Spatial Information System for Risk Assessment of Dust Transport in the Neighbourhood of the Surface Coal Mine

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Abstract: Risk assessment of dust transport from surface coal mines over neighbouring residential zones requires more complex modelling tools in order to analyse satellite images, to attach high resolution aerial images, to create more precise digital terrain models, to integrate time series of meteorological variables, to realize linkage between the spatial database and numerical simulation tools, to provide spatial analysis, and to visualize the results. Thus, a spatial information system based on GIS technology is used for data management, advanced spatial analysis and numerical simulation linked by shared data files. At first, a digital terrain model is created by processing data originating from surface laser scanning, GPS measurements and geodetic surveys. This enables precise modelling of wind flows over potential dust emission sources for an estimation of dust transport. Finally, the simulation outputs are transformed into a set of existing digital map layers, and spatial analysis is carried out for visualization.

Keywords: Spatial Information System; Dust Transport; Risk Assessment; Surface Mine.

1. INTRODUCTION

For the past few decades, various approaches have been developed to perform health risk assessment in compliance with requirements contained in the US EPA methodology as well as with EU instructions [Mower, 1998]. Due to available data, recent projects are mostly focused on short-term direct and indirect effects, such as ingestion through food chains or inhalation, but do not include research for long-term observations and data processing [Finkelman, 2002]. Moreover, evaluations become very complex when several emission sources contribute to the overall concentration of contaminants in the air. Because each emission source has a different emission rate, location and dispersion characteristic, more complex analytical tools are needed in order to manage data, provide analyses, solve numerical models, display results and share data via networks.

The objectives of this paper are to propose and demonstrate a spatial information system that can support risk assessments focused on dust dispersion over a selected surface coal mine and surrounding neighbourhoods in the Czech Republic. In mining areas, suitable remediation procedures have to be carried out to protect the natural environment, because associated impacts on human health have long been recognised. In order to find the best scenarios for remediation, all suitable data have to be collected and analysed.

A prerequisite for exploring the impact of dust deposition is to determine emission sources, spatial distribution and temporal variation [Lu, 2001]. To carry out all these tasks, a spatial information system is needed for data management, spatio-temporal analysis, numerical simulation and final visualization. Despite the existence of software tools for spatial
analysis or temporal analysis, a complex quantitative solution has not been possible until recently. Thus, in order to integrate spatial data and temporal data, a geographic information system (GIS) is used for these tasks [Goodchild, 1996].

2. SPATIAL DATABASE

Nearly all recent GISs can manage data in a relational database, which simplifies data sharing among various software tools and via the Internet. Display and visualization are provided in the framework of digital map layers that include vectors, grids, triangulated irregular networks (TINs) and other objects [Zeiler, 1999; Döllner, 2000]. The spatial data formats offer more complex analyses, ranging from exploratory spatial data analysis (ESDA) to geostatistical interpolation and modelling [Mitchell, 2005; Maguire, 2005].

Data represented by the digital thematic map layers of the surface coal mine and its surrounding areas are stored in the database and complemented by satellite images, aerial images, surface laser scanning, GPS measurements, a geodetic survey, data from local meteorological stations, terrain measurements of dust deposition, and inputs/outputs of standalone modelling tools. The database is created in the framework of the GIS project and is based on ESRI’s geodatabase [Arctur, 2004].

3. SPATIAL INFORMATION SYSTEM

In order to support the risk assessment of dust transport, the spatial information system based on ESRI’s ArcGIS is created to analyse the surface spatial data, local meteorological observations and the inputs/outputs of numerical modelling. In addition to GIS software, many other software tools have been used for data pre-processing.

3.1 Satellite images

An overall view of the surface mines from a Landsat 7 panchromatic image is shown in Figure 1. The area of interest marked in the middle encompasses approximately 1.25 km².

Figure 1. The satellite image from Landsat 7 with the area of interest and the local meteorological stations (panchromatic band 0.520-0.900 µm at 15 meters resolution).
In addition to the panchromatic band at 15 meters resolution, the Landsat 7 Enhanced Thematic Mapper (ETM+) provides 7 bands of multispectral data. While bands 3-2-1 (red, green, blue) create a true colour composite which displays objects similarly to a colour photograph, bands 4-3-2 (near infrared, red, green) and bands 5-4-2 (mid infrared, near infrared, green) are used for classification and identification of geologic rock types and soil boundaries.

3.2 Surface laser scanning

Surface laser scanning is used to capture surface points in an area of temporary coal storage and neighbouring slopes near residential zones, Figure 2. To obtain complete measurements from shielded parts, the final set of spatial points is based on multiple scans from different locations. After spatial transformation, the reduced set is placed into a common reference system and included into the complex DTM.

Figure 2. The clouds of points from surface laser scanning for creation of the DTM.

Figure 3. The draped aerial image and the GPS measurements on the DTM.
3.3 GPS measurements and draping the aerial images on the DTM

The geo-rectification of satellite images, aerial images and clouds of surface spatial points is provided by GPS and data from the geodetic survey. GPS is also used for the location of emission sources, slope shapes, roads and temporary storage sites. The draped aerial image on the DTM is shown in Figure 3. This provides a more realistic view of the area of interest and its neighbouring residential zones.

3.4 Time series from the meteorological stations

Time series of meteorological variables captured by local meteorological stations are pre-processed in order to explore the dominant wind direction, wind speed, atmospheric pressure, and to set model parameters. The wind class frequency distribution and the wind rose based on data from all the meteorological stations are shown in Figure 4.

![Figure 4. The class frequency distribution of wind speed captured by local meteorological stations, illustrated by histogram and a wind rose diagram.](image)

3.5 Numerical simulation

Due to the time consuming numerical operations, standalone software tools are used for dispersion modelling over a part of the surface coal mine. Data linkage between the spatial information system and the inputs/outputs of the numerical simulation is provided by shared data files. The simulation is based on Reynolds averaged Navier-Stokes (RANS) equations for incompressible flows with turbulent closure of the model by the algebraic turbulence model [Kozel, 2007]. The DTM created in the spatial information system assists in a more precise modelling of wind flows over the surface. The output data are located in nodes of the horizontal layers. Each node contains values of the wind velocity vector, the atmospheric pressure and the dust concentration. The example in Figure 5 illustrates the lowest surface layer dedicated for the display of the wind speed and the wind direction over the area of interest. The project is developed in the ArcGIS environment. In this case, the simulation is carried out for one local dominant emission source, the temporary coal storage place. The spatial domain under consideration is represented by the rectangular grids included into 21 layers over the surface. The whole dataset is stored in the geodatabase and managed by the ArcGIS. In addition to the numerical simulation focused on one dominant emission source (temporary coal storage place), data from other numerical simulations based on short and long distance effects can be included into the scalable GIS environment. The resolution of the spatial data used for wind flow modelling in the local scales is based on surface laser scanning and precise GPS measurements complemented by aerial images. The middle scale studies focused on more emission sources with short and long distance effects are supported by spatial data obtained from standard digital thematic maps extended by satellite images. The limits of numerical simulations depend on used computer programs.
Figure 5. The spatial domain for numerical simulation of wind flows in the local scale complemented by the display of the wind speed and the wind direction over the surface of the dominant emission source, the temporary coal storage place.

4. CONCLUSIONS

The presented spatial information system based on ESRI’s ArcGIS can manage and analyse a wide range of data in order to support risk assessment methods focused on dust transport in the area of the surface coal mine. The demonstrated task deals with an estimation of dust emission and dust transport from one of the dominant sources, the temporary coal storage site. Until recently, many studies have focused on estimates of dust rates from various surface emission sources or mining activities [Chakraborty, 2005; Ghose, 2000], on dispersion modelling over simplified surface objects (stockpiles and man-made barriers)
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[Badr, 2005], and on numerical simulations based on US EPA models (IS CST3, ISC-PRIME, AERMOD, AERMOD-PRIME, or CALPUFF) [Wang, 2005]. But, the absence of advanced spatial analysis tools and visualization methods has not allowed more complex explorations in the framework of risk assessment [Matejicek, 2007]. In the case of the presented spatial information system, dust emission, dust transport and potential dust deposition can be studied together with other spatial data sources (satellite images, aerial images, existing thematic map layers, post-processed GPS measurements, pre-processed time series of meteorological variables, advanced methods for creation of the DTM-surface laser scanning). Thus, the scenarios of various site configurations, including man-made barriers and stockpile geometries, can be tested in order to minimize dust transport over the neighbouring residential zones.

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REFERENCES


