It is interesting to mention that the river flows through the central part of Town of Kyustendil being subject to various anthropogenic impacts. Thus, the water quality is seriously anthropogenically influenced exactly in this urban sector. It was interesting to interpret the monitoring data by advanced methods of intelligent data analysis in order to model and assess the risk of pollution in the urban sector of the river flow.

The substantial advantage of the environmetrics in pollution risk assessment is the option to take into account the influence of all water features simultaneously on the water quality rather than to compare single monitoring events to prescribed threshold values. Thus, the environmental system is considered as a multiparametric object affected simultaneously by various natural and anthropogenic impacts. The data interpretation and modeling becomes complete and makes it possible to identify and quantitatively estimate the role of different pollution sources within an environment [1-11].

It is the aim of the present study to assess the quality of the urban sector of Banshtitsa River using rapid monitoring procedure for a certain number of water quality parameters and application of environmetric methods (cluster analysis and principal components analysis) for data interpretation and modeling.

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Experimental

Sampling and monitoring procedures

The monitoring net of the urban sector of Banshtitsa River is presented in *Fig. 1*.

Figure 1. Monitoring net of the urban sector (Town of Kystendil) of Banshtitsa River

As seen in the figure 12 sampling locations are indicated but, in deed, only the first 10 of them were of interest for the study. In general, site 1 is the starting point (entrance of the river stream into the town); sites 2 to 9 are located near to the bridges across the river and site 10 is a typical anthropogenically impacted industrial site named "canal". Through the cemented bed of the canal waste water is introduced to the river stream often without any treatment. On the map the indicated sites 11 and 12 are also similar canal being completely dry during the summer and are not involved in the statistical interpretation.

The monitoring procedure is selected with respect to the instructions of the National system for environmental monitoring and the National Executive Environmental Agency. In this study of the urban sector of the Banshtitsa River the monitoring was performed in a distance of about 3 km with sampling at each 250 m. The monitoring was carried out in the summer period of 2010.

Following 18 water quality indicators were measured:

- pH
- Temperature (T)
- Conductivity (EC)
- Total dissolved sulfur (TDS)
- Nitrate (NO_3^-)
- Nitrites(NO_2^-)
- Chlorine (Cl) (free, total, combined- Clf, Clt, Clc)
- Cyanuric acid (CYS)
- Total hardnes (as CaCO3 - TA)
- Copper (total, free, bonded – Cut, Cuf, Cuc)
- Iron (Fe)
- Radiation (Ra) (background, water, sediment – Rab, Raw, Ras)

Following analytical methods and instruments were used: Hanna HI9813-6 apparatus for measurement of pH, T, EC and TDS after respective calibration by standard solutions. The rest of the water parameters were determined by spectrophotometry (Lovibond instrument). The radiation was measured by Geiger counter Radex RD1503.

It is readily seen that the water quality parameters chosen for monitoring differ from those being typical for assessment of surface water quality. Here we briefly explain the use of some of the non-typical indicators.

Radioactivity was measured because during studied period municipality used waste material from lead-zinc mining industry for wide construction works around the Town of Kyustendil. Moreover the aim of the study was to investigate the impact of the illegal landfills along the river, which are rich of construction waste and domestic waste, including electronic devices.

Cyanuric acid is measured because it is a specific parameter of the water especially of this river. Cyanuric acid is a result of degradation of chemical components which present in the domestic waste – disinfectants, paints, varnish, and etc. so it is an important indicator for the impact of illegal landfills along the river.

Different forms of Cl and Cu suppose better distinguishing between natural mineral forms of both elements and probable their contaminating soluble forms.

Measured parameters are chosen on basis of probable pollutants specific for the studied river environment. The main environmental problem of the target area is domestic waste dumped along the river or imported through the canals (pipes) from the town.

In-situ measurements were carried out after grab sampling allowing not only rapid procedure but sufficient precision and low uncertainty of the analytical measurements.

Environmetric methods

In the data treatment two major environmetrics approaches were used: cluster analysis and principal components analysis.

Cluster analysis [12] is a well-known and widely used classification approach. In order to cluster objects characterized by a set of variables one has to determine their similarity. A preliminary step of data scaling is necessary, where normalized dimensionless numbers replaces the real data values in order to eliminate dimension differences. Then, the similarity (or the distance) between the objects in the variable space can be determined. Very often the Euclidean distance is used for clustering purposes. Thus, from the input matrix (raw data) a similarity matrix is calculated. There is a wide variability of hierarchical algorithms but the typical ones include the single linkage, the complete linkage and the average linkage methods. The representation of the results of the cluster analysis is usually performed by a tree-like scheme called dendrogram comprising a hierarchical structure (large groups are divided into small ones).

Principal components analysis (PCA) [13] is a typical display method, which allows estimating the internal relations in the data set. There are different variants of PCA but basically, their common feature is that they produce linear combination of the original columns in the data matrix (data set) responsible for the description of the variables characterizing the objects of observation. These linear combinations represent a type of abstract measurements (factors, principal components) being better descriptors of the data structure (data pattern) than the original (chemical or physical) measurements. Usually, the new abstract variables are called latent factors and they differ from the original ones named manifest variables. It is a common finding that just a few of the latent variables account for a large part of the data set variation. Thus, the data structure in a reduced space can be observed and studied. The new coordinates are called factor scores and the regression coefficients from the linear combination of the old variables – factor loadings.

In case of many studies related to natural ecosystems PCA and other multivariate statistical techniques are used to determine possible natural or anthropogenic influences in the formation of the determinants total mass. However, PCA does not provide a direct balancing and apportionment.

The software package used for calculation is STATISTICA 7.0.

Results and discussion

In *Fig. 2* the hierarchical dendrogram for clustering of the water quality indicators is shown. The clustering was

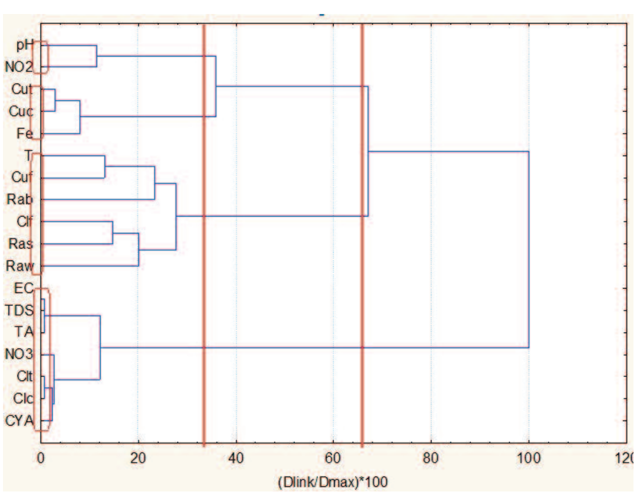

Figure 2. Hierarchical dendrogram for clustering of water quality indicators

performed by the use of Ward's method of linkage, squared Euclidean distance as similarity measure, z-transform of the raw data and Sneath's index for determination of cluster significance.

Four significant clusters are formed:

K1 (EC, CYA, TDS, TA, NO_3, Clt, Clc) – anthropogenic pollution

K2 (Ras, Raw, Rab, Clf, Cuf, T) - radioactivity impact

K3 (Fe, Cuc, Cut) – illegal dumping

K4 (pH, NO_2) – acidity factor

The four cluster reflect in a convincing way the sources which influence the water quality in the urban sector of Banshtitsa River. The first cluster K1 indicates the anthropogenic impact by linkage between chloride, sulphur, cyanuric acid and nitrate content. K2 informs on the enhanced radioactivity impact due probably to the use of specific construction materials in the vicinity of the river banks. The third cluster K3 stands for assessment of the illegal dumping activities around the river. The fourth cluster shows the influene of the enhanced acidity due to anthropogenic impacts (illegal dumping and landfill sites, waste water inlets, construction activities etc.)

In *Fig. 3* the hierarchical dendrogram for clustering of the sampling locations in the urban sector of Banshtitsa River is presented.

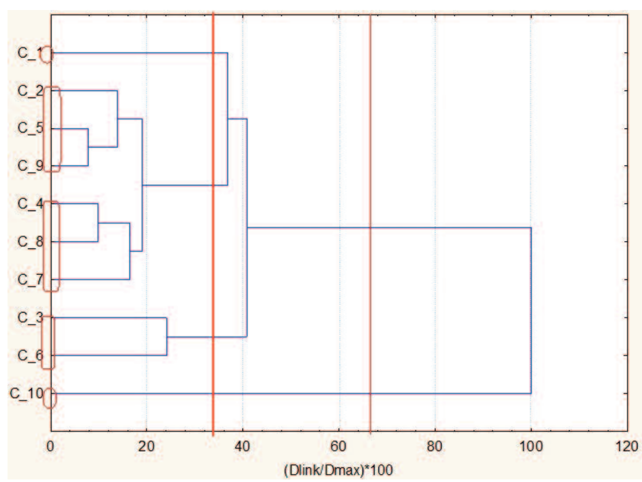

Figure 3. Hierarchical dendrogram for clustering of the ten sampling locations

Two of the sampling sites differ significantly from therest. These are locations 1 and 10 – the starting and the final site in the monitoring scheme of the urban sector.

Site 1 is characterized by very high levels of copper and iron, i.e. is a anthropogenically impacted location. This location is known as an illegal dumping site. It is also illegal landfill for dumping of various wastes as domestic and construction waste, coal ash, and electronic devices.

The other outlier is sampling location marked as site 10

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on the map. It is at the end of the urban sector of Banshtitsa River and from the monitoring results is evident that highest levels of chemicals, mud and sediments are found there. The location is known for very contaminated water content due to car workshops in the neighborhood and some recreation centers.

The other 8 sampling sites show quite homogeneous linkage (high level of similarity). This is an indication that the water quality between the end points of the urban sector (sites 1 and 10) is acceptable and not affected by anthropogenic influences.

Additionally, principal components analysis was performed in order to confirm the results from cluster analysis. Varimax rotation mode was used for better separation of the latents factors identified. In *Table 1* the factor loadings are presented.

Table 1. Factor loadings (significant loadings are marked by bold)

Variable	Factor – 1	Factor – 2	Factor – 3	Factor – 4
pH	0.224	-0.097	0.359	**-0.804**
EC	**0.896**	-0.112	0.195	0.067
TDS	**0.895**	-0.113	0.208	0.039
T	0.255	0.169	**-0.748**	0.333
NO_3	**0.901**	0.257	-0.103	-0.017
NO_2	0.231	0.201	**0.83**	-0.179
Clf	-0.49	0.367	-0.021	0.105
Clt	**0.947**	0.042	0.11	-0.084
Clc	**0.964**	0.029	0.034	0.09
CYA	**0.957**	0.187	0.04	-0.05
TA	**0.934**	-0.035	0.139	0.038
Cuf	-0.316	0.103	**-0.871**	-0.055
Cut	-0.109	**0.94**	-0.231	-0.024
Cuc	0.047	**0.956**	0.233	0.001
Fe	0.144	**0.693**	0.545	-0.316
Rab	0.365	0.116	-0.047	**0.764**
Raw	-0.555	-0.393	-0.062	**0.593**
Ras	0.082	**0.648**	-0.166	0.333
Expl. Variance %	39	17.9	15	11

Four latent factors are responsible for explanation of over 80% of the total variance. The first latent factor PC 1 explains 39% of the total variance and indicated high correlation between the indicators EC, CYA, TDS, TA, NO_3, Clt, Clc (resembling entirely the linkage in cluster 1). This factor could be conditionally named “anthropogenic” factor and it is related mostly to sampling locations 1 and 10.

The second latent factors indicates high correlations (factor loadings) for copper and iron. Both of them are of anthropogenic origin and could serve as indicators for seriously polluted waste water inlet from illegal landfills and industrial wastes. It holds for almost 18% of the total variance and could be conditionally named “waste water inlet” factor.

The natural physical influences on the water quality are expressed by latent factor PC3 which explains 15% of the total variance and its conditional name could be “natural temperature factor”. Its direct explanation by the factor loadings is not very simple since it indicates correlation between temperature and free copper content (indication for the seasonal impact of waste products on the water quality) but there is also negative correlation of these two indicators to nitrite content being marker for oxidative processes (also temperature depending).

Finally, latent factor PC4 is a convincing proof for the enhanced level of radioactivity of the river stream in the urban sector. This factor explains 11% of the total variance and shows good relationship between the radioactivity in the background earth layer and the water. The relationship to the sediment radioactivity is not so strong but it is well known that the accumulation of pollutant in the river sediments needs significant time. Its conditional name could be “radioactivity” factor indicating the pollution by specific for this particular environment pollution by construction materials and wastes.

Conclusion

The environmetric expertise of the monitoring data from the urban sector (Town of Kyustendil) from the main stream of Banshtitsa River has shown that the application of multivariate statistical methods of assessment of the pollution risk reveals more options for identification and classification of suspected but not proven pollution sources. The cluster and principal componets analysis models offer a reliable decision making background for actions to prevent further pollution of the urban sector of the river like elimination of illegal dumping sites, waste water treatment procedures, careful control of the construction materials used for municipal enterprises. The study shows once more the important role of the monitoring procedures esecially those which have been performed in a rapid and reliable way (in-situ analysis).

The present study could be of use for comparative monitoring actions allowing both temporal (seasonal monitoring) and spatial (larger monitoring net) observations and conclusions for the environment in consideration.

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Екометрична експертиза на качеството на водите в градския сектор на река Банщица

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Целта на настоящото изследване е да демонстрира способността на екометричната експертиза при оценка на качеството на речни води. Чрез използване на кластерен анализ и анализ на главни компоненти за интерпретация на мониторингови данни от градския сектор на течението на река Банщица е показано, че поне четири основни антропогенни източници на замърсяване са отговорни за качеството на водите през летния сезон: незаконни сметища, строителни материали, повишена киселинност и изпускане на отпадни води в реката. За всеки от източниците е намерен специфичен маркер.

Ключови думи: екометрия; качество на речни води; мониторинг *in-situ*