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Spatio-Temporal Analysis of the Effects of Air Pollution Hazards on Cardiovascular Health Outcomes in Bangalore, India

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Abstract: Recent research has established a link between exposure to certain pollutants and exacerbation or onset of cardiac diseases. Diseases have a spatial context and the evolution of computer applications, such as Geographical Information Systems (GIS), has favoured the studies of environment and their effects on health and populations. To aid in understanding the extent of air pollution and cardiac diseases in the city of Bangalore (India), this research explores the data requirements and GIS analysis tools that could be used to undertake a spatio-temporal analysis by developing a web-based GIS application. The ultimate goal is to identify hotspots of air pollution, explore the relationships between environmental pollution hazards and cardiovascular diseases, integrate the available data to enable sharing among decision makers and disseminate information.

1. Introduction

Epidemiological studies [1-4] have produced a positive and statistical significant association between high levels of common air pollutants such as SO_2, NO_X, O_3, CO and PM (Particulate Matter) and their deleterious effects on cardiovascular events. These long- and short-term epidemiological and toxicological studies, however, are limited to non-spatial analyses and concentrated in the developed nations. It is not viable to use these findings as inferences for developing nations due to the apparent differences in the sources of pollution, living conditions, lifestyles and quality of healthcare delivery.

Developed countries have devised community-based policies that have had a dramatic effect in curbing emissions and alleviating effects of disease. The UK for example, due to adequate research, prevention policies, interventions and advanced treatment, is rated as having the fastest falling rate of Cardiovascular Disease (CVD) throughout Europe [5]. Conversely, India seems to face a double burden as the country faces the brunt of poor air quality and has the highest CVD mortality rate in the world. According to the 2012 Environmental Performance Index (EPI), India ranks as the bottom country in the category of air effects on human health [6]. The Registrar General of India report states that the highest cause of mortality for all age groups, areas and genders is CVD, and it is estimated that approximately 60% of the world's total cardiac patients are Indians [7].

Furthermore, the country lacks research or investigations and the number of published reports on the prevalence of CVD is rather limited. To introduce cost-effective interventions, knowledge of the areas and populations at high-risk needs to be identified prior to making financial commitments, which otherwise might prove expensive or futile.

A GIS analysis will assist in explaining the disease patterns in terms of their relationship with environmental, socio-economic, demographic and other confounding factors, and highlight areas that need interventions [8]. Web-GIS is an efficient way of disseminating geospatial information over the Internet. It reproduces the main functions of a GIS on a web-interface such as: dynamic map creation, navigation (e.g., zoom and pan), map overlays, interactive querying and spatial analysis [9]. It acts as a medium for processing geo-related information providing access to wider groups of the population without restrictions on the location of access. This process of disseminating information over the World Wide Web will improve accessibility of information and aid in better decision making.

2. Framework

Data on health, environmental factors and any disease tracking system exists in isolated databases which may be referred to as data silos. To control and alleviate the effects of air pollution-induced cardiovascular disease, it is imperative that interdisciplinary teams collaboratively plan, intervene and respond to control the disease and its influencing factors. An integrated framework to manage, store, analyse, map and present the vast amount of existing data and transform it into useful knowledge will support in understanding the extent of the problem and develop solutions.

GIS has rapidly advanced from being a mere useful tool to becoming a framework for sharing information amongst organisations [10]. It should be noted that, as the data for a GIS is obtained from various organisations and shared across various stakeholders, it thus becomes essential that universal standards and common interoperability guidelines are specified to support data sharing. The use of the Spatial Data Infrastructure (SDI) [10] framework, as well as its interoperable standards and interface specifications provided by OGC (Open Geo-spatial Consortium), is widely used for developing Web-GIS applications.

3. Architecture and Functional Components of the GIS

The basic functionalities of a GIS can be classified into: Data capture and input processing; Data storage and management; Data manipulation; Data display and output [11]. To serve each of these functional components, the logical architecture based on a 3-tier client-server specification for the Web-GIS is described below. Conforming to the SDI framework and its defined OGC standards, the design of a GIS system based on this architecture will lead to an optimal system performance. Also, since the requirement for a user to access Web-GIS is only a browser, the need for high-costing GIS systems is no longer a concern.

As shown in Fig.1, the architecture consists of 3 tiers: The Client tier that presents the data to the user; the Middleware Tier consisting of the Web Application and GIS Servers; and the Server Tier including the database that stores the spatial and non-spatial data [12]. The roles of the various components of this architecture include:

Client (Presentation) Tier: Supports various web browsers for presentational purposes. It also includes desktop software for complex spatial data manipulation and visualisation tasks, as well as support for the increasingly popular mobile devices [12].

Middleware (Application) Tier:
Web server: Mapserver is an open-source web server that can render maps by generating objects from the database and its shape files [13]. A scripting language, such as PHP, provides the interaction between the user and the system and executes users' commands by manipulating the knowledge in the database. Open Database Connectivity (ODBC) protocol is available to connect to the database and Mapserver supports numerous OGC standards.

GIS Server: This is distinct from web map servers as it does not provide web mapping services, but rather provides GIS processing functionality such as visualization, spatial data analysis, mapping, and spatial data management services [12].

Server (Data) Tier: The geodatabase in the data tier efficiently stores, manages and retrieves data for relevant purposes [12]. PostgreSQL database is a RDBMS that stores data in various tables as feature classes and feature data sets, displaying it as separate layers [14]. PostgreSQL supports PostGIS extensions and features which define the geometric features that allow spatial querying. The basemap of Bangalore city (in .shp files) is stored in the database of the system; the map defines features such as ward information as polygons, major roads as lines and air quality monitoring stations as points.

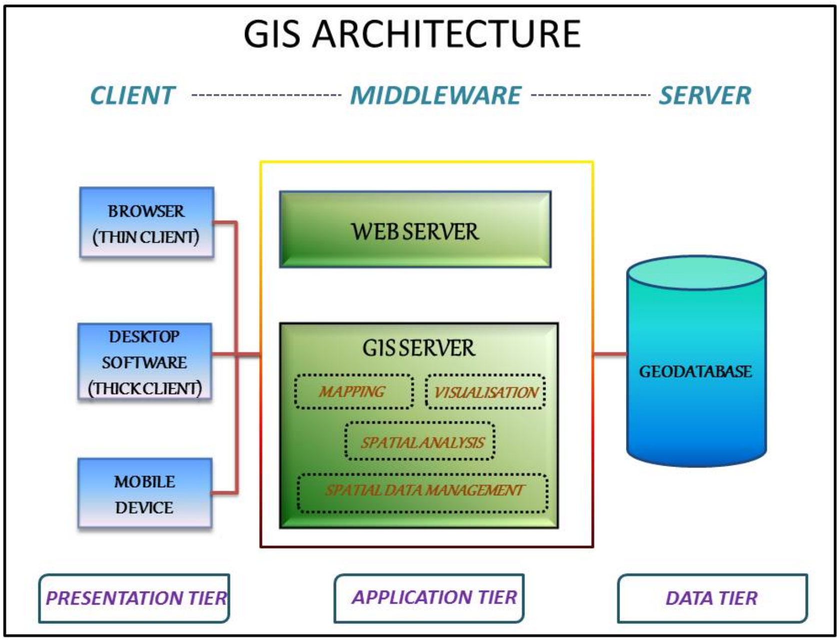

FIG. 1: GIS ARCHITECTURE BASED ON SDI FRAMEWORK (ADAPTED FROM [12])

4. Data and Study Area Description

Bangalore, the 'Silicon Valley of India', is the country's fastest growing economy and has been growing rapidly with an influx of people from other cities converging on it. It is now home to 8.47 million people (according to the 2011 census data), a population increase of 3.88 million since the previous 2001 census [15]. This has exerted a tremendous pressure on the infrastructure of the city which is now witnessing a significant increase in air pollutants and a deterioration of environmental quality and health [16].

A. CENSUS DATA

On a basemap of Bangalore the census data obtained from Bruhat Bangalore Mahanagara Palike (BBMP) according to wards is entered into the database of the GIS system and areas of high population can thus be easily identified [17].

B. AIR POLLUTION DATA IN BANGALORE

The data for air quality is obtained from the Karnataka State Pollution Control Board (KSPCB) which monitors pollution levels continuously at 6 locations in the city, classifying the locations as Industrial, Residential or Sensitive [18]. The data for the years 2005-2011 was obtained and analysed, which revealed that PM is of the utmost concern in the city. Levels were found to be either High or Critical in most areas and at certain locations in the city, $PM_{2.5}$ and PM_{10} levels exceeded as much as 6.6 times and 4.78 times the standard value, respectively. $PM_{2.5}$

and PM_{10} are concomitantly receiving focused attention as studies increasingly reveal the harmful effects of these pollutants on CVD [19].

C. CVD MORTALITY IN BANGALORE

The data was obtained from the Bangalore Directorate of Economics and Statistics (DES), for the years 2006-2010. The data was classified according to the International Classification of Diseases (ICD-10) standards set by the World Health Organisation. Data for every year was recorded according to gender and age. Of the total 148,143 Medically Certified Deaths analysed during the above period, an annual average of 33% was due to CVD alone. The leading cardiac-related causes of mortality were Ischemic Heart Disease (I20-I25), at almost 50%, followed by Hypertensive Diseases (I10-I15) and Cerebrovascular Diseases (I60-I69). CVD mortality also exhibited an increasing trend: in 2006, 32% CVD-related deaths were recorded, whereas in 2010 this increased to 40% of the total deaths.

5. Analysis

Spatial analysis includes a set of techniques that determine relationships between various spatial and non-spatial factors, in addition to methods to examine distances, clusters, hotspots or anomalies in the dataset. The decision-making GIS system includes concepts to transform and manipulate data in a way that may not be possible with other presentational techniques [20].

Simple queries as well as more complex geospatial analyses can be carried out on the data, and the results viewed either on the map in the form of graphs, charts or reports, or on the database table (Figs. 2, 3). Examples of geospatial analysis include (1) *buffer analysis* where the identification of areas surrounding a certain geographic location of interest can be undertaken; (2) *overlay analysis* where a layer depicting areas of high pollution can be overlaid with the occurrences of a CVD layer to identify the highly affected areas (Fig. 3); and (3) *geocoding* whereby any table that contains patients' addresses can be converted into points and displayed on the basemap [21]. In addition, a set of spatial, or descriptive, statistics (such as association, interpolation and regression) can be performed on the data [22].

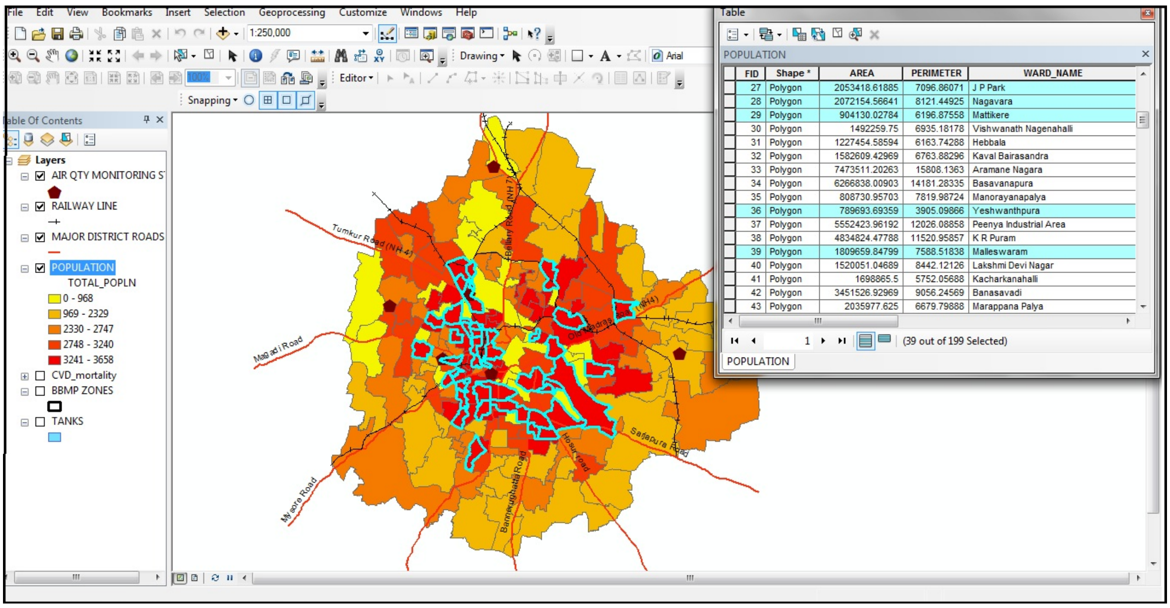

FIG. 2: AREAS OF HIGH POPULATION HIGHLIGHTED BOTH ON MAP AND ON QUERY TABLE

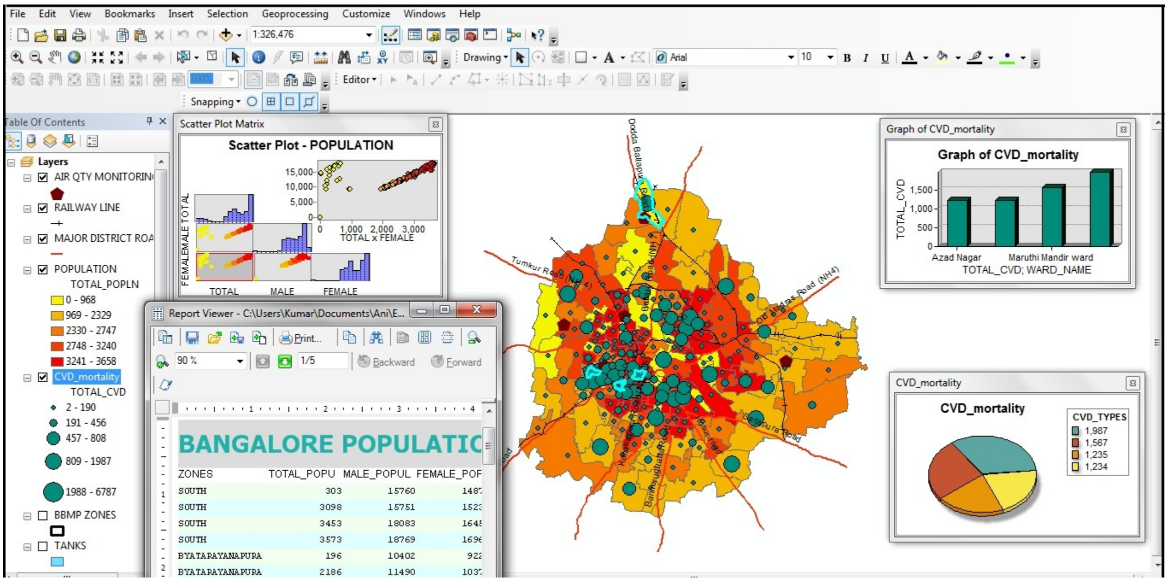

FIG. 3: HIGHLY POPULATED AREAS AND CVD MORTALITY (SIMULATED DATA)

6. Conclusions

This paper outlines the intended development of a GIS system that will aim to integrate environmental pollution data and CVD mortality rates and to test the technical feasibility of acquiring and storing them in a GIS database. The main purpose is to provide the ability to query the information, allow spatial analysis and visualisation and ultimately disseminate knowledge to environmental policy makers, healthcare specialists, epidemiologists and the main beneficiary – the public. A new model of health information system will assist in addressing the challenges faced in Bangalore, which is a fast developing economy, encouraging data sharing across the various stakeholder departments, assisting in decision making and introducing interventions to prevent air-pollution induced CVDs. In addition, as the GIS system is scalable, the design and implementation of this research development set the base to allow the analysis of other health outcomes caused by air pollution. Furthermore, the developed Web-GIS system may be extended to include other cities in Karnataka State and assess their situation.

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