The assessment of the environmental impact of heavy metals in soils by using a GIS
Evaluation de l'impact environnemental des métaux lourds sur les sols à l'aide d'un SIG

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The flood plains are preferred places for settlements and are characterized by intensive agricultural land use. Sewage from industry and settlements which pollutes the rivers caused an enrichment of pollutants in the soils of the flood plains. This pollution is a danger for the whole ecosystem. The pollutants are also in the human food chain. It is necessary to develop a model to predict the environmental impact of heavy metals. Precondition for an effective soil protection is the provision of forecast maps for heavy metal mobility. By the use of an Geographical Information System (GIS) it is possible to reduce the time of investigation and to simulate different scenarios with the aim of improving the process of heavy metal mobility in the soils of the flood plains. Therefore a model of heavy metal mobility was implemented in a GIS to overlay and calculate the necessary layers and to create forecast maps.

With the method which is introduced in this article it is possible to assess the environmental impact of heavy metals in soils by using the heavy metal contamination of soils and plants, and combining this with some soil data. Figure 1 shows an overview on the parameters which influence the heavy metal mobility, the data used for the model and the database.

| parameters determining the ecotoxicology of heavy metals in floodplain soils |
| -------------------- | ----------------- | ---------------- | ------------ | ------------ |
| heavy metal contamination of soils | heavy metal contamination of plants | exchange capacity - organic matter | mobility in soil pH | exchange capacity - clay |

| data sources |
| maps of heavy metal pollution | analysis in laboratory | maps of vegetation and land use | soil maps | soil maps |

| assessment of the heavy metal mobility |

Fig.1: Model for the assessment of the environmental impact of heavy metals in floodplain soils - database
Heavy metal mobility in soils is determined by several factors. The influence of these factors was the subject of several investigations, especially by BLUME & BRÜMMER 1986-1993. One important parameter is the heavy metal content of the soil. A high concentration of a pollutant in the soil has a great potential danger. Even if the circumstances cause a low mobility in the soil at the moment, a change of the conditions may cause a severe release of pollutants. Such a change of conditions might be a change from forest or meadows into agricultural land with a loss of organic matter or a change of pH in soils (for example by acid rain). The total amount of heavy metals in a soil can be easily determined by acid digestion. Especially in industrialized areas maps of the pollution with heavy metals or organic pollutants already exist. This data can be used for the prediction model.

The concentration of organic substances and clay minerals in soils is important for the adsorption of heavy metals. A high concentration of these substances in soils decreases the plant’s uptake of heavy metals. The clay concentration is determined by the subsurface geology or the sedimentation of the rivers in flood plains. Depending on the micro-relief in the floodplains there are areas with a higher concentration of clay (quarries) and lower elevations with sandier soils. Only a large difference in the clay content of a soil has significant influence on the heavy metal mobility, because most of the heavy metals (except zinc) have an affinity to the soil’s organic matter. Due to this aspect a simple field test for the clay content can be used in the model. Another possibility is the use of soil maps such as the German Soil Evaluation Maps of 1:5000 or 1:2500.

The type of vegetation or the land use has the greatest influence on the organic matter in the soils. An investigation in several areas with different types of land use or vegetation units in flood plains showed that the plants in soils with a high concentration of organic matter were significantly less polluted with heavy metals than the plants in soils with less organic matter. The soils in wooded areas have more organic matter than agriculturally used soils (even if the land use was abandoned several years ago). The intensity and duration of agricultural land use (and the kind of land use) have an important influence on the soil’s organic matter. The differences between wood-soils and arable-soils are so significant that vegetation maps or maps of the agricultural land use can be used for the prediction model. It is sufficient to distinguish between wood soils and soils without human influence, and arable land and areas with human impact within the last 10 years. As a basis for the model we use vegetation maps or maps of land use of 1:5000. It is also useful to consider maps of historical land use.

The pH determines the solubility and the chemical condition of heavy metals. It also regulates the strength of the adsorption to clay and organic substances and regulates the plant uptake. Databases are soil maps or soil information systems. Plants have been chosen as monitor organisms because they are location specific and occur in a high abundance individually. Among the analysed species Phalaris arundinacea and Urtica dioica are the most common. Both species are indicators of eutrophication and can be used in the investigation of nitrate pollution. As indicators for wetlands they appear at areas with a high accumulation of heavy metals. The heavy metal concentration in the plant samples can be determined by acid digestion.
For zinc, cadmium and nickel, the pollution of Urtica dioica and Phalaris arundinacea are representative. For copper it is better to take samples from a defined area. A higher pollution with heavy metals causes a more equal uptake by the plants. The advantage of taking plant samples is the direct reference to the food chain and the possibility to register long-term developments during a complete vegetation period. Another advantage is the reaction of the vegetation to the subsurface. The population of species depends on humidity, nutrients and soil type. Even little differences in the soil have an effect on the vegetation. The pollution of plant samples represents an actual aspect of heavy metal pollution.

![Heavy Metals in Plants](image)

**Fig. 2:** Heavy metal pollution of plants in soils with the same heavy metal pollution, but different organic matter due to the different land use

**Example**

The example shows the necessary steps of field work and map analysis to the GIS model. Investigations of flood plains, which had been carried out as blanked coverage of the whole area, showed that most of the soil parameters, which have an influence on the heavy metal mobility, are connected to geology, vegetation and land use. For the model we need the heavy metal concentration in soils and plants, pH, vegetation type and geology. Further investigations (Brück 1995) concluded that by including the heavy metal concentration of plants (esp. Urtica dioica and Phalaris arundinacea which are typical for floodplains) into a model it is possible to assess the environmental impact of heavy metals. All parameters can easily be determined. Vegetation and geology maps are often available.

The investigation area is a floodplain near a former steelworks. Nearby there are many small metal-processing plants. Untreated sewage of the city contaminates the river. The soils are highly polluted with heavy metals, nitrates and other salts. We found several types of vegetation in a small area. There are small riverside woods, meadows (former farmland) and areas with ruderal vegetation. Because of the high concentration of nitrates in the soils the dominant plant is the nettle (and can easily be used for the plant
samples). The soils are sandy alluvial soils with 40-45% clay. The greatest differences between wood and other soils is the concentration of organic matter. The wood-soils have a higher amount of organic matter (7% organic carbon). The plant contamination with heavy metals shows great differences between x ppm in meadows and y ppm in forest soils.

For the model we used a map of vegetation and land use 1:5000, and a map of the heavy metal concentration (blanked coverage 50 x 50m). The data about the heavy metal pollution of plants comes from a recent investigation in this area. Because of the small investigation area, it was not necessary to use a soil map for the soil type. The soil type comes from the German Soil Evaluation Map (1:5000).

Database Operations
The most important part of the model is the implementation of the evaluation method into the database program. It is necessary to assign a risk level to each vegetation or soil unit and to the heavy metal data. The most useful technique was to use 5 risk levels. Figure 3 shows the table with the assignment of heavy metal concentration, pH, vegetation type and soil type to risk levels.

<table>
<thead>
<tr>
<th></th>
<th>rud.veg.1</th>
<th>rud.veg.2</th>
<th>riv.for. 1</th>
<th>riv.for. 2</th>
<th>meadows</th>
<th>Urt.com.</th>
<th>dec.for.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corg. in %</td>
<td>3.1 (5)</td>
<td>3.9 (5)</td>
<td>9.5 (1)</td>
<td>8.3 (1)</td>
<td>4.8 (5)</td>
<td>5.7 (3)</td>
<td>7.9 (1)</td>
</tr>
<tr>
<td>clay in %</td>
<td>20 (4)</td>
<td>20 (4)</td>
<td>40 (3)</td>
<td>35 (3)</td>
<td>35 (3)</td>
<td>35 (3)</td>
<td>20 (4)</td>
</tr>
<tr>
<td>pH</td>
<td>5.8 (2)</td>
<td>6.1 (1)</td>
<td>5.2 (3)</td>
<td>5.4 (3)</td>
<td>5.7 (2)</td>
<td>5.5 (2)</td>
<td>5.6 (2)</td>
</tr>
<tr>
<td>Cd - plants ppm</td>
<td>2.6 (5)</td>
<td>1.6 (4)</td>
<td>0.79 (2)</td>
<td>0.80 (2)</td>
<td>0.98 (2)</td>
<td>1.04 (3)</td>
<td>0.3 (1)</td>
</tr>
<tr>
<td>Cd - soil in ppm</td>
<td>5.0 (5)</td>
<td>4.9 (4)</td>
<td>2.7 (3)</td>
<td>2.5 (3)</td>
<td>2.0 (2)</td>
<td>2.7 (3)</td>
<td>1.3 (2)</td>
</tr>
<tr>
<td>risk level</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig.3: Table of selected analytic data and risk levels (risk increasing from 1 to 5)

Environmental risk assessment is an increasing problem for public administrations and has to be embedded within planning processes for larger areas such as communities or rural districts. Large amounts of data, such as chemical risk potentials in our study, has to be managed nowadays usually with a geographic information system (GIS). A GIS is a datamanagement system that enables experts to generate and process spatial data (BURROUGH, 1984).

Two different types of spatial data management systems are available: a) vector based GIS and b) raster-based GIS. During the past few years, both types are becoming more and more compatible, some GIS-supporters even offer hybrid systems and therefore supply users with the possibility to optimize spatial analysis by combining both system types.

In the case of this study, the vector-GIS PC ArcInfo and the low cost raster-GIS IDRISI came into operation. Current land use in the valley of the Blies river near the city of Neunkirchen [SW-Germany] was mapped during a field work campaign. Representative analysis of soil and vegetation was undertaken in the laboratory. On the other hand, the field map was digitized with PC ArcInfo. Polygon topology was created and attributed
with the land use types mapped during field work.

Topology describes neighbourhood relationships of point, line and/or polygon geometry. PC ArcInfo describes spatial objects by means of coordinates, vectors (=arcs) and or polygons. Data from laboratory results was inputed into the spatial database and was managed for the following parameters:

- exchange capacity of organic matter
- pH
- exchange capacity of clay
- concentration of cadmium in soil
- concentration of cadmium in plants

Classification was processed for each parameter. After that the ArcInfo coverages had been exported to DLG exchange format (ArcInfo coverages are directories, containing a variety of files, that make the „spatial database“). DLG exchange files were imported into the raster-GIS IDRISI. Then a vector-raster-conversion had to be processed. The spatial resolution was 5x5m. After that, thematic maps of the different parameters were created.

To support better geographic orientation, official maps were scanned with an appropriate resolution of 600 DPI and then imported as TIF-files into IDRISI. After georeferencing these „background-maps“ they were overlayed with the thematic maps.

These single parameters (organic matter, pH, clay, Cd in soils and plants) can be used to generate a forecast map of risk levels of soils on the basis of the vegetation map. Figure 4 shows a map of the actual landuse units and the result forecasting map of risk levels.

Fig. 4: risk assessment map for cadmium

The method which is introduced in this article offers an easy way to assess the environmental impact of heavy metals in soils by using maps of the heavy metal contamination and combining this with maps of vegetation, landuse and geology. The heavy metal mobility from soils to plants as well as the eco-toxicological effects can be assessed when the heavy metal contamination of plants is used in the model. By the use
of an Geographical Information System (GIS) it is also possible to reduce the time of investigation and to simulate different scenarios. Like this you can use the model for developing the best methods for remediation or environmental protection.

References


Keywords: heavy metals, risk assessment, GIS, soils of flood plains
Mots clés: métaux lourds, SIG, sols des basses plaines inondables