Theme: D: Management of contamination at regional scale
Thematic Session (LeS): ThS_D1: Land

MANAGEMENT OF CONTAMINATED SOILS IN URBAN AREAS IN THE ORE MOUNTAINS (GERMANY)

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1. Introduction

The Ore Mountains ("Erzgebirge") have been a mining area for more than 850 years. Many villages were founded in the frame of mining and mineral processing. Minerals of special importance were silver, lead, cobalt, arsenic, tin and uranium. Mineralised parts of the ore Mountains were already mapped in the late mediaeval times. The most famous silver mining districts were the Freiberg area, Marienberg and Annaberg-Schneeberg and for tin Altenberg and Ehrenfriedersdorf. Uranium mining was carried out in the mining districts Aue-Schlema-Alberoda, Schneeberg and Johanngeorgenstadt, as well as in and around the city of Annaberg.

The geological conditions, mining and mineral processing had a large influence on the concentration of elements in soil and outcropping underground – especially for the primary element distribution in ore veins, mineralised associated surrounding rock units and the distribution of these elements with periglacial cover units of debris, weathering products and soil in alluvial sediments of river valleys. In addition, elements contained within the ores, were transported to the surroundings of the processing plants by mineral processing (exhaust fumes, fluid and solid mining waste; tailings, slag, stones, dust from flue gasses).

The distribution of ore mineralisation and contaminated sites (mines and processing plants) is well known for the Ore Mountains.

Element concentrations in the top soil depend on the rock composition of the geological underground, its mineralisations and alterations of associated surrounding rock units. Soil formation processes also act on the distribution and dispersion of ore elements. Furthermore, the distribution of the concentrations is influenced by orography, since slope movements shift element increase and decrease.

Human activities in the field of housing developments lead to artificial soil accumulation or denudation. Soil can be taken from the close vicinity or longer distances. Anthropogenic materials with influence on the element distribution in the underground are e.g. urban and mining debris (rubble and processing debris), slag and stones, ashes and tailings.

2. Sustainable Management of contaminated soils – the role of soil contamination maps

Enforcement of soil protection is a challenging task in areas with extensive contaminations. Usually, the requirements of soil conservation regulations have to be fulfilled for hazard assessment and taking of adequate measures to prevent hazards on many land parcels. This concerns also requirements on dealing with soil material. In this respect, a procedure applied to a whole area is of advantage in contrast to case-specific assessments /6/. One instrument to deal with large-scale contaminated soils is the digital soil contamination map (Bodenbelastungskarte, BBK). A BBK gives a complete coverage of contaminant concentrations (contamination maps), as well as spatially differentiated necessities for regulation (evaluation maps) /3/.
BBK thus provide valuable information to prepare hazard prevention measures and preventive soil protection. BBK ease the compilation of statements for planning and approval procedures by Authorities.
With regard to soil contaminations, two site-related evaluations can be distinguished:

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- Areas with necessities for regulations for soil material relocation according to § 12 (10) BBodSchV (German Soil Protection Act),
- Areas with necessities for regulations for hazards in terms of protected property or land use caused by elevated pollutant concentrations according to § 9 SächsABG (Saxonian Waste Management and Soil Protection Law).

Rules for soil material handling in areas with extensive soil contamination help to relocate excavated material and comply with the principle to prevent deterioration. Thus, it is ensured that contaminated material will not leave the area in an uncontrolled manner. However, relocation within the area (differentiated into various categories) is permitted without further chemical analysis.

Rules for hazard assessment and for necessary measures to prevent hazards are fixed in the soil conservation regulations, differentiated according to protected property and land use. Outside of settlements, the pollutant transport into economic plants is of importance. Site delineation is done according to inspection values ("Prüfwert") and action values ("Maßnahmenwert") for arable or pasture use. In urban areas, direct (human) ingestion is the main issue. Under consideration of resorption availability, evaluation values are derived for the land use classes "playground", "housing area", "park and leisure area" and "industrial area". These values are then taken for the delineation of sites. Inner differentiation is realised by indications for probabilities of threshold exceedance and necessary measures for hazard prevention (LfULG 2006).

These measures (for extensive contaminations) are for agricultural use e.g. adaptation of pH values, suggestions for the selection of crop types and additional requirements for analysis prior to harvesting. In urban environments these rules affect conditions in case of land use changes (e.g. new playgrounds or new dwelling developments, especially with regard to soil relocation) as well as rehabilitation measures in case of proven hazards under current land use – to minimise direct contact and ingestion of contaminated soil.

3. Urban test areas

According to the Saxonian code of practice /3/ the general methodological basics for the compilation of BBK in urban areas have to be evaluated in test areas. For preliminary works in the Ore Mountains, the cities of Annaberg-Buchholz and Aue were selected. Prior to the test, extensive samples were available for Annaberg-Buchholz, but not for Aue.

Annaberg-Buchholz is dominated by hilly terrain. The test site was formed by the cities Annaberg and Buchholz, as well as the villages Cunersdorf and Frohnau. Further settlement areas were not considered.
While Annaberg is located around the Pöhlberg hill (approx. 800 m asl), the remaining settlements are divided by the deep Sehmatal valley. On the right hand side banks of the Sehma are Annaberg and Cunersdorf, on the left hand side Buchholz and Frohnau.
Annaberg-Buchholz is a historic mining city (silver mining, subordinate: tin and uranium). Further industries emerged towards the end of the 19^{th} century.
Thus, contaminants are mainly geogenic (As, Pb) and to be expected by mining and mineral processing. Historic smelters are known but not their locations.

Aue, in contrast, has an industrial history of several centuries. It is located along the confluence of the rivers Zwickauer Mulde and Schwarzwasser. Riparian soils cover approx. 25 % of the settlement area. These floodplains are covered by industrial plants for a long time. Extensive anthropogenic backfills stabilise the ground of the industrial plants which dominated the pollutant situation in the urban areas. Less influential was Uranium mining in the neighbouring city Schlema-Alberoda. The main processing plant has a history of 400 years. During recent decades, the focus was on nickel ores whereas in previous centuries mainly cobalt was processed (blue dye).

Test site Annaberg-Buchholz (833 ha) already had a significant amount of samples on stock (approx. 100), which was further condensed by 32 additional samples. The location of new sampling was targeted to optimise the coverage of all land use classes. The distance of each settlement point to the nearest sample location was meant to be minimised.

The same principle was applied in Aue (574 ha). However, only 5 samples were available prior to this study. Further 68 samples were taken according to the standards of the federal soil conservation act ("Bundesbodenschutzverordnung"). The sampling depth was chosen according to land use.

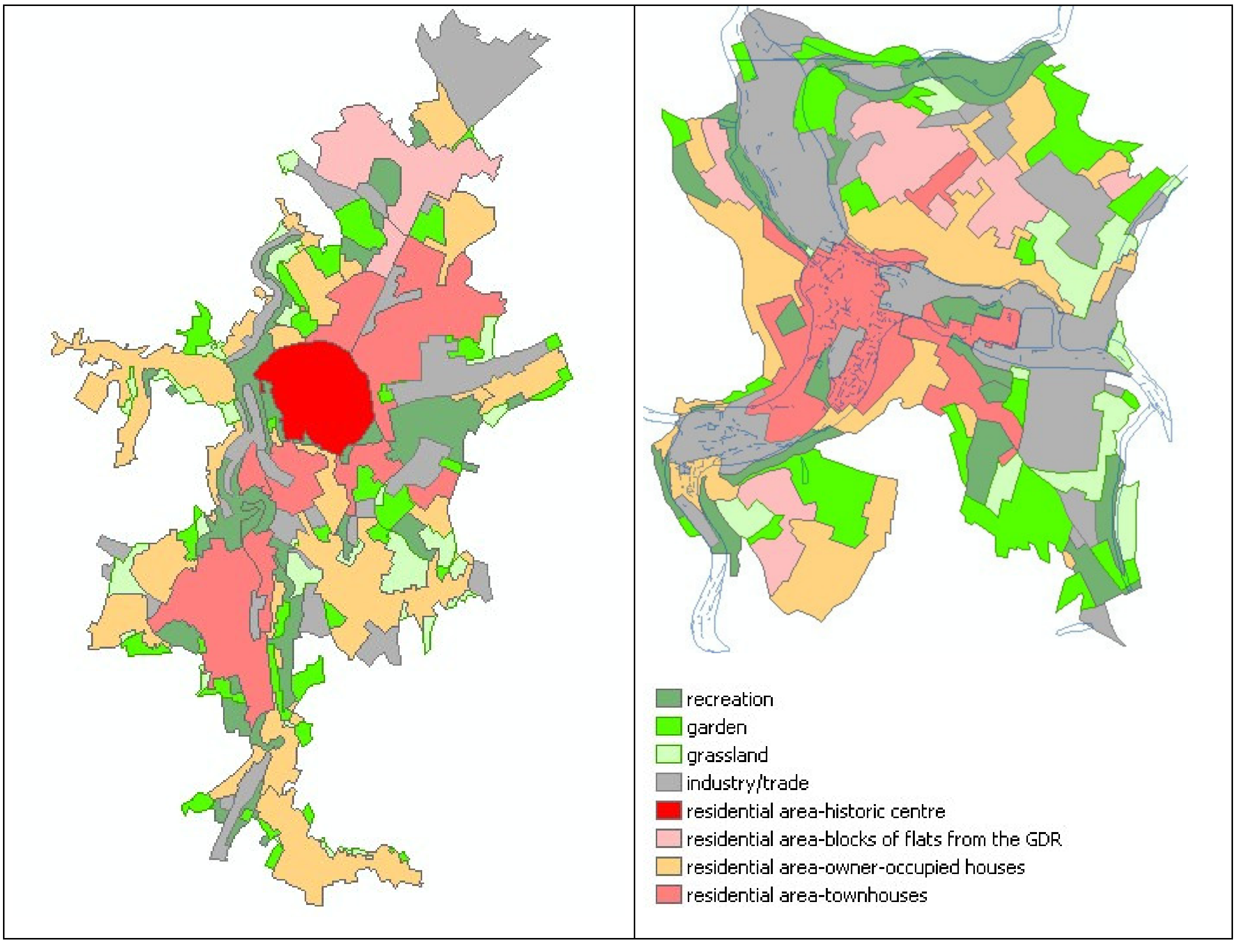


Figure 1: Historical land use in Annaberg (left) and Aue (right)

For both settlement areas (Figure 1), geological maps and soil maps were present in various scales and age. For Annaberg, a detailed map of ore veins ("Gangkarte") by MÜLLER was available /5/. Outcropping rocks of the geological basement are only slightly differentiated for both sites. Housing areas were left out in the soil maps (according to the rules). Thus, for both settlement areas, only few information was present for substrate classification of the site.
Annaberg-Buchholz is characterised by a tight net of mineral veins (Figure 6, right), with seven different vein formations. Main adverse elements are Arsenic and Lead.

4. Three Approaches for Soil Contamination Mapping in Urban Areas

Methodological basics were developed to generate a complete coverage of maps fort he urban areas by LANUV /2/ and LfULG /3/. These methods aim to derive an extensive distribution map of pollutants in urban areas from (few) point information (analyses).

Three approaches were applied:

- immission-based
- substrate-based
- spatial-analytic

For the **immission-based** approach, a point or surface source is required, from which the pollutants are transported by wind to the settlement areas (where they contaminate the soil). For this contaminant path, extensive high element concentrations are characteristic for the top soil (in relation to lower layers). The distribution is controlled by the location of the emitting site and the main wind directions.

For the **substrate-based** approach, the differing, delimitable soil substrates are the main carriers of pollution. The knowledge of spatial substrate distribution is a pre-requisite for the derivation of the contaminant distribution.

The **spatial-analytic** approach considers the settlement types and their temporal development for the spatial distribution of contaminants. The settlement area is subdivided into homogeneous spatial units (Homogene Raumeinheiten, HRE). A HRE is determined by natural and anthropogenic conditions and by the distribution of the contaminant to be modelled. Within a HRE, homogeneous conditions are assumed for adsorption and storage of the contaminant to be modelled (soil-geological conditions, immission, land use, etc.). In particular, no erratic changes of the pollutant concentration are to be expected within a HRE (but along the borders of each HRE). In general, erratic changes are due to natural or anthropogenic causes (e.g. geology or land use).

Table 1 gives an overview of the approaches and their characteristics for data pre-processing and the derivation of BBK.

Table 1: Methodical approaches for soil contaminated maps (from /3/)

	Substrate-based	Immission-based	Spatial-analytic approach
Goal	Capture of substrate-caused contamination	Capture of immission-caused contamination	Capture of contamination differentiated by land use
Applicability	Statistically confirmed substrate contamination	for sites with long-term immissions	For significantly differing contamination of homogeneous spatial units.
Depth	Thickness of fill	0 – 10 cm and 10 - 30 cm	0 - 30 cm
preconditions	According to analysis of correlation	Interpolation after variogram analysis	Interpolation after Standardisation and variogram analysis

In addition to these three approaches, a fourth approach, the standard approach, is introduced as a result of the study /4/. This approach describes the case when the spatial-analytic approach creates HRE which are neither based on the immission-based approach nor on the substrate-based approach. It is characterised by the phenomenon that the pollutants reached their location neither by immission nor by anthropogenic land use which can be classified. This is equivalent to an early stage of knowledge of a study site (e.g. a limited amount of samples or no plausible explanations for the spatial distribution of elements). Nevertheless, interpolations can be done for this approach.

Table 2 shows various approaches to derive a spatial distribution from point information by means of statistic methods.

Table 2: Recommendations for using mathematical interpolation methods under the three approaches

Method	Condition	Approach	Suited for…
Voronoi-Mosaic	Point information can be extrapolated	All	Overview of primary data stock
IDW	Point information can be extrapolated, smooth surface expected	Immission-based, Standard apporach, Substrat-based	True-sample description; deviations of model and true value between sample points are not relevant
Statistical values	Point information can be extrapolated; > 10 - 20 samples	Substrate-based, Standard approach	Transfer of characteristic value to non-sampled substrate-HRE from sampled Substrat-HRE; allocation of characteristic values for marginally

			sampled HRE
Ordinary Kriging	Point information can be extrapolated; > 30 samples	Immission-based, Substrate-based, Standard approach	Continuous surfaces, true-sample description less important than accuracy description at each point; simple trend (constant and linear resp.)
Universal Kriging	Point information can be extrapolated; > 70 samples	Immission-based, Substrate-based, Standard approach	Continuous surfaces, true-sample description less important than accuracy description at each point; non-linear assumption over the random field to be modelled.
Indikator Kriging	Existance of lower and upper samples and measurement value thresholds.	all	Testing for extensive development of measurement values with depth and exceeding probability of threshold values resp.
Artificial neural networks (advangeo®)	Soil samples as training data, raster data for land use, geology, soil geology, ore veins, digital terrain models, contaminated sites, artificial backfill etc.	all	Map presentation under consideration of all main influencing factors and their location, without the necessity to know their exact impact and interaction

5. Example for spatial analytic approach

The distribution of lead concentrations in Annaberg shows a significant dependence of land use: high concentrations have been found in the historic inner city (WG_A), very low concentrations in new housing estates (1970ies/80ies, WG_BL) (Figure 2).
The spatial-analytic approach used kriging interpolation for each individual area as well as for the remaining part (Figure 3). Interpolation results were then taken to compile a homogeneous map (Figure 4).

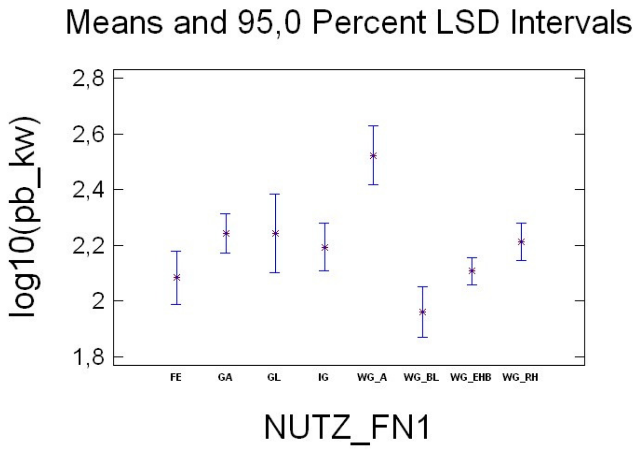


Figure 2: Box-and-Whisker Plot of decadic logarithms of mean values including LSD interval of Pb_KW (related to land use)

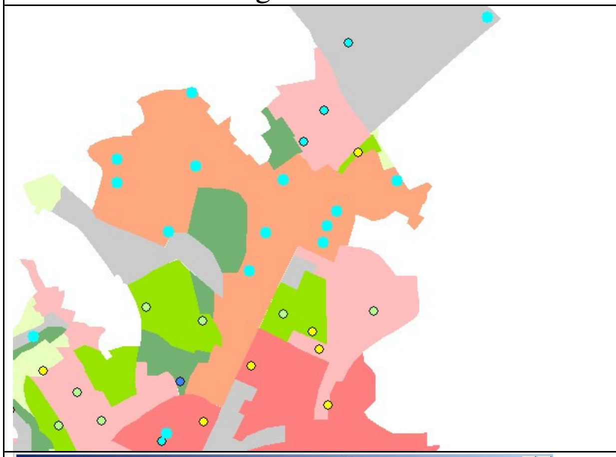
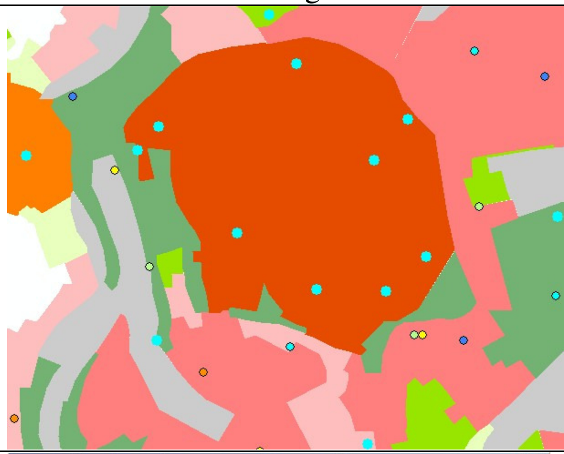
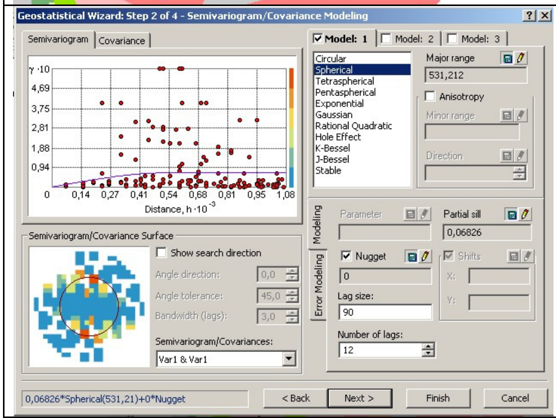
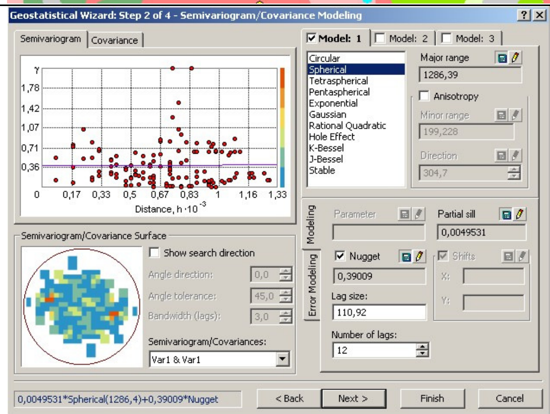
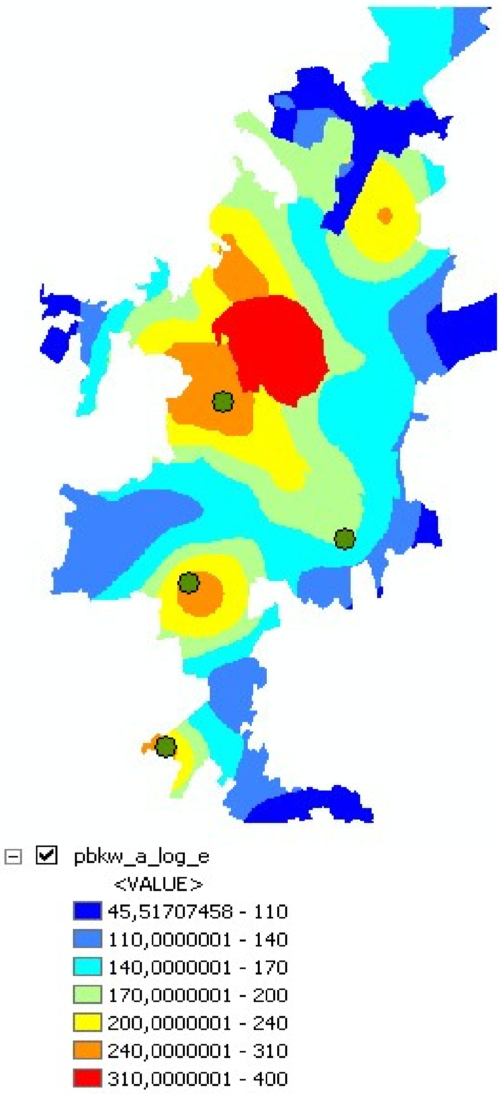
Measuring points and Variogram for blocks of flats of Annaberg from the GDR	Measuring points and Variogram for the historic centre of Annaberg
	
	

Figure 3: Sample points and variograms for two partial areas of Annaberg

Combined prediction of Pb_KW. Four sample points with measuring values outside confi-dence intervals	Combined estimation error of Pb_KW with all measuring points



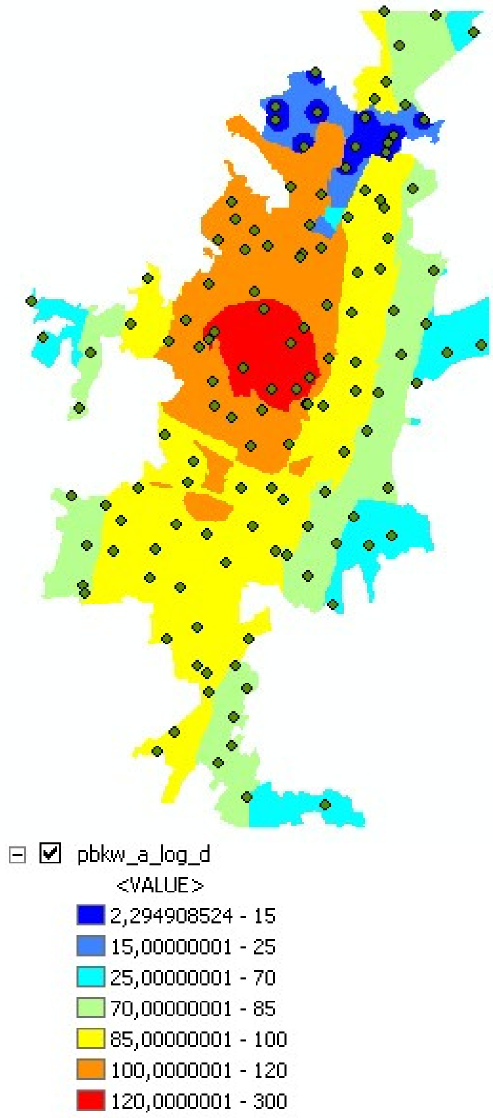


Figure 4: Combined prediction and estimation error for Pb_KW in Annaberg using spatial -analytic approach

6. Synoptic view of all influence factors with advangeo

Statistic and geo-statistic methods resp. allow a 2-dimensional representation of numerical point information. Study sites need to be characterised and classified previously according to the four above mentioned approaches. The interpolation result depends on the existing point values. The spatial distribution of influencing factors, e.g. mineral veins, is only considered for interpolation if sample points are located on the veins. Areas without samples are determined by surrounding sample points but not by the actual situation of the underground.
Artificial Intelligence (AI) can enhance the 2-dimensional representation of soil contamination based on point data by using neural networks. The software advangeo®, developed by Beak Consultants GmbH, was used for this study.
Advangeo® is a tailor-made software for knowledge-based data modelling and the prediction of events and phenomena with spatial relations. It analyses the complex relationships of potential controlling parameters on the probability of any occurring or prognostic events. It models causal structures based

on methods of artificial intelligence. The software uses the ability of artificial neural networks to identify, learn and generalise complex and non-linear relationships.
With this software plus an acceptable effort it will be possible to model processes and events which could not be or could hardly be analysed with mathematical analytical procedures. Thereby the software supports the complete workflow for the design and processing of parameterised models. All working steps like problem definition, data selection, data processing as well as modelling parameters and results will be comprehensibly saved. Integrated data and results of modelling and prediction can be easily visualised in ESRI ArcMap.
The system software advangeo® uses the supervised learning module with a Multilayer Perceptron (MLP).

Figure 5 shows a schematic illustration of a MLP with four input neurons and three hidden neurons in one hidden layer. The right hand side shows a detailed view of one hidden neuron with its activation function.

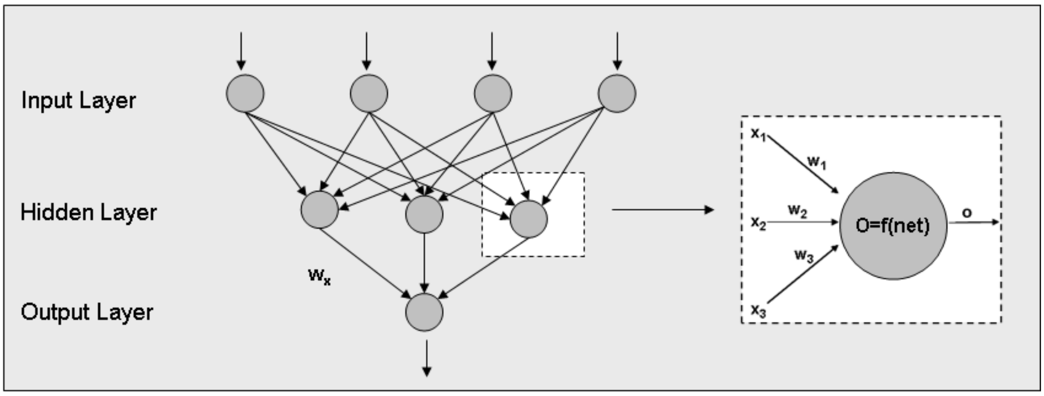


Figure 5: Schematic Illustration of a Multilayer Perceptron (MLP)

Raster data used for Annaberg-Buchholz were

- Land use (9 classes),
- Mineral veins (7 formations),
- Summarised deposit area,
- Samples with slag components
- Digital terrain model

Figure 6 shows the interpretation result for arsenic concentrations in the top layer soil sample Annaberg-Buchholz (depth 0.1 – 0.3 m).
Elevated arsenic concentrations in soils within the city (Figure 6, left) are mainly determined by the location of ore veins (Figure 6, right) (Bi-Ci-Ni- and polymetallic-sulfidic-formations).
In addition, cumulative occurrences of historic mining (small heaps, processing residuals, junction of veins) in the western part of Annaberg-Buchholz (Frohnau) affect significantly arsenic concentrations (red areas).

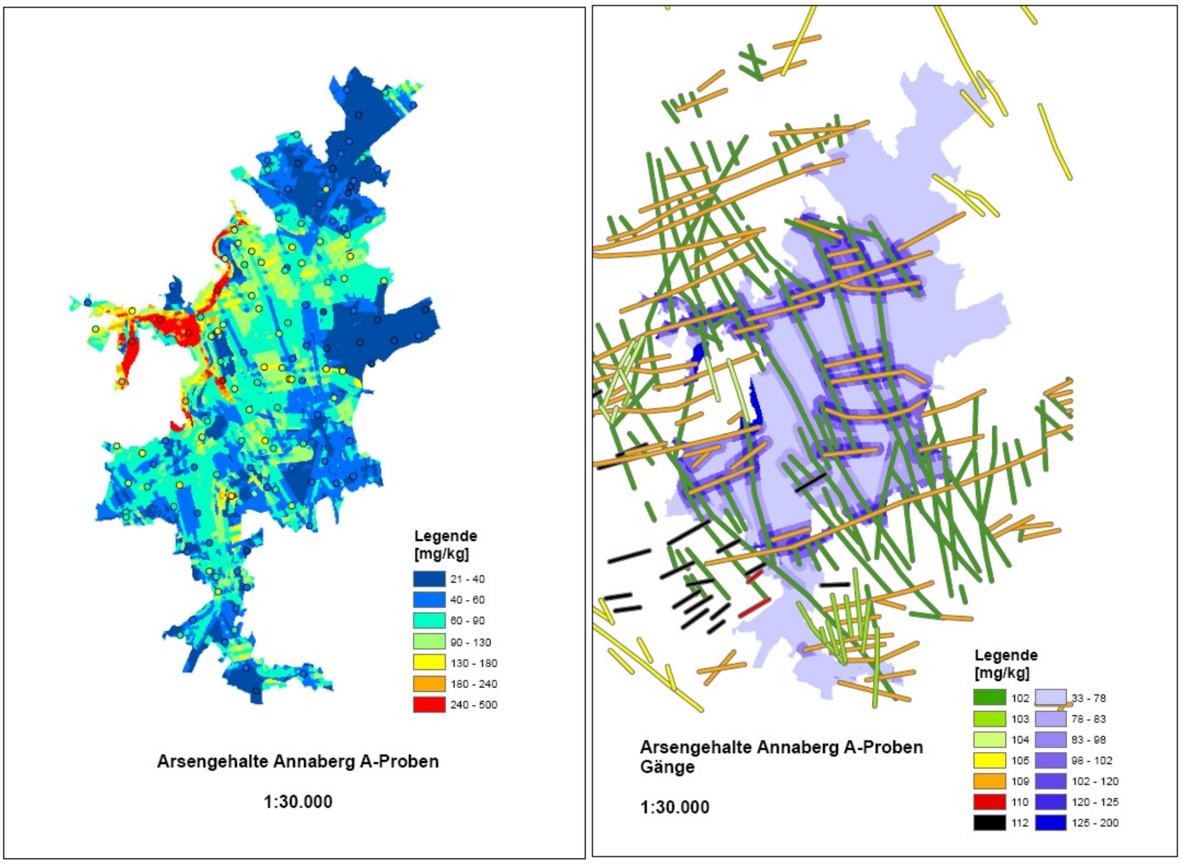


Figure 6: Arsenic concentrations of the top layer sample Annaberg with advangeo (left) and mineral veins in Annaberg (right)

7. Conclusions

For the compilation of soil contamination maps in urban areas, it is necessary to know the influencing factors for contaminant concentrations. These factors need to be quantified to a large extend to enable the use of (few) point data for a good 2-dimensional representation of the contaminants.
Knowledge of underground and its chemical properties has been shown to be of high significance in the test sites. Existing soil maps usually exclude urban areas. Thus, it is recommended to compile city soil maps. A second major source of information, as well in its temporal development, is land use.

If there is a moderate number of influencing factors on the element distribution, it is necessary to conduct a synoptic compilation and evaluation. Based on this, homogeneous spatial units (Homogene Raumeinheiten, HRE) can be delineated. This is a plausible method for a 2-dimensional representation of element concentrations which can be followed by interpolation methods.

In urban areas, a multitude of influencing factors overlaps and contributes to various extents to the explanation of variability of contaminant concentrations. In this case, the concept of HRE reaches some methodological and practical boundaries. As shown by the case studies, especially in complex cases a synoptical consideration of all influencing factors can be done by means of artificial intelligence (e.g. advangeo®).

References

/1/ LANAU (2006): Leitfaden zur Erstellung digitaler Bodenbelastungskarten – Teil I: Außenbereiche. Landesumweltamt NRW, Essen 2000. 116 S.

/2/ LANU (2007): Leitfaden zur Erstellung digitaler Bodenbelastungskarten – Teil II: Siedlungsbereiche. Landesamt für Natur, Umwelt und Verbraucherschutz NRW, Recklinghausen 2007. 107 S.

/3/ LfULG (2007): Erstellung digitaler Bodenbelastungskarten zur flächenhaften Darstellung und Beurteilung von Schadstoffen in sächsischen Böden – Leitfaden – Stand 05/2007. Materialien zum Bodenschutz. Sächsisches Landesamt für Umwelt und Geologie – 71 S.

/4/ Beak (2010)Zwischenbericht 3 zum Forschungsvorhaben „Schadstoffe in Siedlungsbereichen - Untersuchungen zur Verbesserung der Validität flächenhafter Aussagen“. Beak Consultants GmbH, Freiberg, 15.04.2010

/5/ MÜLLER, H.: Die Erzgänge des Annaberger Bergrevieres. Leipzig, 1894

/6/ LfULG (2006): Handlungsempfehlungen für die Umsetzung des Bodenschutzrechtes in Gebieten mit großflächig erhöhten Schadstoffgehalten (Stand 05/2006); Materialien Bodenschutz, Sächsisches Landesamt für Umwelt und Geologie, Dresden