Spatial variability of heavy metal pollution in groyne fields of the middle Elbe – implication for sediment monitoring and risk assessment

MARTINA BABOROWSKI[1], PETER MORGENSTERN[1], THOMAS JANKE[2], BERNHARD WESTRICH[2]

Keywords: Elbe, sediments, transport, heavy metals, monitoring strategies

1 Introduction

Many European rivers like Danube, Elbe and Rhine have been regulated by engineering works for navigation and bank erosion protection. Regulating cross structures along the river banks, so called groynes, concentrate the discharge on the middle part of the river channel and hence, provide higher water level for navigation during low discharge periods. During low water level suspended material is being trapped in the slowly flowing water of the groyne fields and partly deposited whereas sediments can be re-suspended during high water stage (Ockenfeld & Guhr 2003). The German part of the Elbe River has a length of about 730 km, approximately 485 km of this stretch being regulated by about 6900 groynes field elements. Beside groyne fields, floodplains of about 800 km^2 are the main morphological features of the middle part of the Elbe River.

In the past, organic and inorganic pollutants have been discharged into the river system and are still present in deposited sediments due to historical contamination by industrial and municipal activities in the river basin (Heise et al. 2008). However, the water quality of the Elbe River and its tributaries improved considerably within the last two decades (Lehmann & Rode 2001; Zerling et al. 2003; Klemm et al. 2005; Guhr et al. 2006) comparable to other European rivers (Vink et al. 1999). Remobilization of deposited contaminants is a key issue for the river sediment management because of its impact on river ecology. Erosion, dispersion and re-deposition of groyne field sediments are important processes for environmental risk assessment. Hence, pollution sources must be explored and knowledge about erosion stability of fine contaminated sediments must be available to foster a sustainable development of the river system. As shown by Haag et al. (2001) and Gerbersdorf et al. (2007), cohesive sediment stability is characterized by high variability as depending on physico-chemical and biological properties. To assess the spatial variability of the heavy metal pollution of Elbe groyne field sediments, investigations considering horizontal and vertical gradients were performed.

2 Study area and methods

A groyne field, representative for the middle part of the Elbe River, located at rkm 319.5, left bank (nearby Magdeburg), was chosen as study area. The sediments are influenced by polluted discharges of industries located upstream and the input of two major tributaries, Mulde and Saale. The groyne field area is about 1034 m^2.

1 Helmholtz Centre for Environmental Research – UFZ, Dept’s River Ecology and Analytics, Brückstr. 3a, D-39114 Magdeburg, Germany. e-mail: martina.baborowski@ufz.de, peter.morgenstern@ufz.de
2 Institute of Hydraulic Engineering, Universität of Stuttgart– Laboratory, Pfaffenwaldring 61, 70550 Stuttgart, Germany. e-mail: thomas.jancke@iws.uni-stuttgart.de, bernhard.westrich@iws-uni.stuttgart.de

Since 2005 several investigations have been performed at this site in order to quantify the sedimentation/erosion dynamics (Prohaska et al. 2008). The results show high spatial heterogeneity of sediment quality and quantity in the observed groyne field, depending on the sampling spot, sediment layer and the sampling season.

In June 2008 an additional sediment sampling campaign took place at mean discharge. Depth profiles of critical erosion shear stress ($\tau_{crit,e}$), heavy metals and arsenic concentrations were investigated. Two parallel undisturbed sediment cores (10 cm diameter) up to 50 cm length were taken at 12 spots in the groyne field (Figure 1).

The critical erosion shear stress was measured in a laboratory channel, so called SETEG system (Kern et al. 1999). Heavy metals and arsenic concentrations were measured in sediment samples sieved < 2mm. After freeze-drying of the sieved samples, the bulk material was ground, pressed to pellets and finally analyzed by means of both energy- and wave length dispersive X-ray fluorescence analysis (EDXRF: XLAB2000, Spectro Instruments and WDXRF: S4 Pioneer, Bruker-axs). Detailed information on the methodology such as sample preparation, matrix influence and correction, precision and recovery are given in Morgenstern et al. (2004, 2005). The capabilities of different analytical techniques for the analysis of heavy metals in solid and liquid samples are discussed in Wennrich et al. 2004. In a former study (Morgenstern et al. 2008) it was shown, that for the analytical method used, most of the variability of the analytical results (97-99% of the total variance) arose due to the location variance resulting from true concentration differences between individual sampling sites. Estimates for the relative measurement uncertainty (caused by both analytical- and sampling variance) on the other hand amount to 2.5 % for As, 12 % for Cd, 2 % for Cu, 4 % for Cr, 12 % for Hg, 4.5 % for Ni, 1.5 % for Zn, 2% for Pb and 15% for U. Each uncertainty was obtained from a 95% prediction interval and analyte concentrations sufficiently beyond of the detection limit.

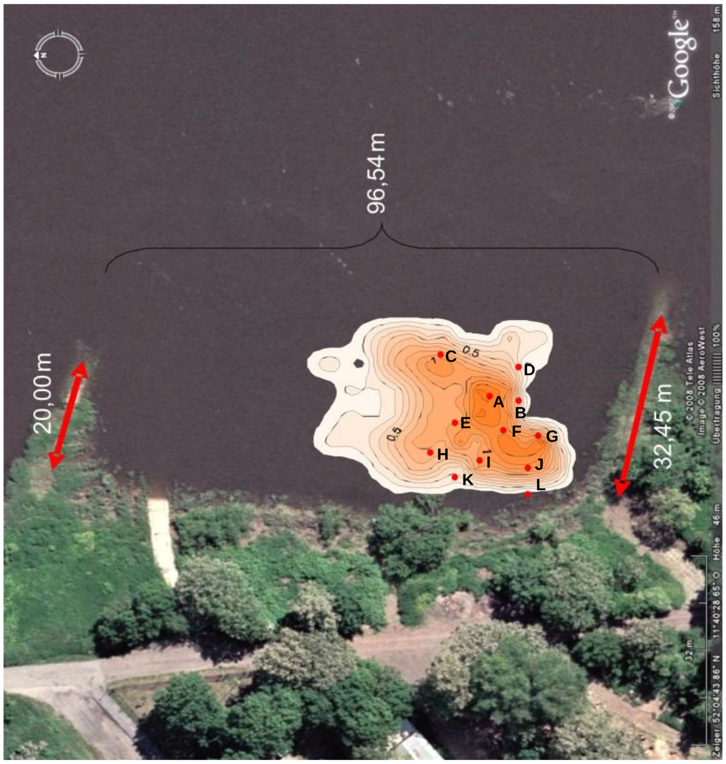

Figure 1. *Topography of the fine sediment deposits within the groyne field (contour lines given in meters) with position of sampling sites*

3 Results and discussion

According to morphological and changing hydrological conditions, the groyne field sediments in the middle part of the Elbe are characterized by varying fine and coarse material layers of different thickness. Expectedly, the critical erosion shear stress $\tau_{crit,e}$ shows a high variability, ranging from 0.3 up to 13.4 Pa. The heavy metal concentrations also show large vertical gradients in each of the cores: the median values of the 12 sediment cores at different depths are displayed in Table 1. The top sediment layer (0-10 cm), representing recently deposited, non-consolidated material, is less polluted compared to deeper and older sediment layers, proving the decreasing trend of the contamination; a more detailed overview of particulate arsenic contamination is shown in Figure 2. Beside the vertical variability, the graphs presented in Figure 2, demonstrate also a high spatial variability of the sediment composition.

Table 1. *Median concentration and range (minimum-maximum) of heavy metals and arsenic of sediment layers in different depth (in mg/kg)*

Depth	As	Cd	Cu	Cr	Hg	Ni	Zn	Pb	U
0-10 cm	33	6	88	101	2	38	999	99	1
	(15-267)	*(1-24)*	*(30-525)*	*(41-350)*	*(1-25)*	*(11-95)*	*(249-2120)*	*(36-476)*	*(1-21)*
0-20 cm	73	13	322	244	18	75	1402	188	8
	(15-269)	*(1-24)*	*(30-553)*	*(41-385)*	*(1-78)*	*(11-102)*	*(249-2228)*	*(36-520)*	(1-45)
0-30 cm	114	18	377	274	19	83	1598	270	13
	(15-343)	*(1-24)*	*(30-553)*	*(41-385)*	*(1-149)*	*(11-102)*	*(249-2407)*	*(36-568)*	(1-69)
Whole core	118	18	400	283	21	84	1658	271	13
	(15-343)	*(1-24)*	*(30-553)*	*(41-385)*	*(1-149)*	*(11-102)*	*(249-2407)*	*(36-568)*	*(1-69)*

Because of the high vertical variability, sediment monitoring must capture not only surface sediments but also deeper layers. As shown in Table 1 and Figure 2, monitoring based on sampling and analyzing surface sediments allows only assessing the environmental impact of discharges causing an erosion depth of less than 10 cm, while the level of uncertainty could be high for discharge events with higher shear stress. Monitoring for environmental risk assessment must be based on data about erosion threshold and contamination up to an anticipated erosion depth. Since environmental risk increases with erosion potential of discharge and contamination level, risk reduction for downstream river stretches, floodplains, coastal area and the sea can be achieved by considering the mobility and bioavailability of deeper contaminated layers of sediments. These are important aspects for the prioritization of sediment management measures targeted to achieve a good ecological status of the water bodies in the river basin.

4 Outlook and conclusions

With respect to remediation projects which are required to achieve the implementation of the EC Water Framework Directive (WFD), appropriate monitoring of sediment and water quality is necessary to assess the efficiency and success of measures. To reduce the uncertainty level, optimization of monitoring strategies is recommended. A first model based approach has been developed to estimate the sediment erosion in groyne fields along the River Elbe in terms of statistical values (Prohaska et al. 2008). Field and laboratory investigations are expensive and model simulations are complex. Therefore, complementary to erosion measurements, tailor-made monitoring of water quality during flood events at river basin scale may be an alternative. Monitoring efficiency can be enhanced by appropriate design of measuring campaigns focusing on erosive discharge events, when remobilization of contaminated sediments is expected (Baborowski et al. 2004); concerted actions together with the Federal State Authorities and the main stakeholders are advisable (Baborowski et al. 2008).

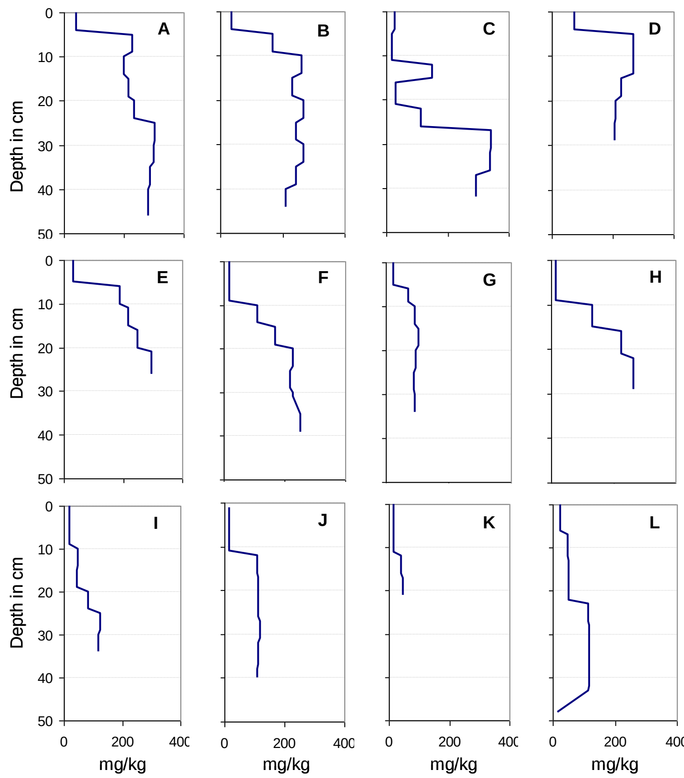

Figure 2. *Horizontal and vertical variability of arsenic concentrations in the cores from the considered groyne field*

Acknowledgements

We thank the ELANA GmbH for assisting the sediment sampling campaigns. The help of Dr. Cristina Sandu and Dr. Jürg Bloesch for discussion and careful reading of the manuscript is greatly appreciated.

References

Baborowski, M., von Tümpling, W., Friese, K. (2004): Behaviour of suspended particulate matter (SPM) and selected trace metals during the 2002 summer flood in the River Elbe (Germany) at Magdeburg monitoring station. Hydrology and Earth System Sciences 8: 135-150.

Baborowski, M., Schwandt, D., Geller, W., Heininger, P. (2008): Tailor-Made Monitoring Programs for Hydrological Extremes – Case Elbe River. Proceed. 4th Internat. Symp. Flood Defence: Managing Flood Risk, Reliability and Vulnerability. Toronto, Canada, 15-1 - 15-8.

Gerbersdorf. U. S., Jancke. T., Westrich, B. (2007): Determination of sediment stability by its physico-chemical and biological properties: considering temporal and vertical gradients at different contaminated riverine sites. In: Westrich, B., Förstner, U. (eds): Sediment Dynamics and Pollutant Mobility in Rivers - Interdisciplinary Approach. Springer Verlag, 79-90.

Guhr, H., Spott, D., Dreyer, U. (2006): Die Wiedergenesung der Elbe nach dem gesellschaftlichen Umbruch in Deutschland und Tschechien. In: Steinberg CEW, Calmano W, Klapper H, Wilken RD (eds), Handbuch angewandte Limnologie 25. Wiley-VCH, Weinheim, 3-56.

Haag. I., Kern. U., Westrich. B. (2001): Erosion investigation and sediment quality measurements for a comprehensive risk assessment of contaminated sediments. Science of the Total Environment 266: 249-257.

Heise, S., Krüger, F., Baborowski, M., Stachel, B., Götz, R., Förstner, U. (2008): Bewertung der Risiken durch Feststoff-gebundene Schadstoffe im Elbeeinzugsgebiet. Im Auftrag der Flussgebietsgemeinschaft Elbe und Hamburg Port Authority, erstellt vom Beratungszentrum für integriertes Sedimentmanagement (BIS/TuTech) an der TU Hamburg-Harburg. Hamburg, 349 pp.

Kern, U., Schuerlein, V., Holzwarth, M., Haag, I. & Westrich, B. (1999): Ein Strömungskanal zur Ermittlung der tiefenabhängigen Erosionsstabilität von Gewässersedimenten: das SETEGSystem. Wasserwirtschaft 89: 72-77.

Klemm, W., Greif, A., Broekaert, J. A. C., Siemens, V., Junge, F. W., van der Veen, A., Schultze, M., Duffek, A. (2005): A Study on Arsenic and the Heavy Metals in the Mulde River System Acta hydrochim. Hydrobiolog. 33 (5): 475-491.

Lehmann, A., Rode, M. (2001): Long-term behaviour and cross-correlation water quality analysis of the river Elbe, Germany. Water Research 35: 2153-2160.

Morgenstern, P., Brüggemann, L., Krüger, F., Hofacker, A., Wennrich, R. (2008): Judging Fitness for Purpose of a X-ray Fluorescence Based Method Investigating the Vertical Distribution of Metals and Metalloids in Soil Profiles. Water Air Soil Pollut 193: 289-298.

Morgenstern, P., Brüggemann, L., Wennrich, R. (2004): Validation of an X-ray methodology with environmental concern. Spectrochimica Acta Part B 59: 185-197.

Morgenstern, P., Brüggemann, L., Wennrich, R. (2005): Effect of the sample matrix on measurement uncertainty in X-ray fluorescence analysis. Spectrochimica Acta Part B 60: 1373-1379.

Ockenfeld, K., Guhr, H. (2003): Groyne field – sink and source functions of “flow-reduced zones” for water contents in the River Elbe (Germany). Water Science and Technology 7 (48): 17-24.

Prohaska, S., Jancke, T. & Westrich, B. (2008): Model based estimation of sediment erosion in groyne fields along the River Elbe. XXIVth Conference of the Danubian Countries. IOP Conf. Series: Earth and Environmental Science 4 (2008) 012042, 11pp.

Vink, R.J., Behrendt, H., Salomons, W. (1999): Development of the heavy metal pollution trends in several European rivers: An analysis of point and diffuse sources. Water Science and Technology 39: 215-223.

Wennrich, R., Mattusch, J., Morgenstern, P., Freyer, K., Treutler, H.-C., Stärk, H.-J., Brüggemann, L., Paschke, A., Daus, B., Weiss, H. (2004): Characterization of sediments in an abandoned mining area; a case study of Mansfeld region, Germany. Environmental Geology 45: 818-833.

Zerling, L., Hanisch, C., Junge, F.W., Müller, A. (2003): Heavy metals in Saale sediments - Changes in the contamination since 1991. Acta hydrochim. hydrobiol. 31: 368-377.