GIS AS A TOOL FOR MONITORING AQUIFER POLLUTION

CASE STUDY – PLOIESTI CITY

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Introduction

Prahova district can be declared the cluster area for petroleum engineering in Romania, as important oil fields (Aricesti, Baicoi, Tintea, Campina,) and refinery facilities are located here. In the past, Ploiesti City had a number of twelve small to large size refineries (Encyclopedia of Romania, 1939) but as a result of the tumultuous history (WWII bombing campaign, earthquakes, economical constrains) (Albu et al., 2002, Chitea et al., 2014) only four of them remained active in the last decade. This intense industrial activity caused in time the severe pollution of the phreatic aquifer, mainly in the S and S-E part of the city. In order to analyze this environmental problem, a GIS database was constructed, merging information about soil and groundwater quality obtained in different stages of investigations. The sequence of aquifer pollution database for the south-eastern part of the Ploiesti City cumulates results of both direct (analysis of water samples) and indirect investigation methods (electrical resistivity), ranging from 1976-2007. The main purpose of data integration was to develop interactive maps in order to visualize the underground pollution direction of propagation, a very useful tool for pollution risk assessment of border localities and helpful in development of remediation strategies.

Aquifer pollution

Information about the aquifer pollution in the surroundings of Petrobrazii, Vega, Astra and Petrotel Refineries was the subject of a large study at the end of the ’80. Screened boreholes where used in order to measure the floating layer thickness formed by the light petroleum products (Manescu et al., 1994). Remediation actions consisting in recovery of free-phase hydrocarbons were executed at that time, but were not sufficient for preventing the further extension of the contaminated area. For all the locations, the affected areas enlarged in the direction of the groundwater flow, recent data showing evidences of the oil pollution reaching settlements as far as 8km from the source (Chitea et al., 2014).

Water samples analyzed within the frame of Phare RO 9910.02 project (2003-2006), coordinated by APM-PH, consisting in chemical analyses of main volatile compounds (benzene, toluene, ethylbenzene and xylene -BTEX) and total hydrocarbons (HC), evidenced the occurrence of hydrocarbons fresh spills. Volatile compounds (BTEX) were detected in samples gathered from boreholes located in Pucheni, Brazi, Tinosu, Rafov and Berceni. There is also a great variability in time and space for the total hydrocarbons values, as resulted from monitoring boreholes (Figure 1).
Construction of GIS project

ArcGIS program (ESRI) was used to build up a spatial related database. Input data consisted in raster images of the geological (36 Ploiesti L-35-XXVII) and hydrogeological (36 C Ploiesti L-35-113) maps of the region, drawings with borehole locations for old measurements of hydrocarbon thickness within the Petrobrazi refinery and its surroundings according to Manescu et al., 1994, and contaminated plume extension according to data from Albu et al. (2002), Chitea et al. (2014). Recent remote sensing images of Ploiesti City were used to facilitate the data translation into a unitary coordinate system (National Projection - Stereo 1970).

![Contour map with time evolution of the extent of contaminant plume based on floating layer of light petroleum products observed in boreholes (1978-1995) and total hydrocarbons mediated values as resulted from chemical analyses of water samples from Petrobrazi refinery nearby localities. Observation boreholes H51-H108 are placed according to Manescu et al. (1994)](image)

Figure 1

Plume extension contours from different documentation sources were digitized and results were compared. More reliable contours were redrawn, considering additional information (GEOMON –UB project database). Considering the presence of the fresh spills observed on site by the authors and the evidences of high levels of BTEX in the localities of Riţov, Tinosu and Puchenii it is clear that nowadays the border of aquifer pollution in the SE- part of the region is much enlarged.

Information concerning the variation of BTEX and total hydrocarbons obtained from water samples are available in digital form, with the lack of spatial references.
The project was completed with geophysical data acquired in the vicinity of Vega, Petrotel, Astra and Petrobrazi Refinery, consisting in apparent electrical resistivity data obtained on profiles of different lengths.

Figure 2 - Location of the refineries of Ploiesti City and examples of VES curves obtained on electrical profiles in the area of Vega, Astra and Petrobrazi refineries

Results and data interpretation

Using GIS software, the historical evolution of contaminated plumes, having as source the Vega, Petrobrazi, Petrotel and Astra refineries, has been constructed. The vectored format allows rapid interrogations of the database and new thematic maps, graphs of evolutions and calculations can be rapidly processed. Calculations of the length or surface areas affected by the hydrocarbon plumes can be made for different time intervals. For example, at the Astra refinery, the first measurements (1976 -1980) revealed an extent of the contaminated plume of 4 km (maximum length), while in 2009 chemical analyses confirmed the presence of high level of BTEX and HC at 10.5 km far from the demarcation contour of the refinery.
The surface extent or affected hydrogeological basin has been estimated at 16.2 km$^2$ for the Petrobrazi refinery in 1995 and a minimum of 50.2 km$^2$ for year 2009. In the lack of supplementary data, the effect of the contaminated groundwater upon the water quality of Petrotel and and Prahova rivers and the extent of underground contamination plume over this natural boundaries could not be constructed. However, the GIS platform has the possibility of storage and systematization of different types of information, and the database can be developed any time when new data are available.

Results from Vertical Electrical Soundings (VES) measurements made on parallel profiles (Figure 2) in the S-E part of Petrobrazi Refinery were imported into the program in order to generate 300m*800m maps of apparent resistivity variations at different depths (AB/2 ranging from 1-50m). Interpolation methods available in the 10.1 version of the ArcMap program allow the use of several options: kriging, spline, nearest neighbor and inverse distance weighting methods. All of them were tested but only the nearest neighbor method proved to be adequate for generating the apparent electrical resistivity maps, considering the data point’s distribution. As the profiles were deployed perpendicular on the pollutant plume, such results can be used for correlation with the sources of pollution located inside the refinery.

Conclusions

By adding to the present data base hydrogeological information (such as hydraulic conductivities, water table depths) and data from a line of monitoring boreholes judicious projected near the contamination sources, the GIS program could be used for generating a basic forecast of plume extension, as it allows construction of complex equations and has the possibility to generate scenarios based on the input data and algorithms.

When the GIS basic program cannot substitute the advanced data processing of specific hydrogeological or geophysical programs, images of 1D, 2D and 3D models of the geo-environment can be added for improved data visualization. The program function of “transparency” allows the superposition of maps obtained from complementary geophysical methods, being useful for data interpretation.

References


Chitea F., Ioane D., Serban A., [2014], Integrated methods for analyzing an area affected by oil and waste water pollution, 14thGeoConferences on Science and Technologies in Geology Exploration and Mining- Conference Proceedings Volume 1, pp. 497-504.

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