

Environmental Decision Making Using a Web GIS to Monitor Hazardous Industrial Emissions in the Community of Valencia, Spain

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Abstract

Air pollution is a critical issue in contemporary times. In Europe such environmental concerns have encouraged the European Environmental Agency (EEA) to create the *European Pollutant Release and Transfer Register* (E-PRTR). The E-PRTR is vital and valuable for society if these data are judiciously used to improve monitoring and advance environmental management. This paper describes a Web GIS developed for the monitoring of industrial emissions using EEA data. Four research objectives are addressed: (1) design and create a spatial database, (2) develop a Web GIS to manipulate the spatial database, facilitate air pollution monitoring and enhance risk assessment, (3) implement OGC standards to provide data interoperability, (4) create a model to simulate the distribution of air pollutants. The proposed approach towards interoperability is an adoption of service-based architecture for implementation of a three-tier Web GIS application. The system's prototype is developed using open source tools for the Community of Valencia, Spain.

Background and Relevance

Air pollution is a pressing world issue in contemporary times. Public officials as well as environmental managers are in need of suitable tools for visualization, manipulation and analysis of pollution related environmental data. Progress in information technologies and particularly Geographic Information Science and Systems has made GIS key for managers interacting with such data [1]. For example, environmental concerns in Europe have encouraged the European Environmental Agency to create the European Pollutant Release and Transfer Register (E-PRTR) database. E-PRTR is a large database containing valuable information concerning pollution from almost all industrial enterprises. Its creation, in part is based on the assumption that society will benefit if these data are used to improve monitoring and aid environmental management. However, one key challenge is: *How do we make (the right) environmental data accessible, open, and mobile while at the same time incorporating interoperable systems for sophisticated and variable data consumption?*

Based on these ideas, the main contribution of this project is to enhance public awareness of industry-based atmospheric emissions and their resulting air quality by delivering distributed geospatial access and visualization to appropriate environmental data; in brief *interoperability*. Renner [2], argues that data interoperability is a key element in the goal of information superiority. Aalders and Moellering [3] further emphasise the value of

information access all over the world through the Internet [3]. Interoperability in this research is achieved by using standard-based services which are components of the service-oriented architecture [4]. This will be facilitated by creating a distributed Web GIS with components on physically separate servers. In this research a *service-based architecture* approach is proposed that takes interoperability strongly into account. System functionality is demonstrated by implementing a prototype developed using open source tools and libraries, as described in the following sections.

Methods and Data

The proposed approach towards interoperability and service-based architecture involves the creation of a Web-based GIS application, or Web GIS [5]. This application will have a three-tier architecture consisting of (i) the presentation tier, (ii) the service tier and (iii) the database tier. This architecture is referred to as a *deployment style* when functionality is separated into layers where each segment can be located on a physically separate computer. We note that the proposed architecture complies with the *Infrastructure for Spatial Information in the European Community* (INSPIRE) directive to establish coordination of information between users and providers to make comparisons between various sectors [6].

The Google Web Toolkit (GWT), an open source development toolkit [7], together with the OpenLayers wrapper library for GWT are used to build this web application. *GeoServer*, a Java-based software server that allows users to view and edit geospatial data by using open standards, is used to create maps out of the data by implementing Open Geospatial Consortium (OGC) WMS (Web Map Service) and WFS (Web Feature Service) standards. GWT offers a Remote Procedure Call (RPC) mechanism to send requests *to* and receive responses back *from* the server over standard HTTP. GWT RPC calls to the server are asynchronous (i.e., they do not block while waiting for the call to return). For developing this prototype, PostgreSQL is chosen to store the spatial data. PostGIS is an extension of PostgreSQL that provides support for geographic objects. It is sufficiently fast and scales well, and has greater capability than the relatively slow MySQL and SpatiaLite, which contain a number of quirks and bugs [8].

Spatial analysis can be considered as the most essential domain of GIS because it involves transformations, manipulations and methods applied to geographic data to reveal patterns and anomalies that are not immediately obvious [9]. In this research, *Inverse Distance Weighting* (IDW), a spatial interpolation technique, is exploited to simulate distribution of pollutants in the atmosphere. IDW estimates unknown values as distance weighted averages over the known measurements at surrounding points, thus the closest points affect more than those located farther away [9].

Since the E-PRTR database is available in Microsoft Access format, a database that adds support for geographical objects is proposed for use in this design. By using OGC based standards and specifications and by incorporating GeoServer, the database can be shared over the Internet in a variety of output formats by implementing WMS and WFS standards. Next, a light client application which is a presentation tier consumes geospatial services, accesses, manipulates and visualizes the geospatial data. Unfortunately, there

were inconsistencies in the initial E-PRTR MS Access database. As a result, preparing the spatial database involved the following stages:

- I. export data sets of interest from MS Access into comma-delimited files,
- II. format and clean the spatial and temporal data,
- III. import data into PostgreSQL format,
- IV. add the spatial component – a point geometry column for every industry based on the geographic coordinates,
- V. publish geospatial data in the database and as a standard-based services.

To make the data available over the Internet, OGC WMS and WFS standards were implemented. The spatially referenced dataset is exposed as WMS and WFS which provides platform independent access. The open source software GeoServer provides geospatial services capability. It's supplied with geospatial data from the database and then by implementing WMS and WFS standards, it creates maps in a variety of formats. WMS and WFS both specify several required request types such as *getCapabilities()* that return parameters about the available layers. The WMS *getMap()* request returns a geo-registered map image that can be displayed in a compliant browser application [10]. Similarly, the WFS *getFeature()* request returns a GML *result-set* containing full geometry and feature attributes respectively [11]. Since OpenLayers is integrated into the GeoServer, the GWT OpenLayers wrapper library offers a set of classes to embed WMS and WFS in the application.

To generate a continuous surface from discrete data points, a regularly distributed grid of points is created that are located within the Community of Valencia. The emission values are then calculated based on the IDW method - we note that the algorithm that models emission distribution is implemented in Java code and resides on the server side. The input of the operation is the project data and information about all the industry emissions over a range of years. From this information, the generated output is a continuous surface, or grid of a specific pollutant distribution in space, where each grid cell represents a pollutant's concentration (inversely) weighted by its distance from the source. Conceptually, the further away from the source, the lower the concentration. Grid cells coordinates are then converted into the Mercator projection, where meters are used as a unit of measurement.

So to recap, after the user specifies a pollutant and reporting year, a value for each cell of the grid is calculated using IDW interpolation. On the client side, the resultant surface is visualized as a polygon-based choropleth map where each spatial unit (i.e., polygon feature) is filled with a value of pollutant concentration. Next, the *equal intervals classification method* is applied to associate a particular colour with a value. By looking at the classified choropleth map, the user is able to easily discern areas with high and low pollutant concentration. By including municipal locations on the map, this result can be used to discover municipalities that are heavily contaminated with specific concentrations and types of air pollution.

Results

The system prototype is developed for the Community of Valencia, Spain, where it provides (i) a searchable group of industries to be evaluated based on a number of criteria, and (ii) spatial analysis functionality based on the distribution of a certain pollutant in a particular year (Fig. 1). Additionally, these results in a spatial layer model that discerns the most vulnerable municipalities, by intersecting the municipality layer with simulated surface of predicted values.

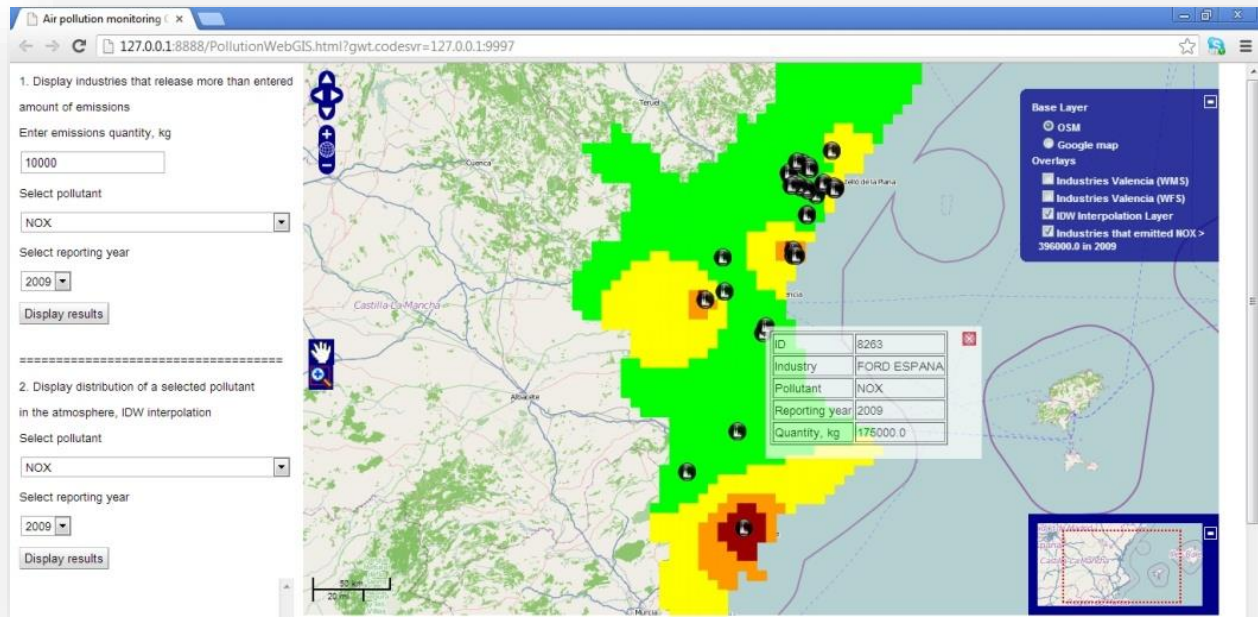


Fig. 1. A Web GIS snapshot showing spatial distribution and concentration of air pollutants. The brown colour represents very high pollution concentration, orange represents high concentration, yellow represents modest concentration and green represents low concentration.

Conclusions

This work describes the development of a Web GIS application which facilitates the monitoring of industrial emissions over the Community of Valencia, Spain. It is a dynamic and interactive application that can be freely accessed on the Web. Distinctive features of the application include the use of the Google Web Toolkit, together with OpenLayers, as well as PostGIS DBMS. It is solely built on open source tools and libraries promoting openness and extendibility.

This system provides various opportunities for organizations to consume environmental data and GIS functionalities over the Internet. It can also be used as a preliminary step for site suitability analysis of new industries. Additionally, the emission distribution surface layer helps discern susceptible and or vulnerable municipalities. Thus, physicians

can evaluate whether respiratory diseases are attributed to the presence of a particular industrial atmospheric pollutant.

This application also enables broad groups of users to easily access hazardous pollution information through the Internet. An additional important contribution of this project is to enhance public awareness about air pollutants and the likely sources of industrial contamination. Users can also access the application to discover the industrial facilities that are located in their residential area, as well as the amount and type of pollutants that are emitted into the atmosphere for a certain year. Furthermore, models can be generated for multiple years and saved as individual yearly snapshots of a specific pollutant, which could then be animated to show how concentrations and distributions change over time.

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