# MAPPING OF ENVIRONMENTAL POLLUTION IN URBAN AREAS WITH GIS

L.Matejicek, L.Benesova, J.Tonika

Institute for Environmental Studies, Charles University in Prague
Benatska 2, Prague 2, 128 01, Czech Republic

**Abstract**

Environmental pollution in urban areas has resulted in the design of monitoring and decision-making systems. These systems are supported by the information systems that can manage spatial dynamics of pollution processes. Due to a wide range of data, which are necessary for modeling of spatio-temporal phenomena, new methods of data collection and management have to be created. This paper describes terrain mapping and data collection concerned on environmental pollution. Mapping is realized by the integration of GIS, GPS and remote sensing technology in the frame of a mobile GIS's station. Spatial data are captured by the GPS together with their attributes that are formed by descriptions of samples, direct terrain measurements (mobile sensors of air, water and soil pollution; noise assessment) and terrain observations (landscape classifications; mapping of fauna and flora and waste production). The mobile GIS station can carry out a number of estimates based on terrain data and shared data through the remote network connection. The GIS functions support decision-making on a few levels (administration of data and basic environmental analyses; sharing of other data and analyses through the network; modeling of spatio-temporal phenomena by dynamic models). A case study demonstrates mapping of sources of pollution and measurements of water quality complemented by other terrain observations. The attached dynamic models demonstrate dynamic modeling of contamination from point and non-point sources of pollution.

## Introduction

Protection of urban areas requires measurements and observations of a wide range of parameters that can characterize levels of environmental pollution. Mostly, the measurements are focused on air pollution, pollution of surface water and groundwater, soil contamination, noise assessment, waste management and landscape protection. Within these fields, monitoring of environmental pollution is created to estimate short and long term changes, to carry out risk assessment analysis, to develop models for prediction and optimization, and finally, to print maps for the support of decision-making processes. In the past, only heavy industrial areas and large cities were monitored and mapped in the local scale. At present, observations in a global scale are carried out to protect all the environment of our planet. A wide variety of techniques in order to determine individual factors of pollution and stress are used for decision-making processes. A number of automatic and manual-operated stations, chemical analyses in laboratories, satellite technology, risk assessment analyses and modeling systems is applied to improve our knowledge about behavior of various types of pollution and its influence on living organisms. Mapping of pollution together with their sources and the living environment helps to illustrate all the phenomena more transparently. Increasingly more powerful desktop and especially mobile computing systems with their graphic capabilities represent a new possibility for digital mapping. In addition to mapping, advanced analyses can be solved by digital computing systems, which can be represented by the Geographic Information Systems-GIS. There are a number of GISs in the market. Their capabilities are mainly focused on spatial data management that includes a wide range of extensions for spatial analyses, development of three-dimensional map objects, network optimization, image processing, etc. New data inputs represent satellite and aerial images processed by remote sensing, and geopositional systems-GPS. Integration of digital tools for mapping of environmental pollution together with standard monitoring systems and environmental measurements illustrates figure 1.
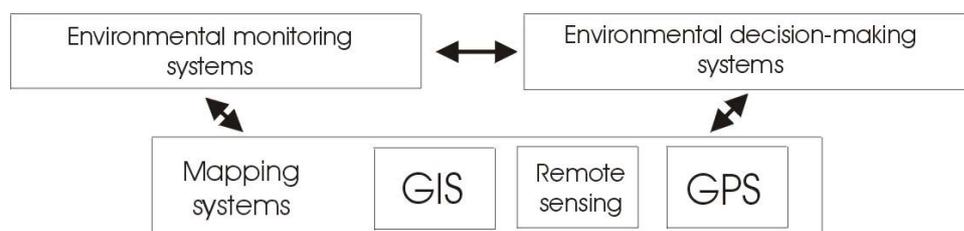


Figure 1: Integration of digital mapping tools in the frame of environmental protection.

**Methods**

Progress in environmental protection depends on a wide range of components. Besides of data collections and standard decision-making procedures, more sophisticated analyses are needed to effectively solve all the problems. In this part of research, new technology in the frame of the GIS and the mobile computing offers portable solutions. Moreover entering, storing and displaying spatial data in the form of maps, computing capabilities of the mobile PCs together with aerial and satellite images supported by the GPS can be directly used for estimates and analyzes of environmental parameters. The results can be displayed by the GIS in the map themes or transferred via the network. As an example, the GIS for mobile data collections and estimates is illustrated in figure 2. The schema is complemented by the software tools for development of modules that can modify and extend existing capabilities of the GIS. The selected environmental analyses, which are described by mathematical rules, are implemented in the software extensions of the GIS. There are a few ways of building extended modules in the GISs. The example illustrates the development of the software extensions by the ESRI's ArcPad Application Builder, which represents the software development kit for programming and design. The ArcPad by itself represents the mobile GIS that can run in the standard Windows or Windows CE environment. In addition to entering data and running of the software applications, direct inputs from the GPS and other mobile devices enable online data collection. All the collected data and information in the GIS project can be visualized in the map layers and transferred via the network to the relational database.
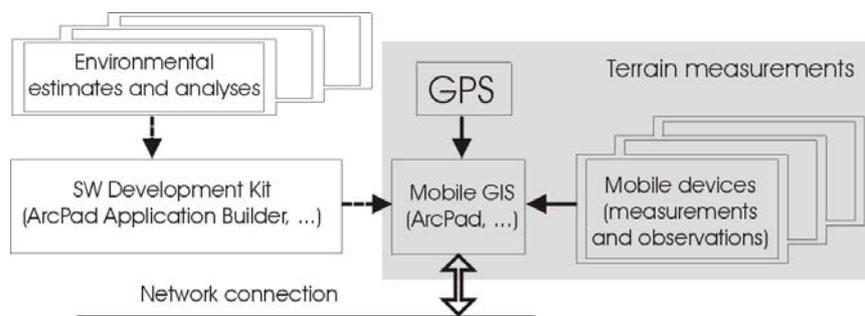


Figure 2: The development and use of environmental analyses in the frame of the GIS mapping.

The methods implemented in the GIS for the support of mapping of environmental pollution are mostly focused on data collection and basic analyses, modeling and predictions. A number of applications, which can be also partly implemented in the mobile GIS, is described in the book: GIS and Environmental Modeling by Goodchild et al. (3). GIS research in the field of water management describes Maidment (6). More general principles of GIS data management and statistical analysis are introduced by Chilěs and Delfiner (2), Legendre (4) and Zar (9). GIS mapping and its applications in environmental studies are partly described in the book written by Longley et al. (5). The selection of appropriate methods for the support of the GIS mobile computing depends on the potentiality of development tools, the capacity of storage devices and the power of a computer. The GIS project described in the frame of this paper is focused on applications in the environment of the Pocket PC, which offer high mobility and adequately performance on its level of computing. The map layers for mapping of environmental pollution illustrates figure 3. The layers are divided into a few classes, which are focused on a specific type of environmental pollution. In addition to the location of pollution in the vector formats (point, line or polygon groups of objects) or raster grids, each object of the layer can contain attributes (the level of pollution, data and time of the location and other specific information). All the special and temporal data can by repeatedly analyzed and preprocessed into new layers (Matejicek, 7, 8).
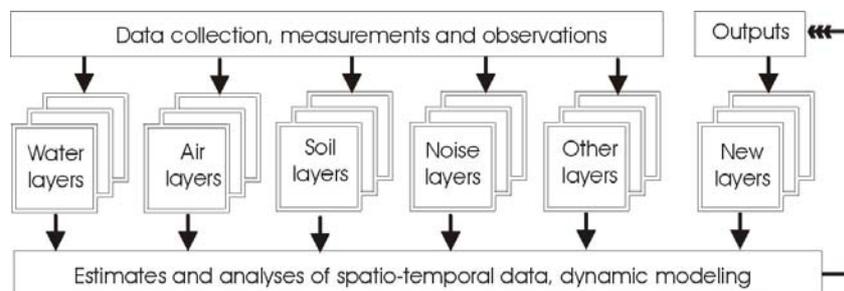


Figure 3: Mapping of environmental pollution by the GIS

In spite of that the estimates and analyses of spatial and temporal data depend on a specific type of pollution, the common tools for the complex evaluation in the frame of the GIS can represent the raster algebra (evaluation of data in regular grids) and the spatial analysis of the vector objects (point, line, polygon objects).

**Results**

The software tools (EnviPad) for mapping of environmental pollution in urban areas are developed in the GIS environment of the ESRI's ArcPad using the Visual Basic script language and the ArcPad XML protocol for its automation and customization. There is a number of methods focused on data collection, spatial data management, data analysis and dynamic modeling in the software extensions. The basic structure of the EnviPad is illustrated in figure 4. The sampling layer is used for the input of data that can be consequently transferred to the modules included in the parts of environmental mapping. In addition to the collected data, positions from the GPS and images from remote sensing can be added into the mapping projects. Input data together with estimates and outputs of statistical analysis and dynamic modeling can be reported or stored in text files. Spatial data together with their attributes are stored in the GIS's shape files, which are used in the frame of data management in the ArcPad and other GISs (ArcView, ArcGIS).
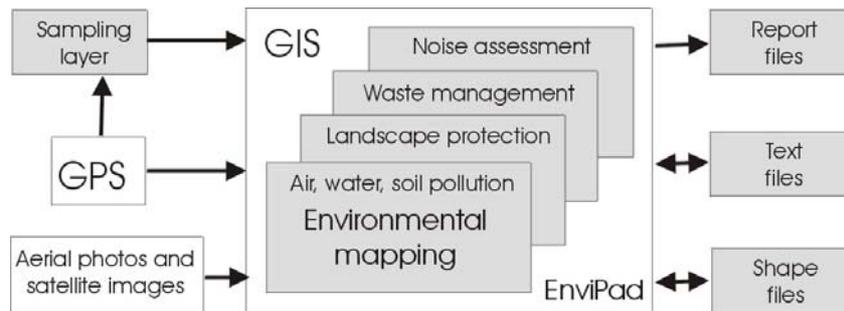


Figure 4: The software tools for mapping and analysis of environmental pollution (EnviPad)

The graphic user interface of the sampling layer is in figure 5. The forms contain identification codes, date and time of sampling, specific information about pollution, a name of the observer and the location (X ,Y, Z). The $X_1$-$X_7$ variables are used for the input of the values, which can be in nominal, ordinal, interval or ratio scales. All data can be complemented by comments and images in the last form. Moreover typing appropriate data into the forms, some data can be directly transferred from the devices (the location X, Y, Z can be captured via the GPS or by placing the pen on the map layer, the values of the variables $X_1$-$X_7$ can be read from digital devices).



Figure 5: The forms of the sampling layer (EnviPad)

There is a wide range of data analyses and dynamic models in environmental studies that are used to estimate and predict various parameters. Due to a limited possibility of the mobile computers (Pocket PCs with Windows CE) and the focus of this paper, selected analyses and dynamic models are implemented to examine the mobile GIS environment for environmental mapping (EnviPad). Generally, the data analyses contain statistical methods (one dimensional and multidimensional methods, testing of hypotheses), modeling of accumulation and transfer linked to the data structure of the vector objects in the maps (points, lines, polygons) and modeling of diffusion in the grids linked to the raster formats (aerial and satellite images). All the data (collected entries, estimated parameters and predicted results) represent the input to the relational database shared by other users, which can assist to carry out consequent analyses.

As an example, the project focused on evaluation of water quality in the basins by the mobile GIS is presented in the next part (Benesova, 1). The fundamental map layers in the GIS include the network of water streams, locations of point and non-point sources of pollution and the locations of measurements. In addition to the previous layers, the aerial and satellite images, general layers (vegetation, road and railway networks, contour lines) and other parameters (temperature, precipitation, agricultural and industrial activities) supply environmental mapping. Figure 6 shows some of the outputs of the project represented by the satellite image and the general digital map.
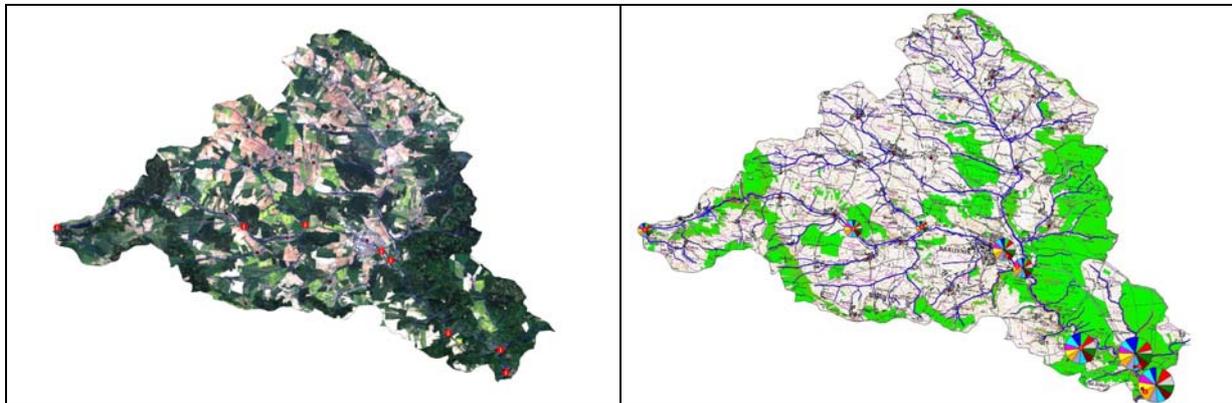


Figure 6: The satellite image and the general digital map of the basin (the measurements of water quality are located by points on the left part and by pie charts on the right part, the pie charts represent the average values of the $BOD_5$ in each month of the year)

The next example represents partial outputs of the project focused on prediction of air pollution supported by the LIDAR technology (Zelinger, 10). The experimental data obtained by direct monitoring methods and by mathematical and physical modeling are integrated in the frame of the GIS project, which is extended by other layers and data (satellite and aerial images, surface models created by triangulated irregular network, general map layers).
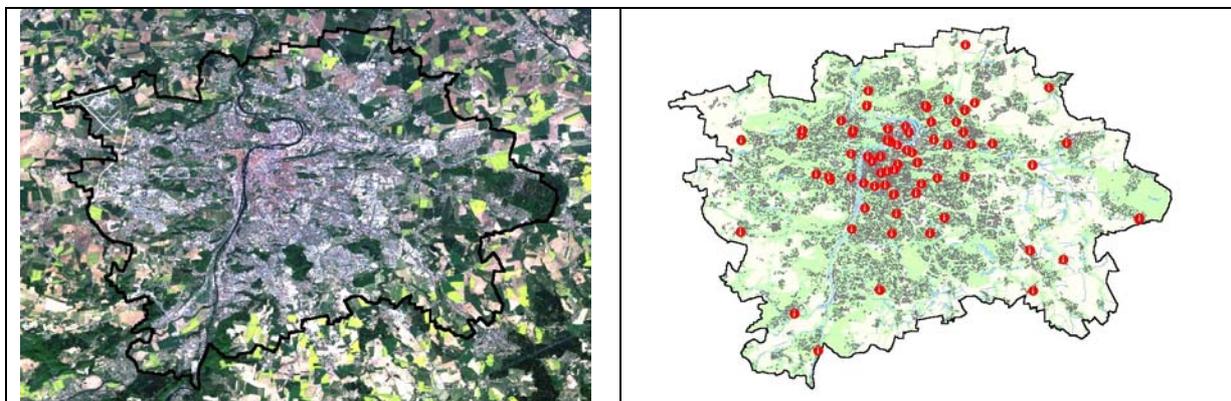


Figure 7: The satellite image and the general digital map of Prague (the measurements of air quality are carried out by the air pollution monitoring network marked by points)

**Discussion**

The mobile GIS (EnviPad) is tested in the frame of the introduced research projects. Implementation of each project into the mobile GIS requires a different approach that is given by the specific data structure of estimated and predicted parameters. In spite of the unique structure of the GIS projects, there are general methods for data analysis and dynamic modeling in the EnviPad. The methods are developed with the Visual Basic script language and the ArcPad XML protocol, which enables appropriate direct modifications. All the arrangement should be concerned primarily on data integration and transfer, which also accentuate the uniform data exchange among the GIS software extensions. The engine of each module contains mostly the implementation of statistical methods or dynamic models. Their modifications are expected in a case of updating or in the frame of more complex integrations. The main advantage of the mobile GIS computing represents online interference during the data collection. The possibility to modify the measurements and consequently to make all the estimates, analyses and simulations enables to improve the final results. The temporary disadvantages of the small storage capacity and the low processor speed limit the size of spatial data sets and the computation of

more complex analyses and models. In this case, the data transfer is realized through the networks. Then, the consequent GIS analyses together with modeling are carried out on another GIS platform. As an example, the ESRI's ArcGIS can be used for complex spatial data management. The EnviPad in the ArcPad environment stores spatial data in the "shape files", which can be directly imported together with their attributes into the ArcGIS that offers a larger range of data formats and spatial analyses. Moreover, advanced spatial data formats extended by topological rules (geodatabase, coverage) enable more effective and complex spatial analyses. Spatial data can be managed by the relational database, which also assists for the data transfer between the mobile GIS and the database server. The spatial data management in the frame of EnviPad is generally realized by the mobile GIS ArcPad and by the routines included into the software extensions.

## Conclusions

The described mobile GIS for environmental mapping (EnviPad) is designed primarily for the Pocket PCs, but can be use in the environment of any standard personal computer. As hardware design and miniaturization of personal computers improve their capabilities, it becomes possible to implement GIS software even on hand-held systems. Likewise the present Pocket PCs have capabilities similar to the desktop systems of a few years ago, the future hand-held systems will manage remarkable larger functionality with the rapidly higher speed and storage capacity. Also, integration of the GPS and other sensors will improve their utilization in the frame of the mapping. On the other size, the hardware of the Pocket PCs together with the software can be installed directly into the mobile devices for the measurement of environmental parameters. The standard computation equipment of these devices will enable to use a number of standard programs and to develop new applications more efficiently. From this point of view, new methodology is needed to estimate directly environmental parameters and their levels of uncertainty. Simultaneously, the results can help to make corrections in the process of data collection. So more sophisticated data analyses (multivariate methods, spatial interpolations) together with dynamic modeling (models for prediction of transport and effects of pollution in the space) can support decision-making processes even in the phase of data collection.

## References

(1) L. Benesova, L. Matejicek, M. Matouskova, J. Tonika, Ecological Assessment of Water Quality in Small Water Basins: The Stream Rakovnicky, Final Report, Charles University in Prague, Prague, Czech Republic, (2001)

(2) J.P. Chilés, P. Delfiner, Geostatistics Modeling Spatial Uncertainty, 1st ed., Wiley, New York, USA, (1999)

(3) M.F. Goodchild, L.T. Steyaert, B.O. Parks, C. Johnston, D. Maidment, M. Crane, S. Glendinning, GIS and Environmental Modeling: Progress and Research Issues, 1st ed., CO: GIS World Books, Fort Collins, USA, (1996)

(4) P. Legendre, L. Legendre, Numerical Ecology, 2nd ed., Elsevier, Amsterdam, The Netherlands, (1998)

(5) P.A. Longley, M.F. Goodchild, D.J. Maguire, D.W., Rhind, Geographic Information Systems and Science, 1st ed., Wiley, New York, USA, (2001)

(6) D. Maidment, Arc Hydro: GIS for Water Resources, ESRI Press, USA, (2002)

(7) L. Matejicek, L. Benesova, J. Tonika, Environmental Modelling in Urban Areas with GIS, Proceedings of the 1st Biennial Meeting of the International Environmental Modelling and Software Society, Lugano, Switzerland, (2002)

(8) L. Matejicek, L. Tlapakova, Modeling in the GIS Environment: Dynamic Processes of Water Pollution, Acta Universitatis Carolinae Environmentalica, **16**, 47-62, (2002)

(9) J.H. Zar, Biostatistical Analysis, 3rd ed., Prentice-Hall, London, United Kingdom, (1996)

(10) Z. Zelinger, M. Strizik, Z., Janour, P. Berger, A. Cerny, P. Engst, Comparison of Model and in-Situ Measurements of Distribution of Atmospheric Pollutants, Proceedings of Physmod 2003, Prato, Italy, (2003).