QUANTIFICATION OF HEAVY METAL EMISSIONS INTO THE RIVER SYSTEMS OF BADEN-WUERTTEMBERG (GERMANY)

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ABSTRACT

The object of the presented study is to estimate the emissions of seven heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, and Zn) into the river systems of the federal state Baden-Wuerttemberg (Germany). The estimation is accomplished with the help of the model MONERIS (Behrendt et al., 2000) which was developed to calculate the input of nutrients into river systems. For an application on heavy metal emissions the model MONERIS has to be upgraded. In addition to a basic module heavy metal typical transport processes and specific pathways are integrated in the MONERIS framework. For substance and pathway specific data an extensive data inquiry has been accomplished. The input data is regionalised with the help of a Geographical Information System (GIS). For verification of the results the estimated total emissions diminished by the loss of heavy metals due to retention processes within the river systems are compared with the heavy metal load measured at monitoring stations. Today‘s emissions of heavy metals into the river systems of Baden-Wuerttemberg are dominated by the input from diffuse sources, e.g. paved urban areas, erosion and inflow of groundwater (Fuchs et al., 2002). For different types of heavy metals different sources and pathways play an important role.

Keywords: European Water Framework Directive, diffuse emissions, heavy metals, model MONERIS, point emissions, river systems

INTRODUCTION

The implementation of the European Water Framework Directive requires an assessment of emissions into both surface- and groundwater bodies. Regarding the nutrient emissions the federal state of Baden-Wuerttemberg (Germany) uses an adapted version of the model MONERIS (MOdelling Nutrient Emissions in River Systems, Behrendt et al., 2000), which was developed to quantify the nutrient input into river systems. The objective of the presented study is to upgrade the model for an application on heavy metal emissions.

Through this the input of seven heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, and Zn) into the river systems of Baden-Wuerttemberg via various point and diffuse pathways will be estimated (Figure 1). The use of this data will enable us to identify significant sources and pathways in order to reduce total heavy metal emissions.

An adapted version of MONERIS was already used in a former study accomplished by the Institute of Aquatic Environmental Engineering for the estimation of heavy metal emissions into the large river systems of Germany (Fuchs et al., 2002). It has been shown that MONERIS is an appropriate tool for an evaluation of emissions from point and diffuse sources. Figure 2 shows the percentage of emissions via the different pathways for Germany (Fuchs et al., 2002). The quality of the estimation is primarily determined by the quality of the input data. The comparison of transported heavy metal loads and estimated loads calculated on the basis of the emission method showed that the variance increases with decreasing catchment size (Fuchs et al., 2002). This is due to the fact, that up to now the specific conditions within small catchments could not be described exactly for the whole area of Germany. Accordingly the aim of the presented study is to optimise the data situation by using detailed and highly regionalised input data on the scale of smaller sub catchment areas varying between 100-400 km².

METHODS

Adaptation of the Model MONERIS

The input of seven heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, and Zn) is calculated on the basis of 116 sub catchments in Baden-Wuerttemberg of the size of 100 – 400 km² (Figure 3).

The nutrient model already contains a basic module including the following information:

- Geographical and statistical data concerning sub catchments
- Land use data
- Data concerning the water balance
- Statistics of urban sewer systems
- Data about drainages of agricultural areas
- Information about soil and geology

Data concerning the water balance has been calculated using the model LARSIM which was developed by Bremicker (2000) and adapted and calibrated for Baden-Wuerttemberg. This basic input data can be taken on for the calculation of the heavy metal emissions.

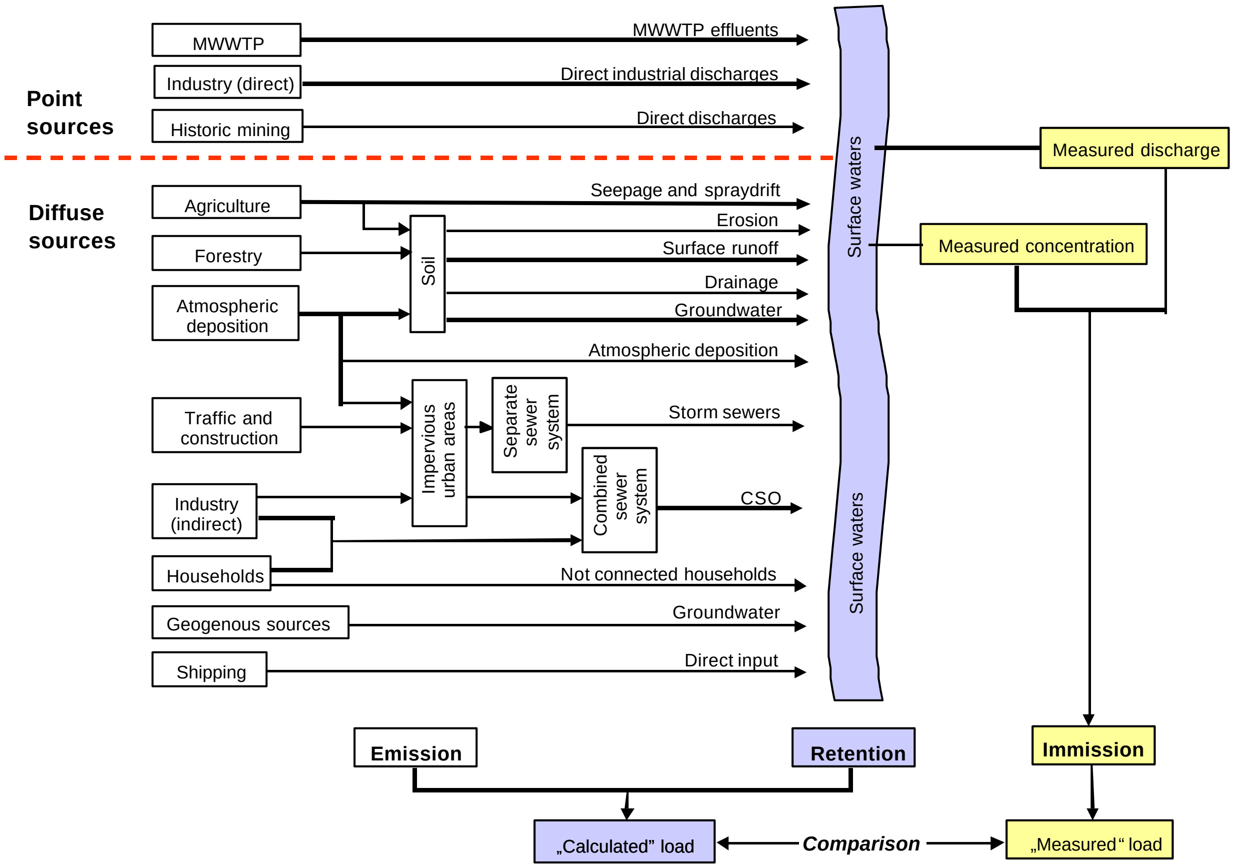

Figure 1: Main sources and pathways taken into account to calculate the heavy metal input into river systems

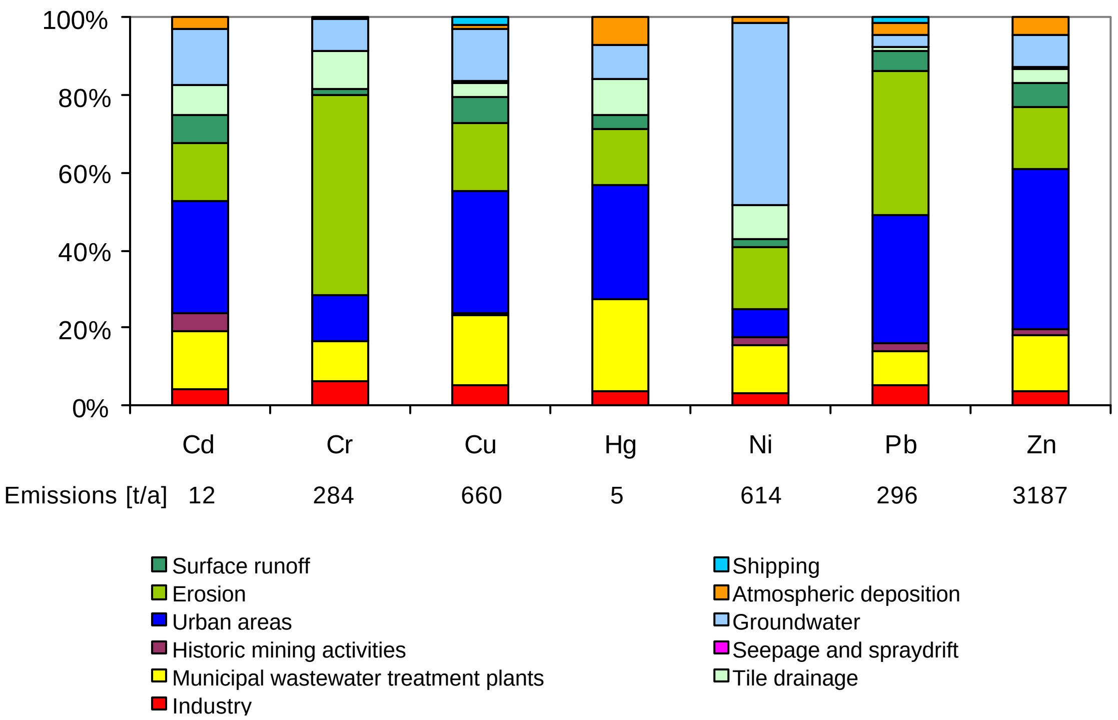

Figure 2: Heavy metal emissions from point and diffuse sources into the large river systems of Germany (from Fuchs et al., 2002)

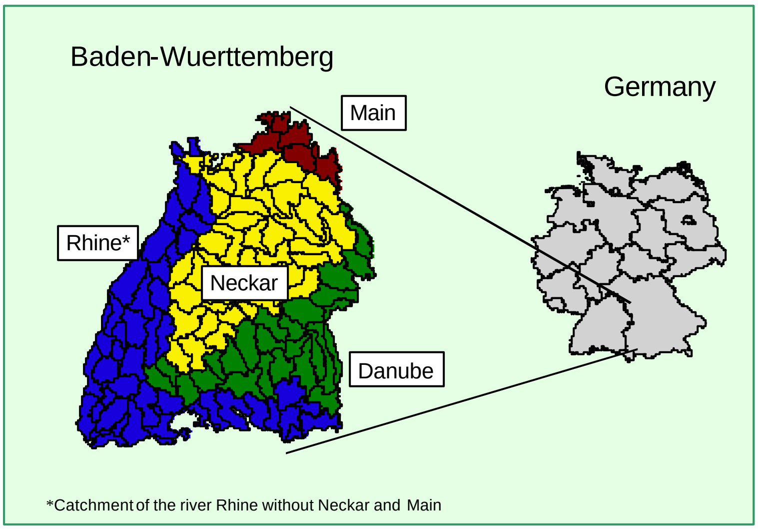

Figure 3:Sub catchment areas and agglomerated catchments of the larger river systems of Baden-Wuerttemberg

In addition to the given database heavy metal concentrations as well as heavy metal typical transport processes and specific pathways such as “shipping” and “historic mining activities” are integrated in the MONERIS framework. Furthermore the model will be optimised for the data situation in Baden-Wuerttemberg.

Substance and Pathway Concerning Data

In addition to the basic module substance and pathway specific data is needed. Therefore an extensive data inquiry has been accomplished including state offices, research institutes, organisations etc.. In Figure 4 the method of quantification, used input data as well as data sources are listed. The data is regionalised with the help of a Geographical Information System (GIS) and can be assigned to every sub catchment. As example Figure 5 shows the data of the atmospheric deposition of cadmium, mercury and lead on the basis of a 50 x 50 km grid provided by the MSC-East (EMEP Data).

Immission and Retention

For verification of the results the estimated total emissions diminished by the loss of heavy metals due to retention processes within the river system are compared with the heavy metal load measured at monitoring stations (Figure 1). The retention is calculated according to the retention functions given by Vink & Behrendt (2002).

FIRST RESULTS

For some pathways the data inquiry is already completed and first results are available. Via the pathway “shipping” lead (Pb) and copper (Cu) are emitted directly into the river. Lead enters the surface water via pumbiferous propeller shaft grease from business ships and copper derives from copper containing anti-fouling paints which are used on sporting boats to avoid fouling on their submerged parts.

Shipping

To calculate the heavy metal input the number of business ships and sporting boats is needed. As no statistic data is available about ships and their navigation area, the number of vehicles was estimated by using data about sluicing activities. The number of boats was taken from reports from the German Motor Yacht Union (DMYV), the Institute for Lake Research (Institut für Seenforschung) and the Lake Constance Foundation (Bodenseestiftung). According to Mohaupt et al. (1998) pumbiferous propeller shaft grease is used by 80 % of the business ships with an input of 1.5 kg Pb/a per ship. Whereas about 25 g Cu/a are emitted per boat.

The navigable rivers of Baden-Wuerttemberg are Rhine and Neckar. The input is calculated according to the number of ships and boats cruising on the river section. The results are depicted in Figure 6. Regarding the total input of Pb and Cu shipping only plays a minor role (Figure 2).

Direct industrial discharge

Concerning the pathway “direct industrial discharges” data was taken from a survey carried out by the “Fraunhofer Institute for Systems and Innovation Research (ISI, Karlsruhe) on the behalf of the Federal Environmental Agency of Germany (UBA) (Fuchs et al., 2002). The data collection contains information from environmental reports from companies, monitoring data from the federal state and reports from industrial associations for the years 1997-2000.
According to the discharge location the data was attributed to the corresponding sub catchment. The emissions of chromium, copper and lead via the pathway “direct industrial discharges” are shown in Figure 7..

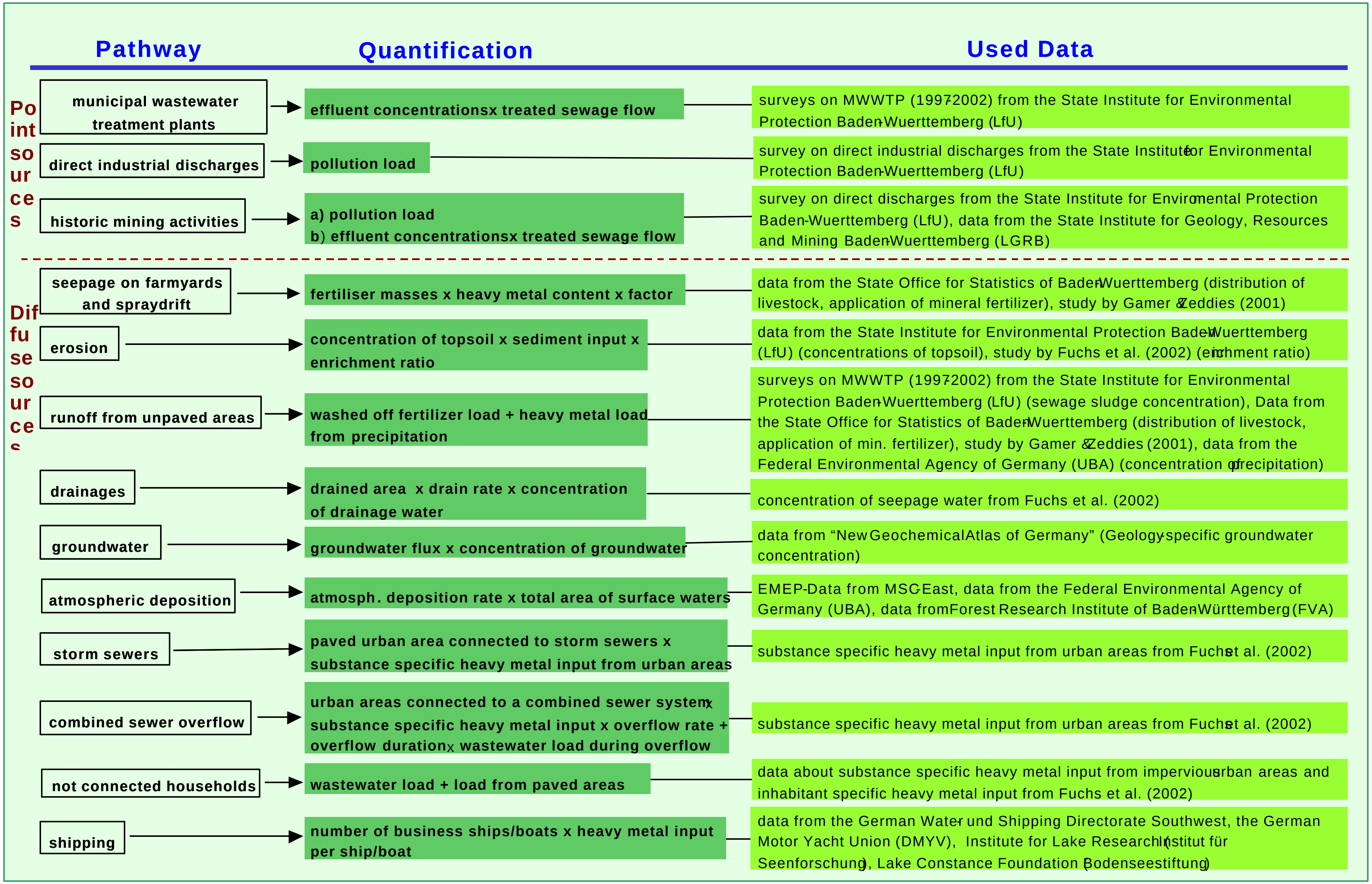

Figure 4:Method of quantification and used input data as well as data sources

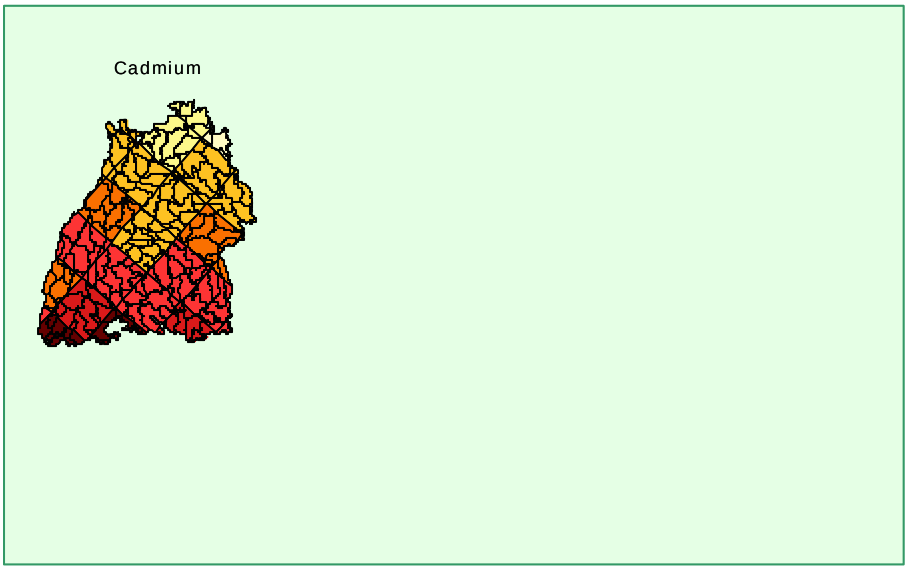

Figure 5:Atmospheric deposition of cadmium, mercury and lead (EMEP data from MSCEast)

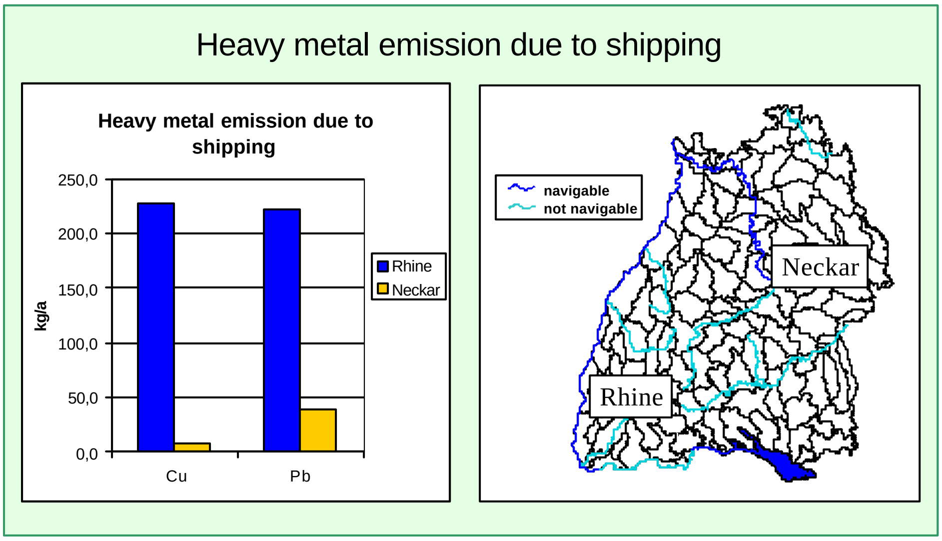

Figure 6:Emission of copper and lead due to shipping on the river Rhine and Neckar

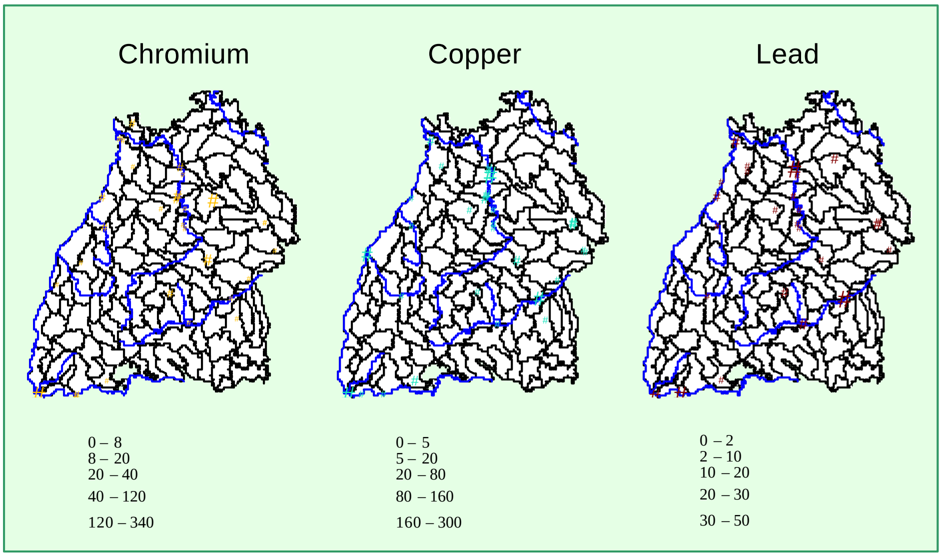

Figure 7:Emission of chromium, copper and lead due to direct industrial discharges

Nowadays the input via "direct industrial discharges" only play a minor role in Germany. All seven heavy metals are emitted at a small rate compared to the total emission (Figure 2). This is due to policies (Water Resources Policy Act), demanding improved wastewater treatment practices for industrial works, reconstruction of direct industrial discharges to "indirect discharges" into the municipal sewer system and new methods of water recycling within the industrial process (Fuchs et al, 2002).

Seepage on farmyards and spraydrift

For the calculation of the emissions due to "seepage on farmyards and spraydrift" the applied fertilizer amount is needed. Concerning the inorganic fertilizer data was taken from a study by Gamer & Zeddies (2001) who calculated the applied nutrient amount based on the intensity of agricultural landuse. The amount of the organic manure was estimated using data from the State Office for Statistics about the distribution of livestock. On the basis of heavy metal concentrations of fertilizers (Döhler et al., 2002; Bannick et al., 2001; LABO, 2000; Boysen, 1992) the input of heavy metals via "seepage on farmyards and spraydrift" could be estimated. Area specific emissions are shown in Figure 8.

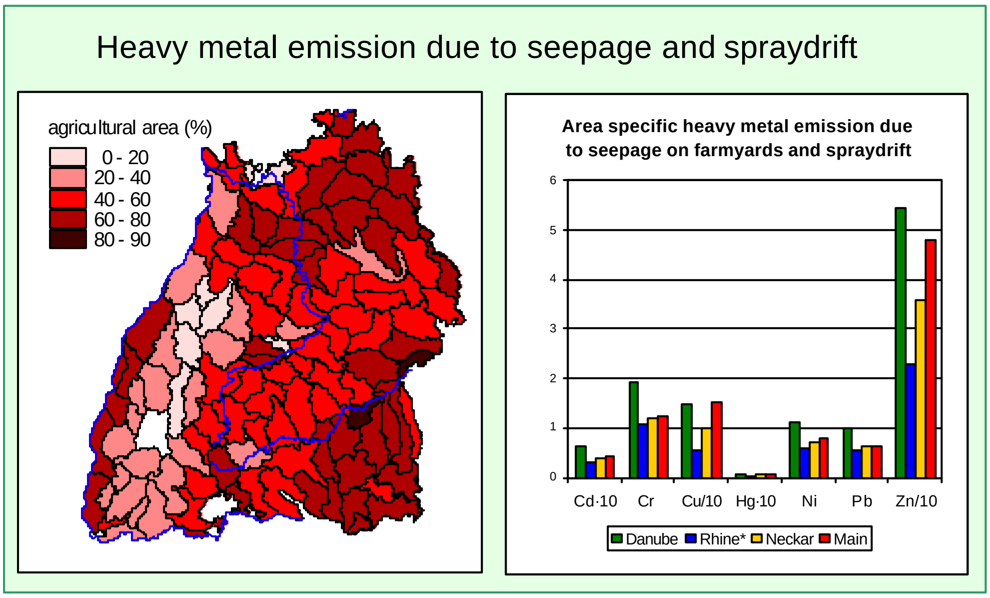

Figure 8:Proportion of agricultural land use and area specific heavy metal emission due to seepage on farmyards and spraydrift concerning the river Danube, Neckar, Main and Rhine (without the catchments of Main and Neckar)

The emissions due to "seepage on farmyards and spraydrift" correlate with the proportion of the agricultural area, e.g. the agriculturally dominated catchment of the river Danube shows a definite higher input of heavy metals (Figure 8).

To identify significant sources and pathways of heavy metal emissions it is necessary to compare the input via all pathways which is not feasible yet because of incomplete input data. But according to former studies (Fuchs et al., 2002) today's emissions of heavy metals into the river systems of Germany are dominated by the input from diffuse sources, e.g. urban sewer systems, erosion and inflow of groundwater (Figure 2).

CONCLUSION AND OUTLOOK

The adapted model MONERIS is an appropriate tool to estimate the input of heavy metals into river systems for sub catchments of 100 – 400 km². As the quality of the results are determined by the quality of the used data it is important to have reliable input data available. For the future work it will still be the aim to optimise the input information by collecting and generating appropriate data and creating a highly regionalised database.

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