Soil information system as part of a municipal environmental information system

H. U. Bartsch · J. Kues · J. Sbresny · J. Schneider

Abstract The objectives of the interdisciplinary pilot project "Development of a municipal environmental information system" in Hannover encompassed the development, modification and improvement of data acquisition methods and methods for describing the environment on the basis of this data, as well as methods for evaluating the data as a basis for measures affecting the environment taken by the community.
The subproject "Urban Soils" had the following two main objectives: (i) development of a data acquisition method for soils in municipal areas and a method for evaluating this data, and (ii) development of methods for making this information available to local government in the form of a "soil information system" for urban areas.
To achieve these objectives, the following work was carried out: (1) a factor analysis to determine which factors affect the soil in an urban area; (2) study of methods for mapping soils in cities; (3) development of a concept for a soil information system; and (4) evaluation of environmental problems of the municipality using the soil information system.
Data acquisition was done in two steps: First, soil-relevant data was selected, standardized, digitized and stored in an alphanumeric and a graphic database for a factor analysis. By intersection of the eight information levels, the factors affecting the soil were determined for the city of Hannover (200 km^2). To test the hypothesis that the results for one site can be transferred to another site with the same combination of factors, 43 test sites typical of urban land use were selected. These test sites were mapped in a way to fulfill geostatistical requirements; physical and chemical analyses of the soils were made. A prognosis of soil distribution and properties was made on the basis of the factor analysis. and compared with the actual conditions. Concurrent with the pedological research, a prototype soil information system was developed. The system consists of databases, a methodbase, a geometrical tool, and a control system. Alphanumeric data is stored in a relational database, the geometric data in ISAM files. Methods for determining soil parameter values were selected and tested for their applicability.
Using the pedological data and the soil information system, information can be obtained about soil conditions in Hannover as well as about soil processes (e.g. infiltration rates) and interaction with the atmosphere, hydrosphere, etc. This information can be obtained in the form of thematic maps and statistical representations, which can be used by decision-makers at the municipal level.

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Introduction and objectives

A pilot project titled "Development of a municipal environmental information system" was sponsored in Hannover, the capital of Lower Saxony, from 1989 to 1992 by the Ministry of Research and Technology of the Federal Republic of Germany. The objectives of the project encompassed the development, modification and improvement of data acquisition methods and methods for describing the environment on the basis of this data, as well as methods for evaluating the data as a basis for measures affecting the environment taken by the community. Therefore, it was planned as an interdisciplinary project, organized under the headings "Air," "Water," "Soils," "Biotopes" and "Urban Land Use."
The subproject "Soils" was further subdivided into the subprojects "Urban Soils" and "Processes in Urban Soils." The objective of the latter was the description of substance and energy flow in typical urban soils. The subproject "Urban Soils" had the following two main objectives: (i) development of a data acquisition method for soils in municipal areas and a method for evaluating this data, and (ii) development of methods for making this information available to local government in the form of a "soil information system" for urban areas.

To achieve these objectives, the following work was carried out: (1) a factor analysis to determine which factors affect the soil in an urban area; (2) study of methods for mapping soils in cities; (3) development of a concept for a soil information system; and (4) evaluation of environmental problems of the municipality using the soil information system.

Factor analysis for an urban area

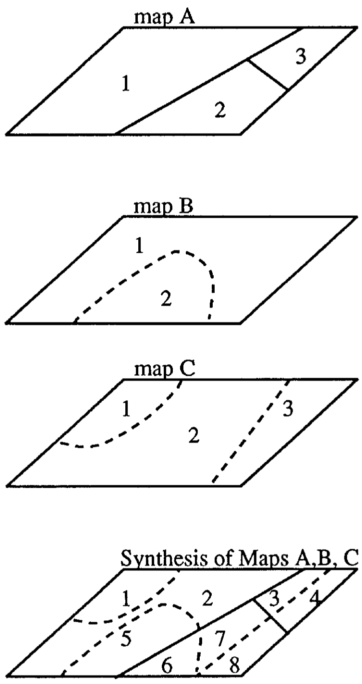
A factor analysis was to be carried out to determine which factors affect the soil in an urban area. This was to be the starting point for the development of a procedure for supplying decision-makers with information in the most effective way in terms of both time and expense. First, pedologically relevant data was selected for data acquisition, processed, and evaluated (Arbeitskreis Stadtböden 1989; Kneib and Braskamp 1990; Schneider and Kues 1990; Grenzius 1991) in order to determine the initial geogenic situation and the anthropogenic changes. This information was stored in various thematic layers for map overlays and intersection in the information system (Fig. 1). The resulting map was used as a base for field work.

For the rural areas of Lower Saxony, the available documents are routinely used in preparation for pedological mapping. A factor analysis is then carried out for the preparation of the base map for the field work. This map is used to facilitate determination of soil type boundaries in the field. The areas on this map showing the same combination of factors are used as a basis for the preparation of the field map, in which the results of the field work are presented. The map resulting from the factor analysis is a prerequisite for targeting areas for the field work, facilitates comparison of the results, increases the accuracy of the soil survey, and shortens the time needed for the survey, and consequently the cost (Oelkers and Eckelmann 1983).

In order to evaluate the available information, the data must be converted to a standard form. Emphasis in Hannover was the preparation of a scheme for interpreting historical maps with respect to land use (Ostmann 1993), the development of guidelines for integrating geological and soil assessment data, as well as the updating of the Guidelines for Translating Soil Assessment Data into Modern Nomenclature (Benne et al. 1990).

When this work was completed, the following information levels were available:

- Information about the initial geogenic factors:
  - 1:25,000 geological maps
  - 1:25,000 general soil maps of agriculturally used fields and wooded areas
  - 1:5,000 soil assessment maps
  - 1:10,000 maps of anthropogenically affected foundation soils
- Information about anthropogenic factors:
  - 1:25,000 historical land-use maps
  - 1:25,000 maps of current land use, derived from biotope maps
  - 1:1,000 maps of potentially contaminated commercial sites
  - 1:5,000 maps showing suspected abandoned landfills



map A	
area	attribute
1	A_1
2	A_2
3	A_3

map B	
area	attribute
1	B_1
2	B_2

map C	
area	attribute
1	C_1
2	C_2
3	C_3

Syntesis of Maps A,B,C	
area	attribute
1	$A_1 \wedge B_1 \wedge C_1$
2	$A_1 \wedge B_1 \wedge C_2$
3	$A_3 \wedge B_1 \wedge C_2$
4	$A_3 \wedge B_1 \wedge C_3$
5	$A_1 \wedge B_2 \wedge C_2$
6	$A_2 \wedge B_2 \wedge C_2$
7	$A_2 \wedge B_1 \wedge C_2$
8	$A_2 \wedge B_1 \wedge C_3$

(Kleefisch 1993)

Fig. 1
Schema for map overlays and intersection of various thematic layers containing pedologically relevant data in the information system

The resulting map for Hannover contains information from all eight levels. The information for the delineated areas was then classified in the soil information system. This was done to reduce the amount of attribute data and to obtain a basis for evaluating the data.

The following aspects were taken into consideration for this:

- Factor combinations typical of cities were investigated at several test sites to test the validity of the following hypothesis: The same land use and the same initial geogenic material or anthropogenic changes lead to the same soil, i.e. the same soil features and properties. This has already been demonstrated for rural soils. Thus, emphasis was placed on urban factors.
- Because the above hypothesis does not need to be tested for the data from the soil assessment maps and

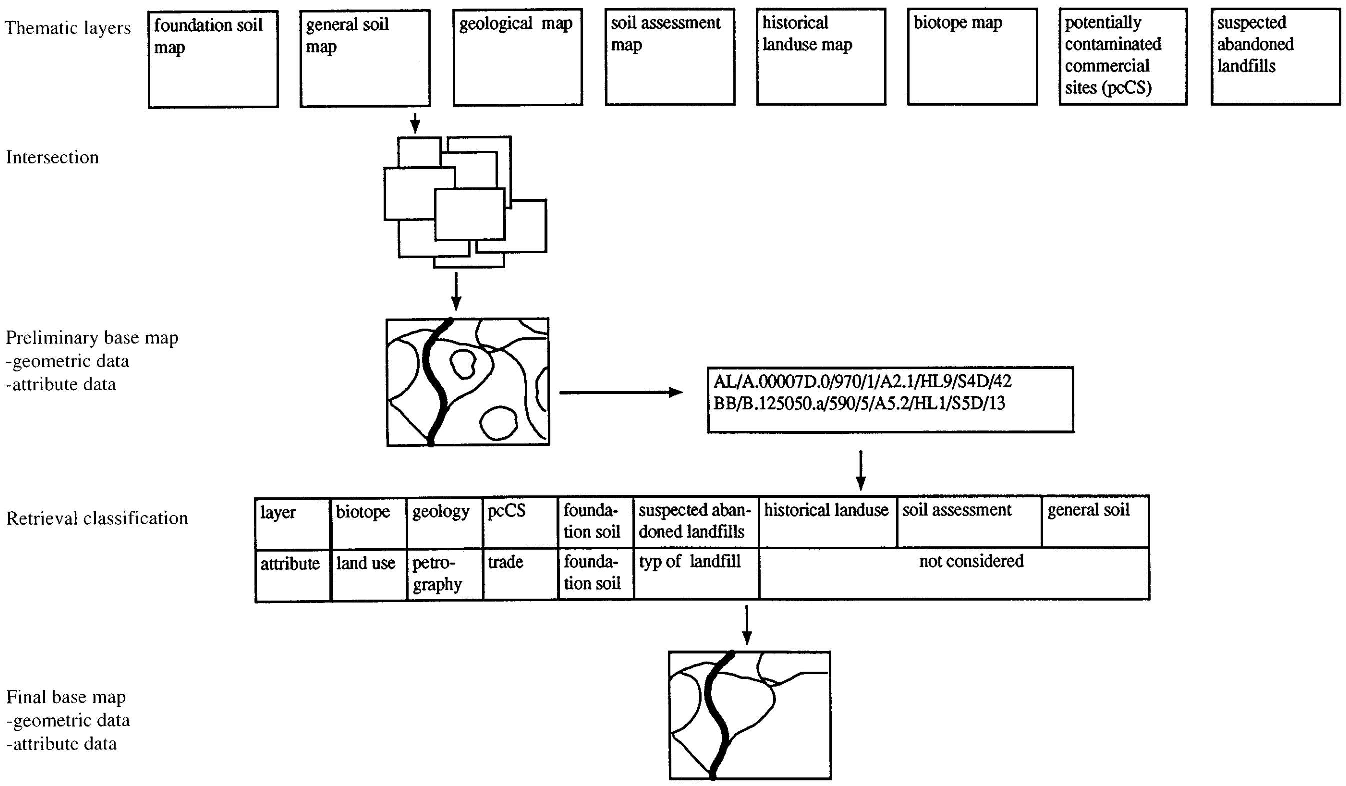


Fig. 2
Flow chart for the classification of factor combinations

the general soil maps of agricultural areas, these factors were not included in the analysis; they were, however, included in all other aspects of the analysis. It was possible to verify the pedological data later on the basis of the available information.

— Historical land use was also not included in the intersection of data, because there is no field evidence in urban Hannover for this information.

Thus, information from the following overlays was included in the classification procedure: geological maps, maps of suspected abandoned landfills, maps of anthropogenically affected foundation soils, biotope maps (i.e. maps of present land use), and maps of potentially contaminated sites.

The sites on the last-named map were classified according to the type of business using it (Kinner et al. 1986; Niclauss et al. 1989). The geological units were classified according to their petrography, and the biotope attributes according to land-use (Fig. 2). These new factor combinations were then linked to the areas of the base map for the field work. A total of about 4000 relevant factor combinations were identified.

The information on the base map was checked and the above-described hypothesis tested at 43 representative sites using 77 factor combinations. If the above hypothesis is confirmed, then the investigated factor combinations would provide information for about 25% of the area of the city of Hannover (Fig. 3).

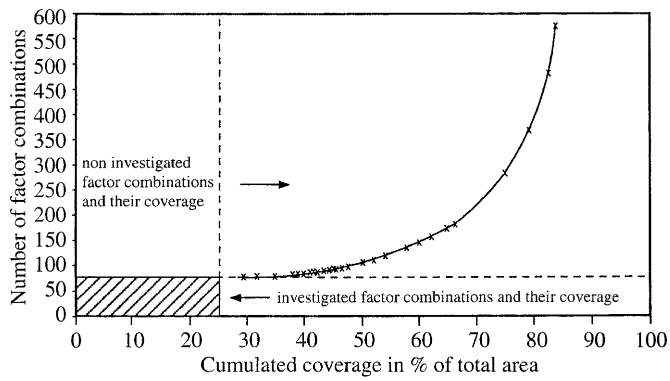


Fig. 3
The proportion of the total area of Hannover covered depends on the number of factor combinations investigated. The hatched area shows the factor combinations investigated in this project.

Field work

The boundaries on the base map, obtained by overlay and intersection, were checked in the field at selected test sites on the basis of the project objectives. This was done at three sites for each factor combination.

Normally, boreholes were drilled in a grid or along a profile in order to be able to evaluate the data statistically (Dutter 1985; Sachs 1980). The spacing of the boreholes was selected according to the expected variability of the test site. On the basis of the information on the base map, the following spacings were chosen:

— tilled fields 100 m
— wooded areas 100 m
— grassland 50 m
— parks (parent material of the soil anthropogenically unchanged) 50 m
— parks (parent material of the soil anthropogenically affected) 15 or 25 m
— industrial sites 10 m
— commercial sites 10 m
— areas of railway tracks 10 m

The spacing was selected to optimize the use of the information on the base map and to test its suitability for soil surveys at urban, commercial, and industrial sites.

When the field data had been evaluated, key profiles were selected and samples were taken for chemical analysis (inorganic and organic contaminants) and determination of physical parameter values (e.g. pore-size distribution and fluid conductivity).

The factor analysis, mapping, sampling, and analyses provided information about each site with respect to factors affecting soil formation, classification of soil types and profile description, and the physical and chemical properties fo the soil. The boundaries between soil types were obtained from the generalization of the point data into areal information. Areas of isogenic and isofunctional, or at least isomorphic soils were marked on large-scale maps. The following steps were involved: selection and interpretation of available information; selection of borehole sites in the field; profile description according to the guidelines of the Urban Soils Working Group (AK Stadtböden 1989); and fixing of boundaries between soil types on the basis of the information on the base map, the features observed in the field, and the information derived from the boreholes.

The identified soil units were characterized by the main soil in a map unit and displayed on large-scale maps of all the test sites. The data were then stored in the soil information system. Data on the sealing of the ground by construction and life in the soil obtained in the course of the Urban Soils project are also stored in the soil information system (Hammerschmidt 1991; Wolff 1991).

Concept and prototype of a soil information system

The investment involved in obtaining pedological knowledge (data and methods) can be sensibly and efficiently used only if this information can be provided to the user (the decision-makers) in appropriate form. This can be done with information systems that can relate pedological data and methods in a problem-oriented form.

Concept behind a soil information system

The main objective of the project was to determine how the user of a soil information system can be supported in his/her search for pedological data. The data in the information system is classified according to types of problems that decision-makers must deal with. In dialog with the system, the user selects the type of problem for which information is needed. No new pedological methods are to be developed for the system, because it was intended to use existing methods only.

The following relationships between the data and the types of problems are a prerequisite for more or less automatic processing of soil data to obtain pedological information and must be stored in the system:
— Which parameters are relevant and in which form is the data stored?
— Which methods are needed to calculate the required parameter values?
— How should the information be presented to the user?

To provide a basis for linking data and methods according to pedological criteria, the data and methods have to be stored in the system in a defined structure. A modular system was used for the methods, i.e. the methods were divided into the smallest possible units with which a meaningful result can be obtained from the data stored in the system. This was done to increase the number of combination possibilities and thus the potential amount of information that can be obtained from the system. Further advantages of modules are ease of maintenance and exchangeability.

An extensive range of standardized data [e.g. Pedological Data Key, AG Bodenkunde (Urban Soils Working Group) 1982; Pedological Data Key, Oelkers 1984; Geology Symbol Key, Preuss et al. 1991] was available for inclusion in the system, in addition to the data collected in the field during the project. This makes it possible to automatically evaluate a wide range of data. In addition to the data listed in the previous section, the following data was available for Hannover: weather data for the last 30 years and the results of a mapping of the sealing of the soil by construction.

The spectrum of information that can be obtained from the information system ranges from descriptions of the status of soils to methods for evaluating soil properties for various problems to descriptions of various processes, e.g. groundwater recharge. This information can be linked with information from the other geospheres (e.g. atmosphere, hydrosphere).

The following modules for evaluating basic data in the soil information system were programmed as part of the project and integrated into the system:
— determination of the pH value desired in the topsoil of agricultural and forest land;
— determination of the relative retention capacity of the topsoil for heavy metals;
— determination of the potential evapotranspiration;
— determination of the potential evapotranspiration for specific crops;
— classification of the depth to the water table;
— determination and classification of the permeability;
— determination of the mean capillary rise;
— determination of the available water;

— determination of the soil moisture class and the degree of influence of the groundwater on the soil moisture;
— determination of the vulnerability of mineral soil to erosion by water;
— determination of the vulnerability of the soil to erosion by water or wind as a function of soil cover;
— determination of the vulnerability of the mineral soil to erosion by wind;
— determination of the vulnerability of peatland to erosion by wind;
— a water regime model.

Implementation

The prototype soil information system completed during the project comprises a database and a methodbase, as well as components for problem-oriented linkage of the two. The system utilizes an expert system shell (Nexpert Objekt from Neuron Data), the RDB relational database system and the geometrical data tool GIROS (Preuss 1988), and the graphical user interface system UIS (from DEC). The prototype system does not allow modification of the data in the databases.
A block diagram of the system is shown in Fig. 4. In addition to the databases (RDB and Filesystem) and the methodbase (RDB, Filesystem, and object libraries), the control component (Nexpert and extentions) is of special importance. It includes the interfaces to the databases, the methodbase, and the geometrical data tool, as well as dynamic data structures for the results. The main task of the control component is the problem-oriented integration of all system components. Rules and object networks are used for mapping, for example, the relationships between the data sets and between the data and the methods. The relationships between the information that can be obtained from the system and the possible problems are mapped as part of the rule set in the user interface for problem specification. The module sequencer determines the sequence in which the modules will be used to provide the information needed for the selected problem.

Application

The user does not need to know any of the technical details of the system to use the prototype (e.g. the organization of the databases). The user, e.g. an urban planner, can "communicate" with the system using his own terms. The system links data and methods and makes them available to the user. A flow chart is shown in Fig. 5 for an application. The main steps are as follows:
1. Definition of the problem (determination of the relevant data structures): First, the user specifies, in dialog with the system, what kind of information is needed. For example, the map scale is selected by the user, the precision of the data, and whether the results are to be presented in qualitative or quantitative form.
2. Selection of the data set: When the problem has been specified, a map of the area related to the problem is called up. The user can select a particular part of this map. The area selected determines which data will be provided.
3. Linkage of the data (optional): If the problem requires the use of methods in the methodbase, a sequence of modules will be generated. The output data is stored in memory.
4. Presentation of the results: If only perusal of data in the database is desired, the user must select the areas or points on the selected map section for which information related to the problem is needed. The data will then be output to a window on the screen. If methods are used, the results will be shown on a map.

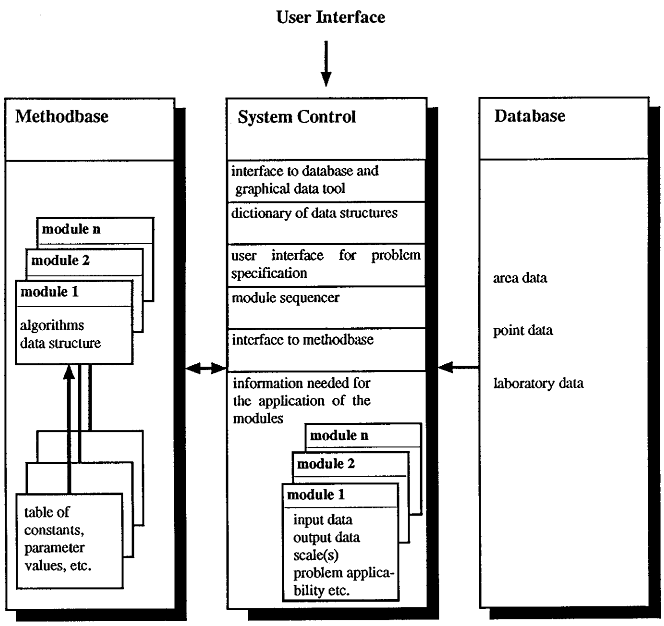


Fig. 4
Components of the soil information system

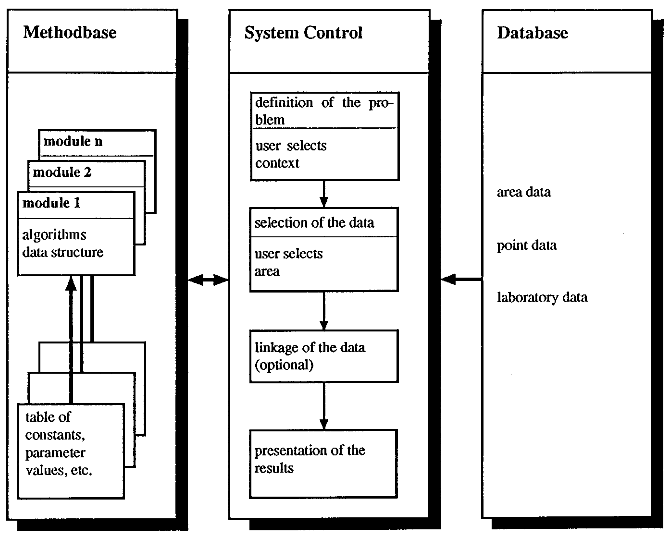


Fig. 5
Flow chart for a session using the soil information system

After an application, the system status is not changed so that the same context and related area can be used for another application.

Prospects

The prototype provides an insight into the potential of problem-oriented integration of pedological data and methods. Despite inadequacies of its technical capabilities (e.g. insufficient capabilities of the graphic tools or the databases) and content (e.g. errors in the handling of errors or assignment of data to a problem), it is being used as a basis for further development at the Lower Saxony Geological Survey.

Examples of the application of the system

Mapping methods for urban areas and methods of computer-aided evaluation of the data were dealt with in the "Urban Soils" subproject. The soil information system developed within the project and the extensive data provide a good basis for the handling of problems related to soils in the environmental information system. A prototype system was created with which data and methods can be linked according to the problem at hand. Moreover, this system can be used by someone who is not a specialist on soils. The results can be plotted on a map that can be easily read and that can be used by municipal decision-makers.
Several examples are given in the following sections to demonstrate the possibilities for a city administration to utilize the extensive data and numerous methods of the soil information system.

Water management

Example: Map of infiltration rates (Fig. 6).
Infiltration rates are necessary for the calculation of groundwater recharge rates for water management planning as well as for models of the migration of substances in the soil for risk assessment. Using a method developed by Renger et al. (1987), infiltration rates were calculated for areas not covered by building, streets, etc. using a numerical water regime model based on climate data, soil type, depth to the water table, and vegetation (Renger et al. 1982). For barren areas and areas covered by buildings, streets, etc., values were determined empirically for different types of ground cover. The climate data were obtained from the Hannover-Langenhagen weather station.
Homogeneous areas were obtained by intersection of the following maps: soil type map, produced from the digital geological map; map of the depth to the groundwater table, produced with an isoline program from the mean depths to the water table in 450 wells; and land use map, produced from the digital biotope map by classification of the biotope types in ten classes of ground cover. Infiltration rates were calculated for the resulting areas according to soil type, depth to the water table, and ground cover class. The resulting map shows infiltration rates for about 82% of Hannover.

Monitoring of the environment

Example: Groundwater quality or contamination of groundwater by heavy metals leached from soil.
Important parameters for predicting contamination of the groundwater are input of various substances and soil properties. A method in the methodbase of the soil information system was used to calculate the vulnerability of vegetated areas along streets to contamination with heavy metals (Fig. 7). The evaluated profiles show little to very little vulnerability. Input of cadmium from the street is relatively high, but owing to the soil properties of the site, there is little risk of groundwater pollution. The reason for this is that heavy metals migrate only within a narrow pH range. The pH values at the studied site are within the carbonate buffer range; no migration of heavy metals occurs within this range. Thus, the method used shows that despite the exposure of the site, there is no risk of groundwater pollution.
Example: Chlorohydrocarbons in groundwater and potential polluters.
A map of sites potentially contaminated with chlorohydrocarbons was produced by a search of the database for businesses and industries that use chlorohydrocarbons. This map was then overlaid with a map of chlorohydrocarbon contamination of groundwater as derived from well data. The resulting map shows a distinct correlation between the sites and the chlorohydrocarbon concentrations (Fig. 8).

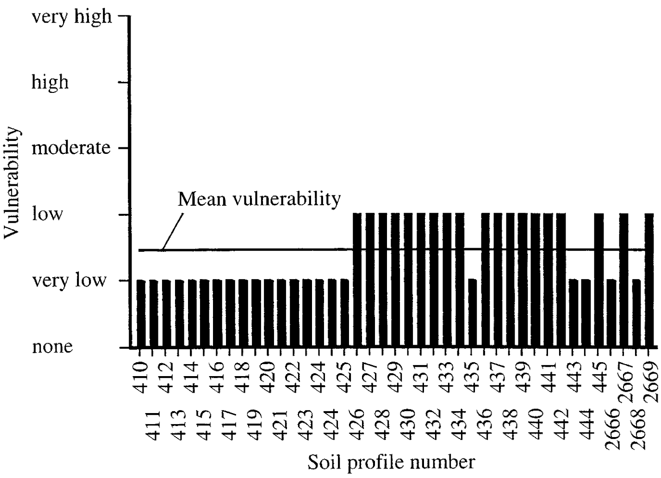


Fig. 7
Vulnerability of the groundwater to contamination with cadmium

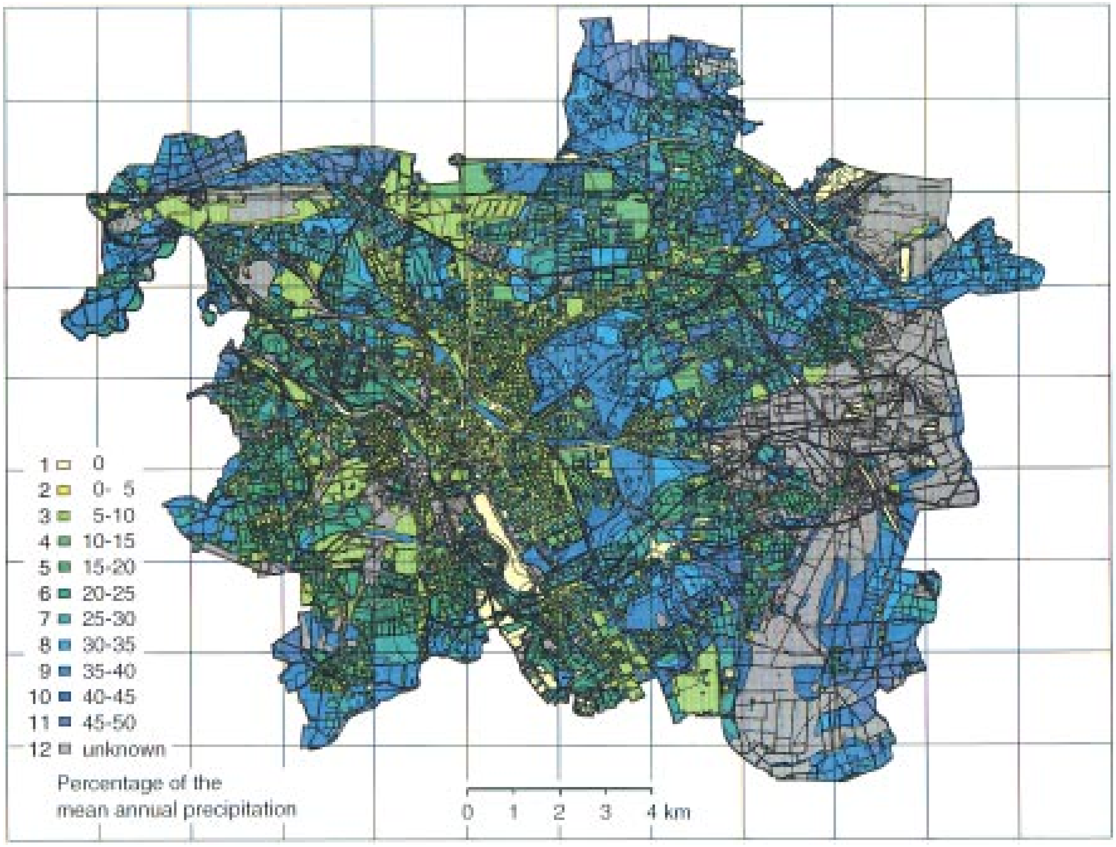


Fig. 6
Map of infiltration rates

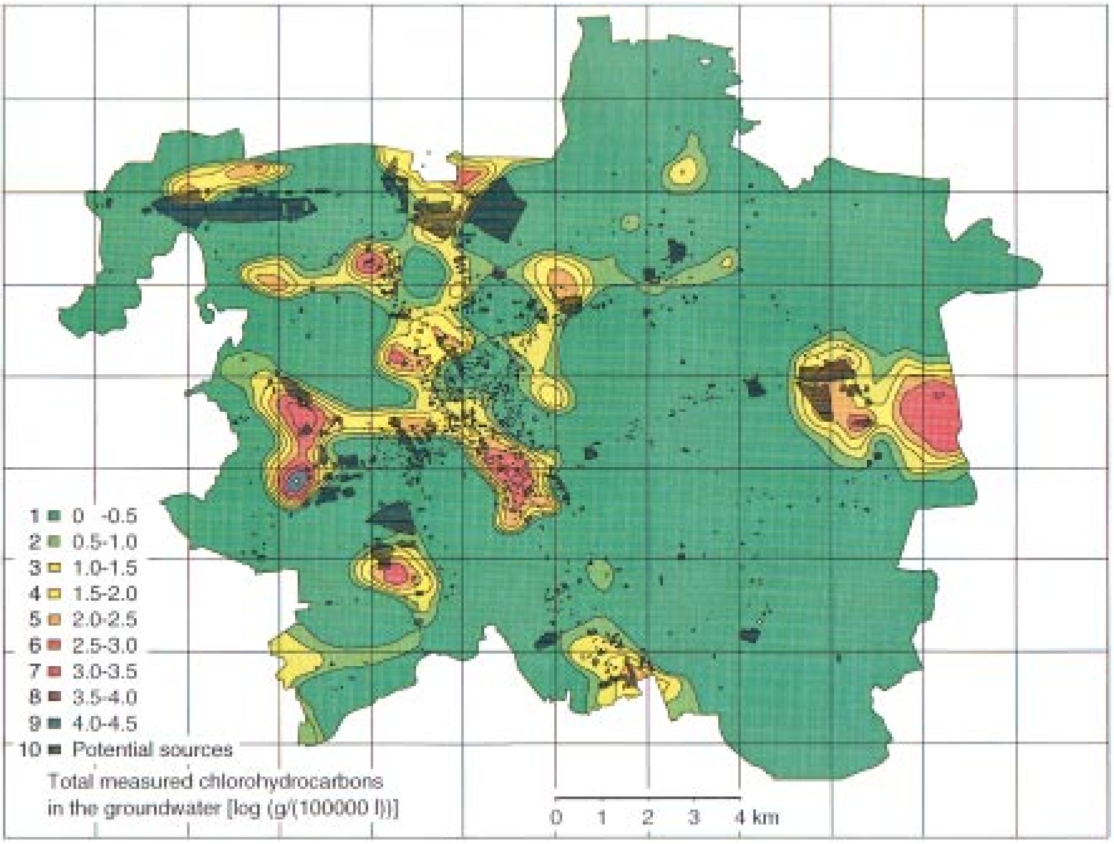


Fig. 8
Distribution of chlorohydrocarbons in the groundwater and potential sources

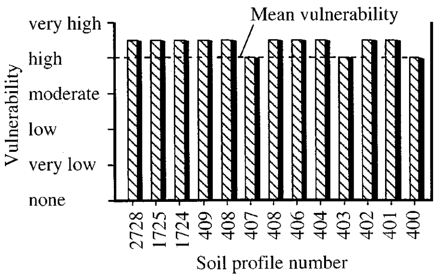


Fig. 9
Vulnerability of the groundwater to contamination with benzene

Example: Risk that gas stations pose to groundwater (Fig. 9).
Estimation of the risk posed by gas stations with respect to contamination of the groundwater with organic substances also illustrates the use of the soil information system for monitoring the environment. Evaluation of the data from a detailed site investigation shows that there is a high risk of groundwater contamination with benzene. The soil information system makes it easy to determine where remediation measures are necessary.

Agriculture and landscape planning

Example: Urban wooded areas.
In addition to mapping the wooded areas of Hannover within the scope of an investigation of soils in these areas (Kues 1987), a soil chemistry inventory was made to determine the situation with respect to nutrients and contaminants. Proposals were then made for melioration measures. The results were integrated into the soil information system and the environmental information system of the city of Hannover.
A map of buffer zones in the top soil of urban wooded areas provides information about the soil chemistry in these areas and the vitality of the vegetation (Ulrich 1981). Melioration measures were suggested on the basis of this evaluation of the mapping results and analytical data (e.g. capacity of the soil to neutralize bases). These recommendations have already been carried out by the city forestry office.
Example: Landscape planning.
Pedological data and evaluation methods provide an important basis for decisions by environmental protection agencies. For example, the potential for the development of biotopes may be derived from soil water regime and soil chemistry data (Arum 1992).

Advising activities

Environmental reports, workshops, and help with specific problems are part of the work of an environmental protection agency. The soil information system can be used for the statistical and cartographic analyses for these activities.

Applicability to other municipalities

This pilot project clearly showed how a municipal soil information system can be set up for other cities. The basis is the databases, which are used to obtain information about the present soil conditions and the processes causing them. The content of these databases will depend on the available data and on the capabilities of the municipality for which the information system is set up. A soil survey can be targeted using the base map prepared for the field work. The resulting high data density makes it possible to include the soil in municipal planning. The programmed methods can be used directly or after slight adaption to a specific site. The data processing tools implemented in this prototype system for problem-oriented evaluation at the municipal level can be easily transferred to other hardware. The following aspects are important for the decision as to which GIS is to be used:
— intersection capability,
— assignment of user-selected attributes to graphic data,
— sufficient exactness for query input,
— input data must not overwritten with calculated data,
— programmer interfaces,
— possibility of combining methods,
— database interface(s) (SQL),
— (in Germany) EDBS interface to ATKIS data.

Conclusions

The "Urban Soils" subproject within the "Development of a municipal environmental information system" project within the scope of an ecological research program of the city of Hannover had two main objectives: (1) development of an effective method of data acquisition and storage of pedological information that can be used at the municipal level; and (2) development of a prototype soil information system for urban areas to improve the availability of information to the city administrative bodies.
Data acquisition was done in two steps: First, soil-relevant data was selected, standardized, digitized and stored in an alphanumeric and a graphic database for a factor analysis. By intersection of the eight information levels, the factors affecting the soil were determined for the city of Hannover (200 km^2). To test the hypothesis that the results for one site can be transferred to another site with the same combination of factors, 43 test sites typical of urban land use were selected. These test sites were mapped in a way to fulfill geostatistical requirements; physical and chemical analyses of the soils were made. A prognosis of soil distribution and properties was made on the basis of the factor analysis. This prognosis was compared with the actual conditions (Schneider 1994).
Concurrent with the pedological research, a prototype soil information system was developed. The system consists of databases, a methodbase, a geometrical tool, and

a control system. Alphanumeric data is stored in a relational database, the geometric data in ISAM (indexed sequential accessed memory) files. Methods for determining soil parameter values were selected and tested for their applicability. Most of the methods integrated into the system were selected because they need relatively little data for the desired results. The geometrical tool is the GIROS package developed by the NLfB (Preuss 1988). Using the pedological data and the soil information system, information can be obtained about soil conditions in Hannover (in some cases, for the entire area), as well as about soil processes (e.g. infiltration rates) and interaction with the atmosphere, hydrosphere, etc. This information can be obtained in the form of thematic maps and statistical representations, which can be used by decision-makers at the municipal level.

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