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RISK MANAGEMENT SCENARIO FOR MULTIPLE HEAVY METAL CONTAMINATION AT RIVER SEDIMENTS IN THE MIDDLE ISKAR CASCADE

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Abstract

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In the middle part of Iskar River, the effects of complex pollution with organics and difficult-biodegradable compounds have been observed from decades. Nowadays this part of the river is a subject of intensive hydrotechnical activity for construction of a cascade of 9 mini-hydroelectric power stations and this strongly poses the question of ecological improvement and achievement of high energy efficiency. The main objective of this work was to design, develop and apply a management scenario to indicate the potential risk level of heavy metal concentrations in river sediments, related to response of sediment microbial communities – one of the most sensitive indicators for pollution and ecosystem self-purification potential. The study was realized on 5-step schedule including: a long-term monitoring of water and sediment quality; identification of risk with primary significance and real risk situations for this period; analyses of the risk factors; evaluation of response of the microbial communities; assessment of relation between level of risk factor and response by correlative dependences. The heavy metals concentrations were determined by atomic absorption spectrophotometry; the total microbial count and number of bacteria cultivated on Endo-media were analyzed by standard BDS-EN-ISO cultivation methods. The assessment of relevant microbial response shows an obvious effect of risk metals concentrations – a strong reduction of total microbial count with high correlation coefficients at the beginning of the cascade where organics accumulation processes are not significant. At the other sampling sites the relation is more clearly presented with the Endo-bacteria. The correlative description of this relationship and implementation of specific risk management scenario allows to collect updated information for ecosystem response at shock pollution with hazardous materials and to initiate the development of bioremediation strategy for improving of the environmental status of the river sediments.

Key words: risk management; hazardous pollutants; river sediments; microbial indicators

Abbreviations: CFU – colony forming units; HMs – heavy metals; MAC – maximal admissible concentration; TMC – total microbial count

Introduction

Heavy metals and micropollutants contamination of the sediments is a serious problem in hydroecosystem scale, which has not lost its relevance in recent years (Schwarzenbach et al., 2006; Wang et al., 2004). In Bulgaria there are still many unsolved problems with hazardous pollution of the river sediments subjected to strong

anthropogenic impacts in the past and present. A typical example is the middle part of Iskar River, where these problems remain very acute and the sediments in this area continue to be a critical ecosystem component with a high risk level for the environment and humans. At the same time the growing need of using of renewable energy sources and hydrological characteristics stimulate the development of projects aimed to utilization of hydropower

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in the middle part of Iskar River. In last 8 years, the river sector has been object of intensive hydrotechnical activity for construction of cascade of 9 micro-hydroelectric power plants and the importance of the sediments status and the fate of accumulated toxic and difficult-biodegradable pollutants have been increased to the primary risk level (Todorova and Topalova, 2010a; 2013).

The aim of this work was to design, develop and apply a management scenario to indicate the potential risk level of heavy metal concentrations in river sediments, related to response of sediment microbial communities – one of the most sensitive indicators for pollution and ecosystem self-purification potential (Pronk et al., 2009; Sandaa et al., 1999).

Materials and Methods

Experimental design and analytic procedures

The study was realized in the area of Middle Iskar cascade – 33 km river sector between Svoje and Elisejna. In the river sector, the long-term extensive monitoring program was applied for assessment of water and sediment quality in connection with construction and functioning of hydropower plants. In this work the emphasis was placed on the analyses of chemical and microbial indicators for sediment status in three sampling sites – critical control points for management of risk situations in the cascade. The first site was at the beginning of the river sector – Prokopanik, the second site was at dam wall of the first hydropower plant Lakatnik and the third – at the end of river sector Gabrovnica. The initial position of the first two points has a crucial role for further functioning of the whole cascade and the final location of third allows the implementation of adequate process control. The detail scheme of study area is presented in Todorova and Topalova, 2010a and 2010b. The sediment samples from river sector were collected during the summer low water periods in years 2006–2012. The first sampling year for Lakatnik Dam was 2008 – the initial year of its functioning. A total of 19 sediments samples were processed (all at least in triplicate). The heavy metals concentrations were determined by atomic absorption spectrophotometry and were presented in mg kg^{-1} ; the total microbial count and number of bacteria cultivated on Endo-media (coliforms, *Pseudomonas*, *Aeromonas*) were analyzed by standard BDS-EN-ISO cultivation methods on specific media (Scharlau Chemie, S.A.). Cultivation was carried out for 24–48 h at 35°C for both of groups. The data for microbial counts were presented as Ln CFU.g^{-1} .

Results and Discussion

The proposed risk management scenario for sediment status in Middle Iskar cascade is given on Figure 1. The scenario is realized on 5-step schedule including the following steps:

Monitoring and screening: A long-term monitoring program has been applied for assessment of actual water quality, sediment status, ecological state and self-purification potential of middle Iskar hydroecosystem. The obtained results for various parameters of waters and sediments, and different segments of biocenoses are published and discussed in details (Lincheva et al., 2010; 2011; Todorova and Topalova, 2010b; Mihailova et al., 2013; Yotinov et al., 2013).

Identification of risk with primary significance: The monitoring data analyses identify and prioritize one general ecological problem in sediments of cascade – heavy metals contamination and uncontrollable accumulation/deaccumulation of these pollutants in sediment surface layers and waters. The concentrations of priority pollutants Cd, Hg, As and Pb, and specific pollutants Cu and Zn were determined and analyzed for 7-years period in sediments of three critical control points in cascade. The further identification defines several **real risk situations** during the studied period: a sharp increase of Cd, Zn, Cu, Pb and As concentrations at the beginning of the cascade in 2009; the increase of cadmium concentration in 2009 was registered clearly in the other sampling sites of the cascade, too; Hg-concentration was over the limits in 2011 for the tree sampling sites (Figure 2). The chosen criteria for evaluation of this scenario step are maximal admissible concentrations (MACs) for each heavy metal. The exceeding over MACs according to Bulgarian legislation was registered for all of these risk situations.

Analyses of risk factors: At this step with critical meaning is answer of questions: *Does the registered exceed is for one or more heavy metals? And is there impact of other risk factors with cumulative effect?* The specific scenario for each of these variations must to be developed although the next steps are the same.

Identification and evaluation of response of the sediment microbial communities: The applied criteria are numbers of key microbial indicators and % of their reduction or increase at risk situation. The dynamics of microbial abundance is shown on Figure 2. At multiple heavy metal contamination, registered on sampling site Prokopanik in 2009 (1st risk situation), the heavy metals concentrations were increased with: 48% over the means for Cd, 76% for Zn, 99% for As and with 150%

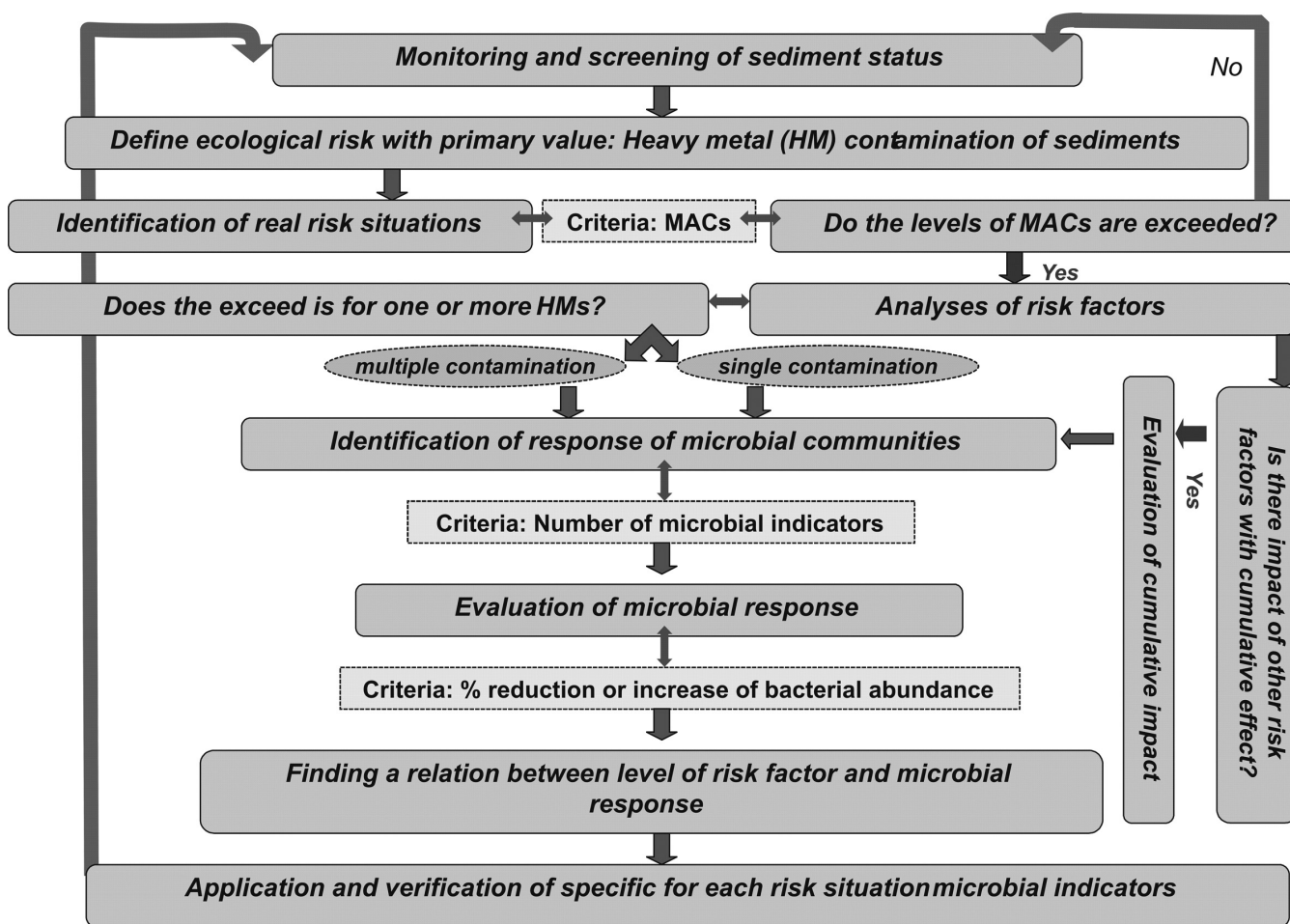


Fig. 1. Flowchart of the proposed risk management scenario

for Cu and Pb. The sediment microbial communities respond with a strong number reduction – more than 88% for TMC. During this year, a same increase of Cd-concentration was measured in the other sampling sites (2nd risk situation) but the degree of TMC and Endo-bacteria number reduction varied depending on the presence of simultaneous organic pollution in the site – 37% reduction in sediments of Lakatnik Dam (high organic accumulation) and 68% reduction in sediments of Gabrovnica (no organic accumulation). The results were similar for 3rd risk situation in 2011 – at high Hg-concentrations (two to four-fold increases) the microbial communities respond depending on the degree of organics accumulation – 30% reduction of Endo-bacteria numbers in sediments of Lakatnik Dam and 60% reduction in river sampling site (Gabrovnica).

Finding a relation between level of risk factor (increase of heavy metals concentrations) **and specific microbial response** (inhibition, activation or adaptation): The last step of proposed risk management scenario is to present statistically the relationship between excessive concentration of heavy metals and degree of microbial reduction. The correlation matrix is presented on Table 1. The TMC shows a strong negative correlation with variations of heavy metals concentrations in sediments of Prokopanik and this microbial parameter is suitable indicator for response of microbial communities in the first sites of the Middle Iskar cascade. For the micro-dams and the last sampling sites in the cascade, the number of Endo-bacteria presents a statistically significant negative correlation with change of heavy metals concentrations in sediments. The individual analysis for each heavy metal

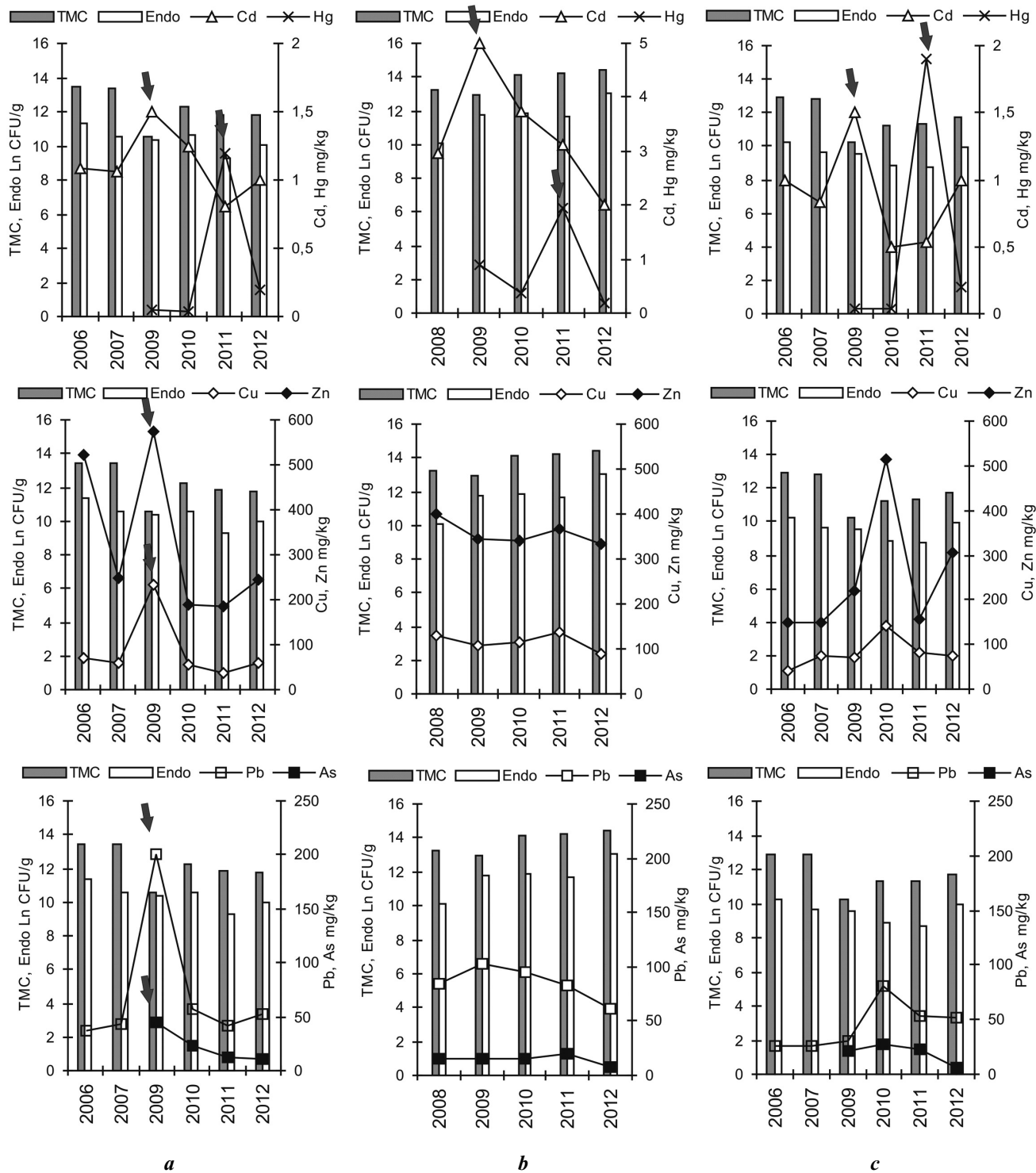


Fig. 2. Heavy metal concentrations and numbers of microbial indicators at three sampling sites Prokopanik (a), Lakatnik dam (b) and Gabrovnica (c) during the studied period

Table 1. Correlation matrix between heavy metals concentrations and number of bacterial indicators (bold correlations are significant at P<0.05)

	Sampling site	Cd	Hg	Cu	Zn	Pb	As
TMC	Prokopanik	-0.788	0.532	-0.884	-0.759	-0.952	-0.994
	Lakatnik	-0.717	-0.126	-0.196	-0.403	-0.670	-0.419
	Gabrovnica	-0.288	0.243	-0.380	-0.477	-0.372	-0.443
Endo-bacteria	Prokopanik	0.470	-0.951	0.146	0.264	-0.066	0.565
	Lakatnik	-0.209	-0.677	-0.760	-0.919	-0.383	-0.641
	Gabrovnica	-0.619	-0.584	-0.742	-0.754	-0.670	-0.851

shows a difference for Hg – the increase of mercury concentration correlated only with numbers of Endo-bacteria in the all sampling sites. This result can be explained by the high biotransformation potential of *g. Pseudomonas* and *g. Acinetobacter* as part of Endo-complex to xenobiotic substances with strong toxic effect.

Conclusion

Implementation of specially developed risk management scenario will allow to collect updated information for ecosystem response at shock pollution with hazardous materials and to initiate the development of bioremediation strategy for improving of the environmental status of the river sediments.

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