GIS-based Monitoring and Analysis of Environmental and Epidemiological Factors

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Abstract

Environmental pollution is one of the main reasons for health abnormalities and health problems. Pollution originated from industrial premises is one of the causes for high health risk in urban areas. In this case, environmental surveillance can have a valuable role in the protection of inhabitants. We present a GIS – based survey system that allows monitoring of environmental and epidemiological factors near industrial premises. The system was implemented in the framework of the "Environmental Health Surveillance System in urban areas near incinerators and industrial premises" project (Enhance Health), which is financed by the Interreg IIIC East EU program.

Keywords: Environment surveillance, environmental monitoring, GIS-based system, industrial premises, risk assessment analysis, public health factors

1. Introduction

Environment surveillance involves the monitoring of a variety of factors focused on environmental, epidemiological and meteorological aspects. A combinative analysis of the values of these heterogeneous data nearby an area of interest comprises a significant basis for applying risk assessment analysis, future environmental and urban changes forecasting and decision-making. Such information, when mapped, creates also a powerful tool for monitoring public health factors in correlation with the surrounding environment. GIS technology plays a crucial role in the generation of maps depicting attribute data associated with spatially referenced data.

In our work, the problem of managing over the same area urban dwellings, industrial premises and waste management plants (specifically incinerators) is examined. The main objective is the development of a data processing and result surveying tool that will produce scientific knowledge and will promote common sustainable territorial policies through a correct planning of both environmental and health aspects. Our tool comprises a web-based surveillance system which takes advantage of GIS technology to visualize the rates of several environmental and epidemiological factors on maps that depict the areas around industrial premises.

The system presented here constitutes the outcome of the "Environmental Health Surveillance System in urban areas near incinerators and industrial premises" project (Enhance Health - http://thaleia.westgate.gr/enhance) which was financed by the Interreg IIIC East Program (http://www.interreg3c.net). The project's main objective was the acquisition of knowledge and the achievement of scientific results regarding the determination of the short and long term health effects of monitored pollutants through environmental and health planning tools.

The presentation of our surveillance tool is organized as follows: In section 2, the related work is presented. In section 3, the system functionality overview is described. Next, in section 4, the methodology for the GIS-based monitoring, the combinative analysis of the heterogeneous data, and the risk assessment steps is further highlighted. In section 5, the experimental use of our surveillance system is discussed. Finally, in section 6, the conclusion includes future work directions.

2. Related Work

The fact that environmental pollution is one of the main causes for health abnormalities and health problems led the scientific community and many international and national organizations to study available environmental data and to develop tools for monitoring pollution. In this section we will present some of these applications, in our effort to outline related work on this field.

ECOSIM (ECOSIM project - http://www.ess.co.at/ECOSIM) is a project of the European Union that produced an environmental management information system that integrates monitoring and simulation modelling for environmental decision support in urban areas.

AirQUIS (AIRQUIS system - http://www.nilu.no/airquis/aq_gis.htm) is a GIS based air quality planning system. The system can be used for monitoring and to estimate environmental impacts from planned measures to reduce air pollution. The main objective of a modern environmental surveillance platform of this kind is to enable direct data and information transfer and obtain a remote quality control of the data collection. This system combines monitoring, data presentation and modelling in one package, which enable the user to present and evaluate the present situation and to undertake environmental planning for a sustainable future.

Apart from these complete GIS systems, there are also several web sites where air quality measurements are monitored. Such web pages exist for the city of London (http://www.londonair.org.uk/london/asp/home.asp), for Norway (www.luftkvalitet.info), for the Alsace area (http://www.atmo-alsace.net/cadre.asp?ss_rub=rub02) in France and for the area of Haifa (http://www.aironline.info/haifa/map_aqi2.cfm) in Israel. In all these sites the levels of measurements of several chemical elements found in the air (CO_2, SO_2, NO_2, O_3 etc) and very interesting and useful statistics are presented.

3. System Functionality Overview

The system we present in this paper is a web-based, GIS application for environmental health surveillance consisted by two parts: one for the administrator, which should be an environmental expert and another for simple users that can be scientists, local authorities etc. The design architecture of the system is shown in figure 1.

The main element of the system is the server. The server is responsible for the following tasks: interacting with the client, receiving input data from the administrator, processing these data and communicating with the database. All data are stored in the database: level measurements of environmental and epidemiologic factors and also spatial data of the under study regions. These data are provided as input by the administrator through a web interface that was designed specifically for this purpose. A web interface is also provided for the interaction with the users. Through this interface they are able to form and send their environmental queries, which the server analyzes and processes, and to receive back the results.

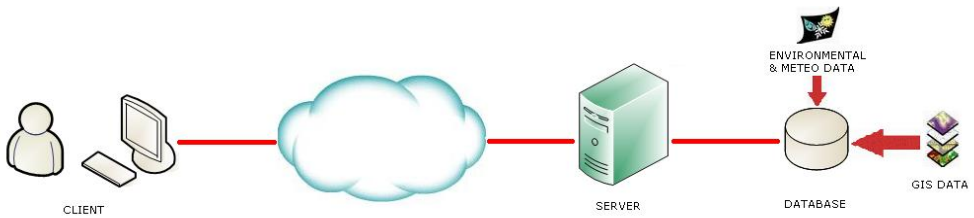

Figure 1. *System Architecture*

4. Methodology

4.1 GIS-based Monitoring

As already mentioned, our system is built on the basis of GIS technology in order to benefit from the advantages it carries out. Before describing the way that it is incorporated in our monitoring methodology, we sketch here summarily the assets of GIS-based monitoring systems over conventional ones (Johnson et al. 2001). First of all, GIS permits the integration of environmental information on landscape maps and the spatial correlation between risk factors and epidemiological aspects. Moreover, the powerful tools that it offers for visualization allow the generation of ranged color maps or proportional symbol maps that may be easily understood even from those that are not familiar with the technology. We should also note that different pieces of information may be overlaid in the same map and a radius around a point of interest may be specified for the monitoring of selected features by the use of GIS technology. For the areas of interest, GIS may calculate basic statistical results, such as the proportion of population that falls in a specific radius around a point and answer queries that require the extraction of information from the map. At last, it provides a noteworthy feature, the web-based GIS, which gives the possibility of publishing dynamic maps on the web in order to be accessed remotely by the end users.

Our system provides two modes of environmental monitoring; (a) surveillance of the specific factors levels in distinct radiuses and (b) surveillance of the mean values of specific factors in predefined geographic square parts. The second mode comprises the default presentation of the visualized results to the user query. According to the incinerator that interests the user, the neighbor area is divided to 20 squares of equivalent size, which are colored based on the mean value of the selected pollutant in the corresponding geographic area. Finally, every square on the map may have one of the possible five colors (dark green, green, yellow, orange, red) representing whether a pollutant constitutes a threat to the specific area habitants. In the case of buffer analysis, measurements of a specific pollutant are recorded for several distinct ranges around an incinerator. The map produced depicts colored ellipses which have the same centre, the incinerator, and provides visualized information about the criticalness of specific pollutants levels while getting off the incinerator.

4.2 Heterogeneous Data Combinative Analysis

Our system incorporates the surveillance of three different sets of data in order to provide in-depth scientific research and assessment of the relations between cause and effect of the pollutants considered: environmental, epidemiological and meteorological data. Although, any environmental factor may be inserted in the system in order to be monitored, some indicative substances of air pollution that are used in order to determine emissions of waste plants are: HCl, SO_2, HF, Dust, Nox, Pb+Cu+Mn+Cr, Ni+As, Cd, Hg, HCN, P_2O_5, C organ., Policyclic Aromatic carbohydrate, DIOKSIN and FURANs. The meteorological data used are: temperature, wind direction, wind speed, boundary layer height and cloud cover. The biological data which have been defined as identical of the effect of industrial premises existence to public health contain pregnancy outcomes, such as, the number and proportion of spontaneous abortion, stillbirth, preterm birth and small-for-age birth weight, the acute respiratory morbidity of children, upper respiratory diseases, lower respiratory infections and diseases involving some allergic reactions.

The simultaneous monitoring of the levels of heterogeneous factors for the same time interval offers an important boost to the effort of figuring out the impacts of industrial premises to the surrounding environment. Considering that for a long time period the measurements of pollutants values exceed the predefined acceptable levels, our tool offers an easy and quick way to visually present the values of selected epidemiological factors for the same time period around the same plant. These data are complemented with the mean values of meteorological factors for this time period. In this way, an expert user of the system may extract significant knowledge about the correlation of environmental and climate factors, as well as their effect to the public health.

Particularly, when the surveillance tool detects an outside value of a factor contained in the user query, there is the possibility to automatically perform the same query for the other category of factors. For example, if there is an alert for an environmental factor, the user can study the results of the same query, but for all epidemiological factors and vice versa. This option allows the scientists to conclude if there is a relation between alerts in environmental and epidemiological factors. In any case the meteorological data are also presented for the time interval under surveillance.

4.3 Risk Assessment

GIS-based surveillance and monitoring systems are playing a crucial role in risk assessment and decision making support. Visualization of available data allows the evaluation of possible current risks and the prediction of future risks. Our system focuses significantly on risk assessment with two features: alert indication and CUSUM analysis.

4.3.1 CUSUM method

The CUSUM method (Statheropoulos et al. 1998) is widely used in the research literature, in particular in the statistical control of the industrial processes. A good result has been obtained also in the application of this method to health events (Rossi et al. 1999), where the distribution of the data is similar in the two processes because of the rare expected events in one case (anomalous productive process) and also in the other case (health outcome). CUSUM methods cumulate deviations between observed and expected counts during a given period and generate an alert or signal when cumulated observed counts exceed expected counts by a predetermined threshold (Rogerson et al. 2004).

4.3.2 Alerts Indication

For each factor the maximum allowed level is stored. Values higher than the maximum allowed level consist a threat for public health and therefore an alert must be indicated. The system provides the users with the possibility to observe a history of all the alerts indicated. Moreover, when the user is sending a query to the system and is accessing the data visualization page, for each date period that is examined, if the level of a factor is higher than the maximum, an alert is indicated.

5. Case Study

The system, that has been developed, has been applied for specific territories of Italy, Poland, and Hungary, where waste incinerator plants are located nearby urban settlements. The results of the specific case study combined with the scientific evidences will guide the definition of a suitable strategy for risk communication to citizens as a participative and sustainable policy model. In order to analyze the values of several incinerator emissions for the specific areas of interest, we have entered in our system the GIS data of these territories, as well as measures of these emissions during several time intervals and meteorological data for the same time intervals through the system administration interface.

In order to demonstrate our system usability, we provide, in the following, examples from the implementation of the case study so far for the area of Coriano in Italy. We consider the case of monitoring through our system the levels of the environmental pollutants, Benzo[*g*,*h*,*i*]perylene and CO around the area of the CIS incinerator at a monthly range. Benzo[*g*,*h*,*i*]perylene, also known as 1,12-benzoperylene, is a polycyclic aromatic hydrocarbon (PAH) with six aromatic rings. We aim at studying the range of these pollutants values per month, as well as their possible impact to health indicators in conjunction with the meteorological conditions during the crucial time intervals.

In the following figure, the measurements of the CO pollutant are represented nearby the CIS pollutant for the January of the year 2004 and are followed by the results of the CUSSUM analysis. As depicted on the map, measurements have been taken in three different places around the incinerator. Moreover, there is no alert indication, neither through the simple alerts detection module, nor through the CUSSUM analysis.

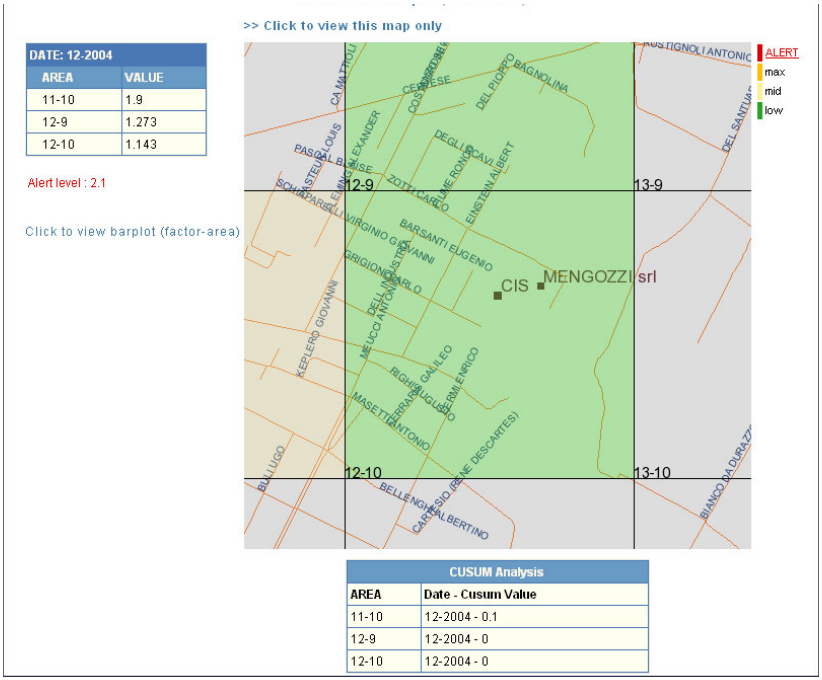

***Figure 2**. Geographic representation of CO measurement nearby CIS incinerator with theCUSSUM analysis results.*

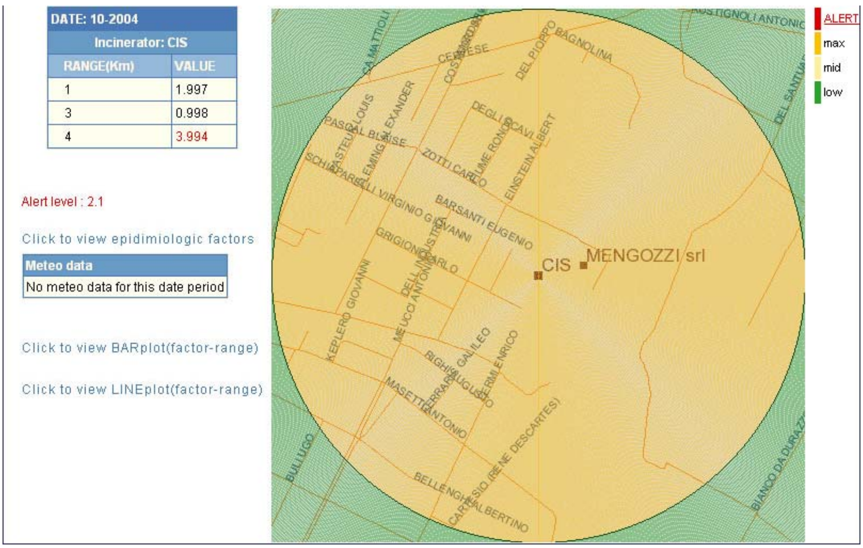

***Figure 3.** Colored ellipses around the CIS incinerator depicted the measurements of the CO pollutant in specific radiuses*

In the figure 3, the measurements of the CO pollutant are depicted in distinct radiuses for the October of the year 2004. This is the second option of our tool which enables an alternate mode of factors surveillance.

6. Conclusions

In this paper we are dealing with the problem of monitoring and analyzing pollution and epidemiological factors in urban areas industrial premises and waste management plants. Such settlements alleviate the environment and may have short or long term health effects.

We have presented a GIS – based monitoring system for surveying environmental and epidemiological factors, which can be used in decision making planning of both environmental and health aspects.

In the future, we would like to automatize the data analysis procedure and we intend to develop mechanisms for the automatic detection of the critical points that occur from the analysis. Based on the experimental use of the system under real conditions, further improvements are also to be discussed. A procedure for automatic detection of the correlation between dangerous level of environmental factors and epidemiological factors and the relation between meteorological conditions and pollution could be within this direction.

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