

GIS Application in Urban Traffic Air Pollution Exposure Study: A Research Review

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Abstract: This paper reports a preliminary study of the evaluation and forecast of transport-related air pollution dispersion in urban areas with the help of Geographic Information System (GIS) platform and a simulative system with graphical interface. The urban population growth, economic development, energy consumption, growing transportation demand and living standards play major role in pollution exposure in atmosphere. A lot of research has already been done to investigate the functional relationship between air quality and air pollution from transport. This study is an effort to develop a more flexible framework of model to find the exposure of the air pollution in the atmosphere. This review article describes the development of framework of different GIS inputs that help to find the exposure of vehicular pollution in megacity.

Keywords: Dispersion, Pollution Exposure, GIS Application, Urban Air Quality, Vehicular Emission.

Introduction

In current scenario the air quality remains one of the major environmental issues in modern society (Tiwary & Colls, 2010). Quality of air affects the entire human race as well as plant and animal populations on the earth. The population growth, economic development, growing transportation demand as well as living standards contribute major role to polluting the surrounding area and atmosphere (Onursal & Gautam, 1997). Urban areas produce complex gases and particulates whose characteristics depend upon a wide range of factors such as: population density, energy consumption, industrial processes, and modes of transportation and usage, which affects public health, damages agriculture, weather, and climate (Pant & Roy, 2012). At present, urban outdoor air pollution causes an estimated 1.3 million deaths per year worldwide, according to the World Health Organization (WHO, 2012). The annual growth rate of the vehicle population in India is around 10% during the previous year (Nagpure *et al.*, 2013). The GIS helps to monitor the various temporal scales and thus can reduce the cost and time of field surveys, which would play a crucial role in conservation of environment. The objective of this paper was to find out the exposure of vehicular pollution to society with the application of GIS.

Emission of toxic pollutants from motor vehicles

Motor vehicles produce more air pollutants than any other single human activity. Motor vehicle emissions from highways might be viewed as a mobile line source with an emission rate per unit length of highway. In a regional scale model, the consolidated emission from an entire urban area might be viewed as an area source with an emissions rate per unit area. In city centers and congested streets, traffic is responsible for 80% to 90% of these pollutants and this situation is particularly severe in cities of developing countries (Whitelegg & Haq, 2003; Batterman *et al.*, 2014). Emissions from motor vehicles with spark ignition engines are from the exhaust, engine crankcase, and fuel system. Carbon dioxide (CO₂) and water vapor (H₂O), the main products of combustion, are emitted in vehicle exhaust (Onursal & Gautam, 1997). The major pollutants emitted from gasoline-fueled vehicles are carbon monoxide (CO), Hydrocarbons (HCs), Oxides of Nitrogen (NO_x) and lead (Pb). In most industrialized countries, people who live in urban areas tend to be more affected by allergic respiratory diseases than those who live in rural areas. Road traffic is the main contributor to air pollution in most urban areas and there is evidence that living in the vicinity of high

traffic roads is associated with impaired respiratory health. Transportation of freight and passengers, especially in Delhi, is primarily dependent on road traffic. As a consequence of the high traffic density in Delhi, the average speed within the city is relatively low (Gurjar *et al.*, 2008). Large quantities of CO₂, CO, HC, NO_x and particulate matter (PM) are emitted regularly from motor vehicles. The mobile air toxins such as benzene, formaldehyde, acetaldehyde, and lead, along with secondary aerosols can cause adverse human health impacts (Amato *et al.*, 2010).

Factors affecting vehicular emission

Real world vehicular emissions are highly variable. Several factors account for the variability in emissions in different vehicles and the amount of environmental damage they can cause. However, due to relatively higher average temperatures, poor fuel quality, poor vehicle maintenance culture, and a high proportion of old vehicles, the level of emissions from mobile sources are usually high. Figure 1 shows the various factors that are major cause for vehicular emissions in the transport sector.

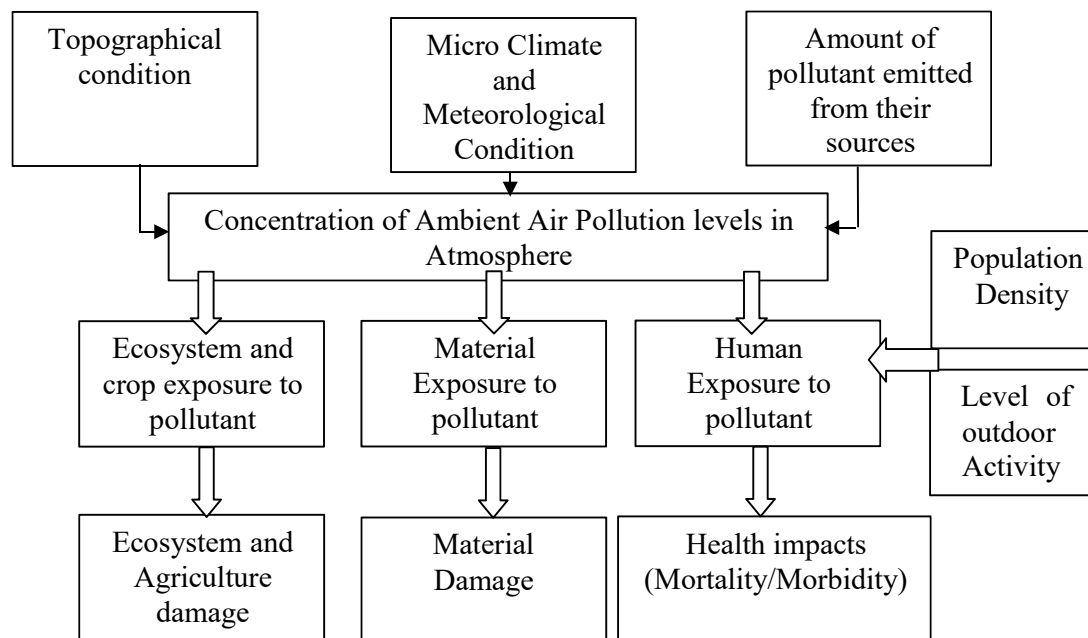


Figure 1. Factors influencing the environmental damage due to release of air pollutants.

Worldwide scenario of air pollution

Worldwide road transport vehicles like cars, trucks, and buses play a significant role in air pollution. In the European Union road vehicles are the largest sources of CO, NO_x and non-methane hydrocarbons. The recent trends indicate that road vehicles are responsible for 74% of NO_x and 94% of black smoke emissions in London (USEPA, 2010). According to the United States Environmental Protection Agency (USEPA, 2010), diesel vehicles account for 32% and 87% of total emissions for these two pollutants respectively. Likewise, due to rapid vehicle increases, vehicle emissions have now become a major environmental concern in China (Huo *et al.*, 2011). In Indonesia, 70% of air pollution is

due to transportation activity and 30% comes from industrial activity (Sutanto *et al.*, 2005). The WHO reported that the two thirds of death occur-red due to the outdoor air pollution in Asia. In 2010, particulate air pollution in Asia led to over 2.1 million premature deaths and 52 million years of healthy life lost. The outdoor air contributes to 1.2 million deaths in East Asia and 712,000 deaths in South Asia.

The World Health Organization (WHO) 2014 reported that the urban air quality database covers 1600 cities across 91 countries which are facing air pollution health risks. In April 2014, the WHO reported that outdoor air pollution was responsible for the deaths of 3.7 million people under the age of 60 in 2012. The numbers of automobiles increased at a rapid rate in mega-

cities during last decades in India. Delhi is regarded as one of the most polluted city in the world. Annual growth rates of motor vehicles are continuously increasing due to rapid motorization. The most disturbing factor is the rising

density of the vehicles in urban area. The rising density of vehicles is responsible for the emissions of different vehicular pollutants like CO, NO_x, SO_x, PM₁₀ and PM_{2.5}.

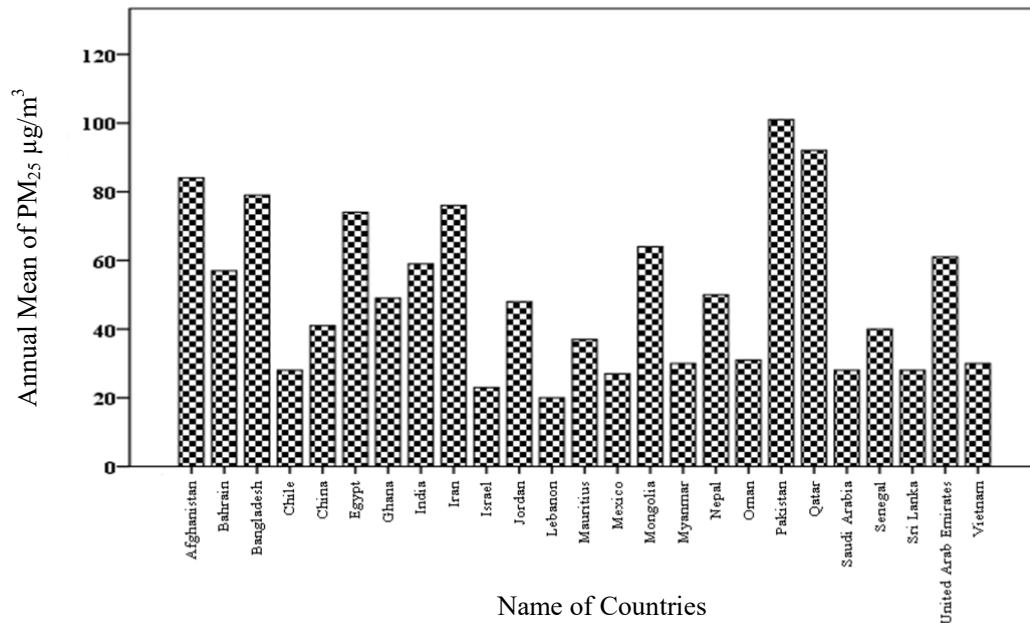


Figure 2. Annual mean of PM_{2.5} µg/m³ in various countries (Source: WHO Report, 2014).

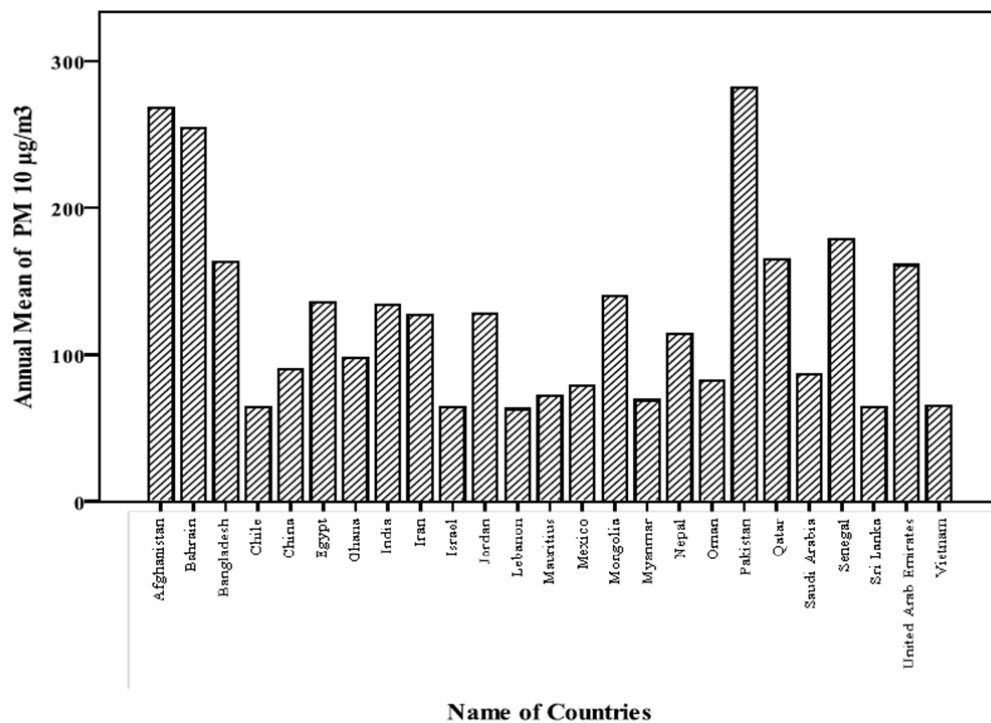


Figure 3. Annual mean of PM₁₀ µg/m³ in various countries (Source: WHO Report, 2014).

Figure 2 represents annual mean concentration of particulate matter of size $2.5\mu\text{m}$. Various countries that exceeded the National Ambient Air Quality Standards (NAAQS) were Pakistan, Qatar, Afghanistan, Bangladesh, Iran, Mongolia, United Arab, India, Bahrain and Nepal. The lowest concentrations were observed in Lebanon. The people are also suffering due to the risk of serious health problems in these countries.

PM_{10} have higher annual mean concentrations *i.e.* more than $100\mu\text{g}/\text{m}^3$. The human population is more exposed to PM_{10} in the respective countries. The figure 3 depicts the annual mean concentrations of PM_{10} in different countries. Some countries that exceeded the NAAQS are Pakistan > Afghanistan > Bahrain > Senegal > Qatar > Bangladesh > United Arab Emirates > Mongolia > Egypt > India > Jordan > Iran > Nepal. The lowest concentration of particulate pollutants was found in Lebanon.

Trends of air pollution in India

The outdoor air pollution has been listed as one of the top ten killers in the world, with 65

percent of the air pollution deaths occurring in Asia and close to quarter of this in India. The Central Pollution Control Board (CPCB) conducted a study in six major cities *i.e.* Delhi, Kanpur, Bangaluru, Pune, Chennai and Mumbai and found more than a 30% contribution of these cities in ambient air quality. The major cities like Delhi, Mumbai, Chennai, Kolkata, Bengaluru, Hyderabad and Ahmedabad, as well as secondary cities with populations of more than 2 million like Pune, Surat, Indore, Bhopal, Nagpur, Jaipur, Varanasi, Nagpur, Agra, Guwahati, Patna, Kanpur, Panaji, Trivandrum and Cochin are growing both geographically as well as in population, putting pressure on local infrastructure and life style. The increase in traffic along with inadequate infrastructure facilities is responsible for the emissions of air pollution and greenhouse gas emission (GHGs) emissions. Vehicular pollution is a major contributor towards the increase of air pollution in urban cities with respect to domestic and industrial sources, according to the Central Pollution Control Board (CPCB 2012). The following chart shows the contribution of different sectors towards the ambient air quality (Figure 4).

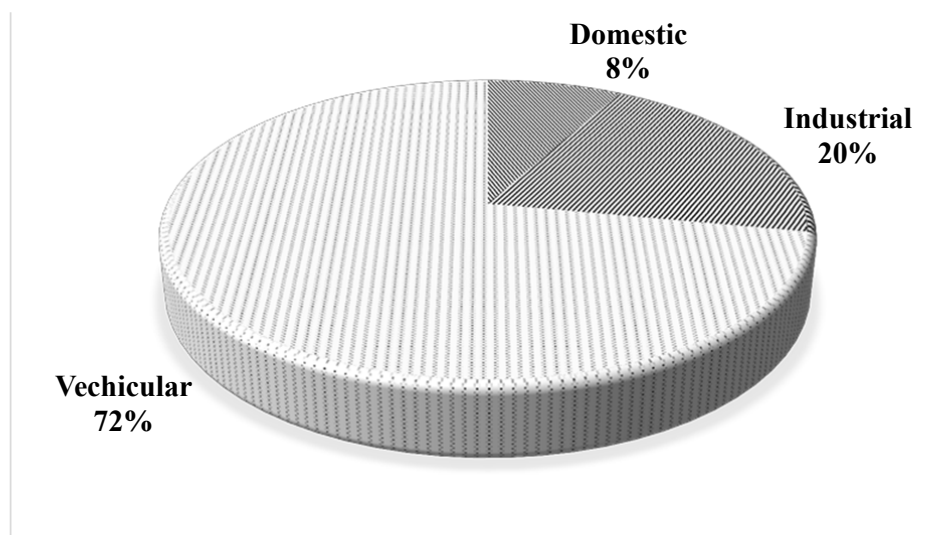


Figure 4. Contribution of various sectors to ambient air quality in urban city (Source: CPCB, 2012).

In addition to this, the annual mean of PM_{10} and $\text{PM}_{2.5}$ in different Indian cities are presented in figure 5 and 6. In figure 5, the highest concentration of $\text{PM}_{2.5}$ was found in Delhi; whereas, the highest concentration of PM_{10} was observed in

Gwalior (Figure 6). Warangal city was found in much better condition in comparison to other Indian cities due to far less concentrations of $\text{PM}_{2.5}$ and PM_{10} (Figure 5 and Figure 6).

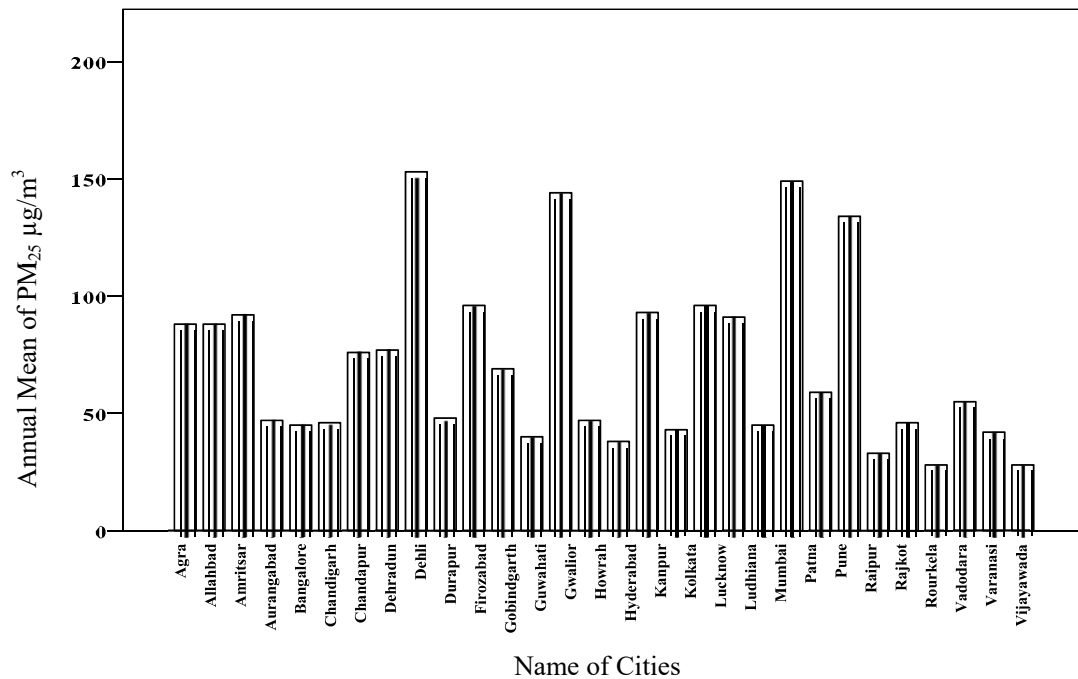


Figure 5. Annual mean of PM_{2.5} µg/m³ in various Indian cities.

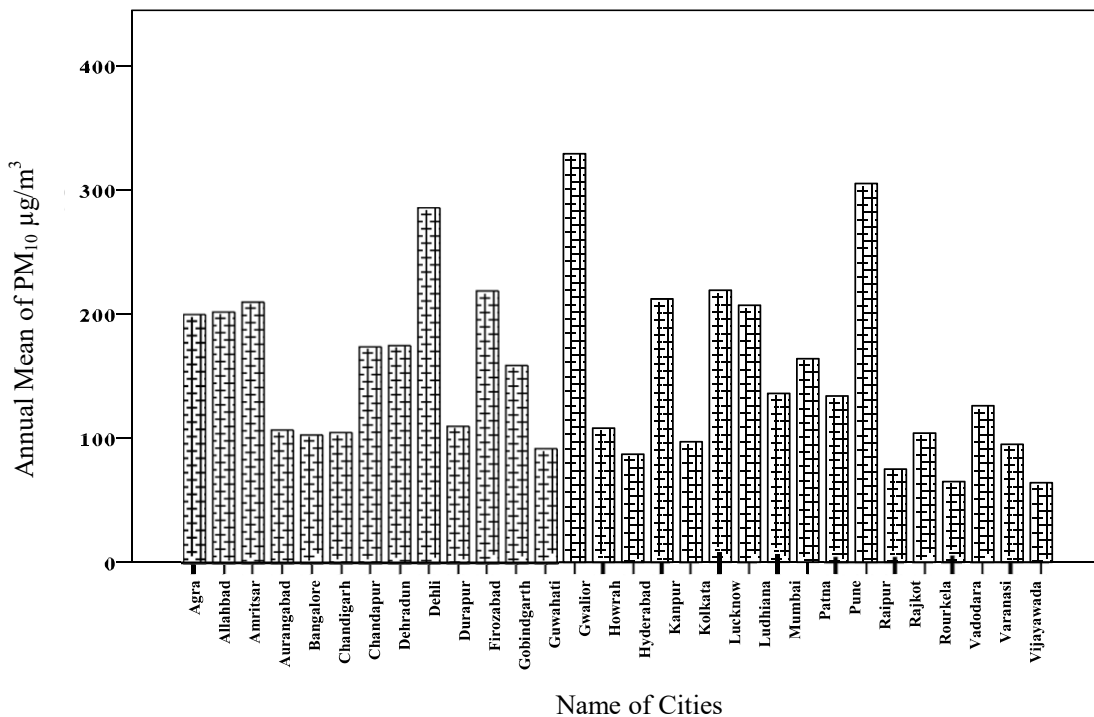


Figure 6. Annual mean of PM₁₀ µg/m³ in various Indian cities (Source: WHO Report, 2014).

The World Health Organization (WHO) estimates that air pollution contributes to the deaths of approximately 800,000 people annually

(WHO, 2012). Different studies of megacities on different spatial scales used various modeling tools to understand their local-to-regional-to-

global impacts and implications (Guttikunda *et al.*, 2001; Gurjar & Lelieveld, 2005). Outdoor air pollution causes approximately 1.3 million deaths every year worldwide (WHO, 2011). Around 40 million people within the 115 largest European cities are still exposed to air quality exceeding the European Union (EU) limit values for at least one pollutant (WHO, 2012). In megacities, people travel everyday using different types of vehicles. The daily increase in the number of people in megacities results in increased traffic volume. Every person uses vehicles according to their life style. The different types of vehicles in urban cities are buses, autos, light commercial vehicles, heavy commercial vehicles, Car/Jeep and 2-wheelers are playing a major role in the air pollution in mega cities. The buses travel more in a day, they emit more pollution and two-wheelers emit less pollution. According to a local survey, 30% of Delhi's population is suffering from respiratory disorders due to air pollution. The respiratory disorders increased 12 times as compared to all other states of India. Due to that, Delhi is characterized as the "asthma capital" of India (Guttikunda *et al.*, 2012; Das *et al.*, 2004). Increases in deaths due to air pollution have made air pollution the fifth leading cause of death in India, with 620,000 premature deaths. This is up from 100,000 in 2000, a six-fold increase (WHO, 2014). Below, figure 5 and figure 6 show the annual mean of particulate matter in various cities in India.

GIS application in air quality mapping:

A geographic information system (GIS) is a computer-based tool for mapping and analyzing geographic phenomenon that exist and occur on earth. Yan *et al.* (2009), Ryttonen *et al.* (2004) and Hammond *et al.* (2011) utilized GIS to study the community level pollutant concentrations and associated health risks. They explored Toxic Assessment, Air Quality System, and National Emission Inventory for identifying risks of exposure to air pollutants at the community level. GIS basically integrates baseline data and unique visualization of geographic analysis on the maps. It is very useful to acquire the pollutant spatial distribution, variations and characteristics information because of its flexible spatial data management and effective spatial data analysis methods. It is an innovative and important component of many projects for public health and epidemiology studies. GIS may also involve

more sophisticated spatial analysis of disease occurrence and contributing environmental factors. Scoggins *et al.* (2004) used model concentrations were converted from point base grid coverage to polygon grid coverage using GIS. Polygon grid coverage concentrations were then converted to census area unit concentration. It creates very informative graphical presentation and is easy to understand. Sahzabi *et al.* (2011) also conducted a study to predict CO₂ dispersion and optimization of the dispersion model. GIS is used for visualizing model results and better analyses of CO₂ concentration status at a particular geographical area. Morality rates were calculated using the number of people exposed to pollution at census area unit level. It plays a vital role in the planning of air quality management in megacities. In present scenario the GIS techniques are used for exposure air quality assessment (Nuckols *et al.*, 2004). It simulates traffic, emission, and dispersion patterns of the pollution. The GIS and modeling characteristics are presently used for air quality assessment. The various sub layers are represented different in figure 8, including topographical, land use data, transport network infrastructure, socioeconomic, demographic data, traffic data, different air pollutants, and environment impact parameters. The analysis of transport planning and transport systems management can also be done through GIS technology. The GIS maps show a combination of data layers as presented in Figure 8. The GIS database is systematic on the basis of geographical base line data, which consists of inputs of attributes in the GIS software. The road corridor network map of the study area is digitized with GIS software. These linked maps are integrated with a number of various topographic morphological attributes of the study area. In particular, the whole territorial database, which has been set up within GIS, is designed according to the details of inputs. The use of GIS as a database integrator for a transport study area and schematic diagram represents a set of individual databases for the study area, which comprise a mixture of spatial, numerical, and perhaps textual data. The GIS is a very dynamic technology capable of integrating large quantities of geographic spatial data. The GIS database is provided by road networks corridor data, traffic demand characteristics, driving cycles and fleet composition. GIS integrating models are aimed at reproducing traffic behavior, emission and dispersion scenarios (Elliott & Wartenberg, 1997).

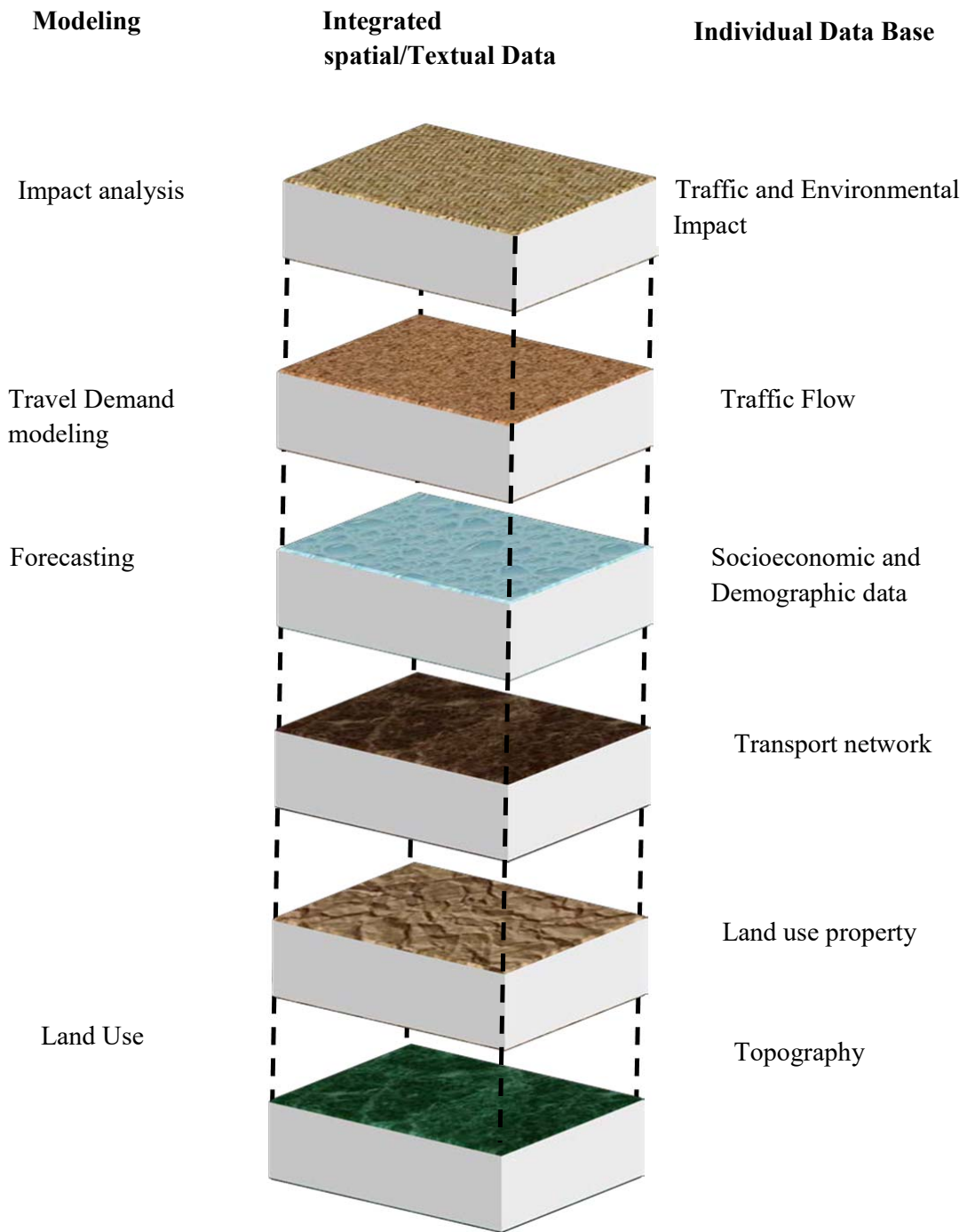


Figure 8. Layout of superposition of data layers in GIS.

Materials and Methods

The principle of Geographical Information System (GIS) is basically superimposed of all spatial data and attributes of the study area. Figure 9 shows the different sub spatial data of thematic map data, transportation network data and population data. Each road link contains attribute data, which is required by the air pollution simulation model. Figure 8 also shows a combination of various input parameters, which help to develop the various models. All these

models are integrated step by step with GIS and help the spatial mapping of the air pollution. The information is imported to the GIS software action to spatial datasets. The result shows the overlay to display, the intersection of sub systems as a geographical map. The base line data was collected from the different air pollution monitoring stations. The other data like meteorological parameters, different types of pollutants and their concentrations are necessary for the GIS integration for air pollution assessment.

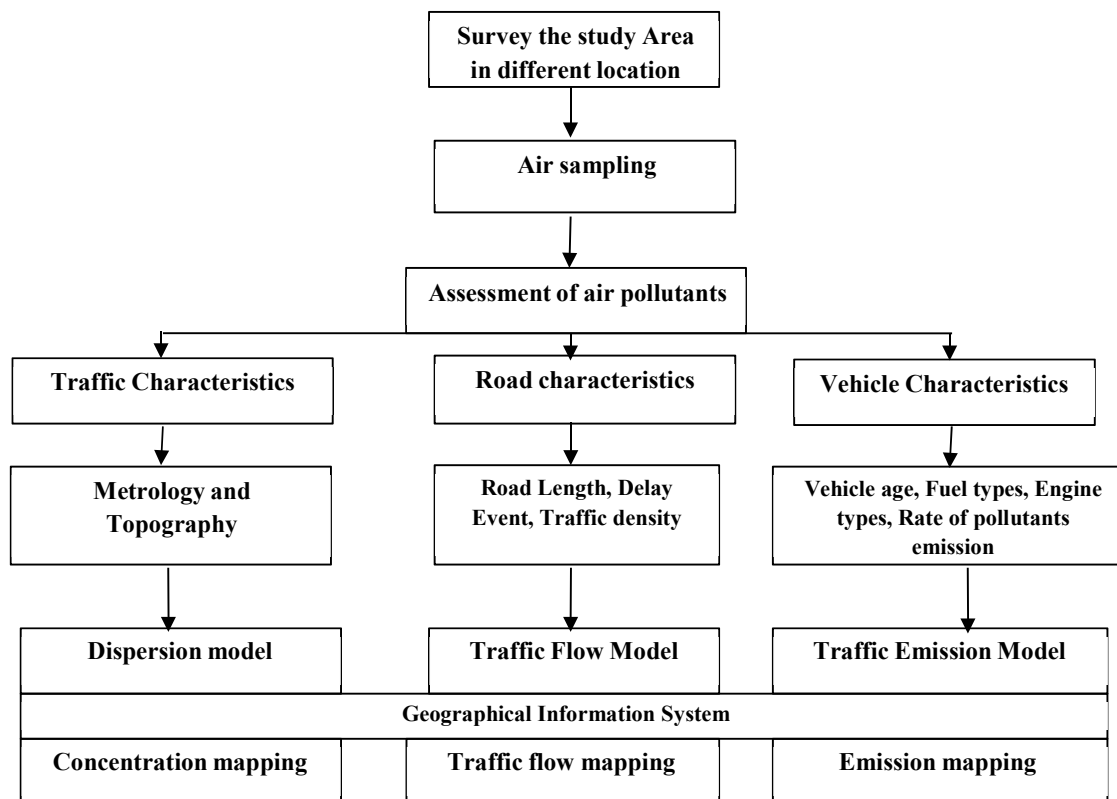


Figure 9. Air pollution exposure modeling with integration of GIS.

The base line monitoring data from pollution monitoring station include pollution concentration of various pollutants. Pollutant concentration is measured in grid zone of the study area like 2KM X 2 KM grid plot. It could be monitored more accurately and ideally using grid-based methods such as Discovery Net Project (Richards *et al.*, 2006). Spatial interpolation could be implemented in many types GIS software, such as Geomatica10, ArcGIS10.2. Exploratory Spatial Data Analysis (ESPA) is carried out

according to the characteristics of the data before interpolating in order to choose the suitable interpolation methods.

Figure 10 show the mapping of the PM_{2.5} and PM₁₀ in the Delhi NCR. The distribution of vehicle exhaust and the brick kilns. The dark brown color shows the maximum concentration of the particulate matter. In the study, South and Central Delhi was found to be most affected zone due to particulate matter pollution.

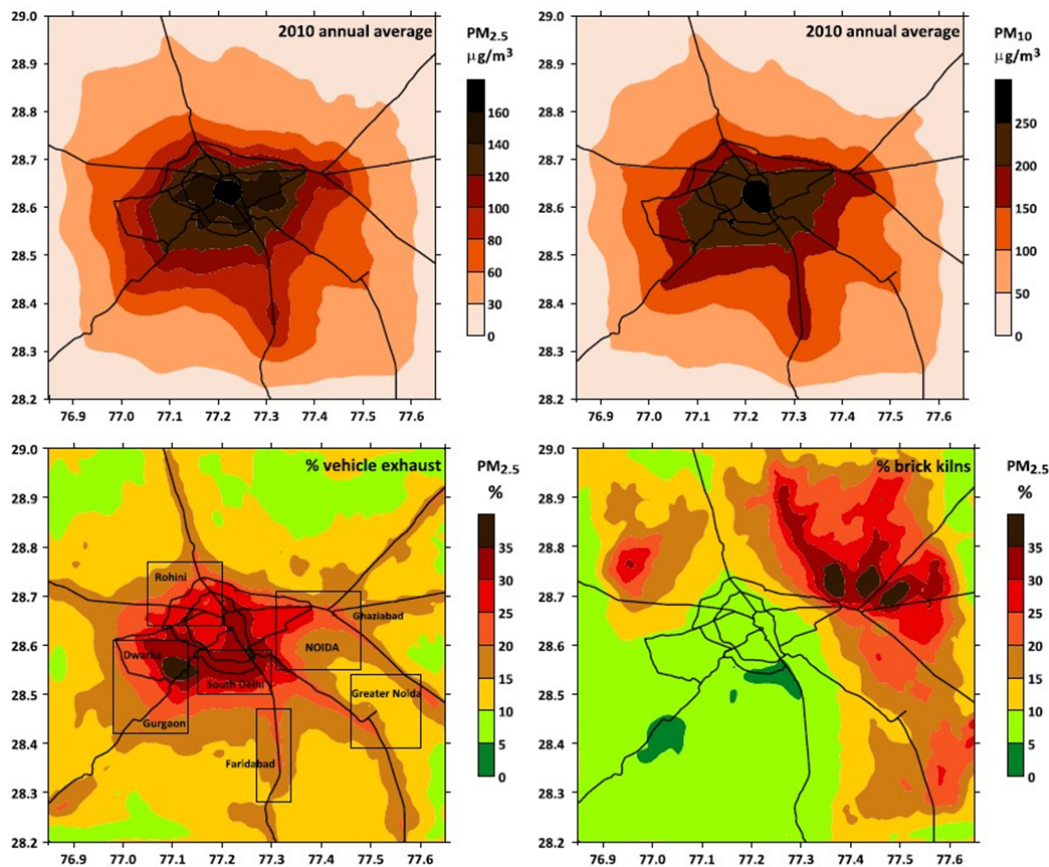


Figure 10. Annual average percentage of $PM_{2.5}$ and PM_{10} from the vehicle exhaust and brick kilns emission for year 2010 in Delhi, India (Source: Guttikunda *et al.*, 2013).

Figure 10 show the mapping of the $PM_{2.5}$ and PM_{10} in the Delhi NCR. The distribution of vehicle exhaust and the brick kilns. The dark brown color showed the maximum concentration of the particulate matter. In the study, south and central Delhi is found most affected zone due to particulate matter pollution.

Emission and dispersion models

Air quality models are used as mathematical, numerical techniques to simulate the physical, chemical processes that affect air pollutants in the environment. The different inputs like meteorological parameters, source information and emission rates of pollutants are used to characterize the primary pollutants emitted directly into the ambient air. All these models are important for the assessment and management of air quality of environment. It is very useful to identify source contributions to air quality problems and to assist in the design of effective strategies to

reduce harmful air pollutants. The air quality models can also be used to predict future pollutant concentrations from multiple sources (US-EPA 2012).

The various emissions of pollutants and dispersion models simulate the pollutants. This traffic related pollutants are major source of air pollution in the urban traffic corridor. The emission estimation of various pollutants is found out with the help of emission model. The emissions of the entire vehicle fleet are calculated on the basis of emission coefficients, traffic volume, and road segments (Equation 1).

$$E_i = L \times C_i \quad (1)$$

Where E denotes the emissions of pollutant i, L denotes the vehicle kilometers traveled, and C denotes the emission coefficient of pollutant i. Dispersion models simulate the dispersion of pollutants after its emission. Line source Gaussian plume dispersion model is originally used to

predict the impacts of carbon monoxide near different transport corridor. The Gaussian solution for linear sources which is based on is based the principle of overlaying various component,

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) \right] \quad (2)$$

Source of emission at ground level,

$$C(x, 0, 0) = \frac{Q}{2\pi u \sigma_y \sigma_z} \quad (3)$$

Where

$C(x, y, z)$ is the concentration unit (gram/meter³)

at some point in space with coordinates x, y, z

Q = the emission rate of the pollution source (in gram/second)

u = the average wind speed in (meter/second)

σ_y = the standard deviation of the plume in the y direction (meter)

σ_z = the standard deviation of the plume in the z direction (meter)

Emission and dispersion models can be carried out using integration of GIS and environmental models. Emission models are used for the various transport corridor which gives traffic volume, gridding zone of the study area with suitable cell-size raster, finding the cells that intersect with road segments. The output raster shows the emission rate from the source area. The 2 KM X 2 KM divided as gridding in the study area with suitable cell raster that calculating each cells value second equation using second equation. The obtained raster indicates the spatial distribution of pollution concentration.

Land use regression

Land use regression (LUR) combines monitoring of air pollution at a small number of locations and development of stochastic models using predictor variables usually obtained through GIS software. The regression model is then applied to a large number of locations in the study area. The input data include traffic characteristics of different land use area, physical geography. (David *et al.*, 1997; Gerard *et al.*, 2008). The climate variables such as wind speed direction and wind speed has significant effect on pollution dispersion distance. The climate variables are neglected when using LUR; it will

which assume the concentrations of emitted substances at the receiving equal to the sum of dispersions of all infinite points sources which is together in line source.

bring an error to value of the predictor variables that are computed from the circular zones around each monitoring site. Gulliver *et al.* (2011, 2005) evaluated GIS-based dispersion model Space Time Exposure Modeling System-Air pollution (STEM-Air) to simulate traffic related air pollution. Behera *et al.* (2011); Mion *et al.* (2002) developed an emission inventory for all sources responsible for PM₁₀ pollution in Kanpur, India, with the then used ISCST3 dispersion model to simulate PM₁₀ concentrations to identify pollution hotspots in the city and to evaluate the contribution of each source in PM₁₀ pollution level. Elbir *et al.* (2004) developed a decision support system for air quality management in big Turkish cities. The developed GIS system was based on the CALPUFF dispersion model and related databases to calculate emissions from various sources. Pollutant concentrations were predicted using the CALPUFF dispersion model and results were compared with observed air quality data from actual monitoring stations. After model calibration, GIS was used for air quality mapping and scenario analysis.

As shown in figure 9, the GIS is integrated with different sub models, which aimed for stimulating each sub models that process involved in the entire air pollution phenomenon. These are traffic emission estimations, dispersion models all linked together. The survey input of all geographical information which is important for the study area. Road traffic is simulated through a deterministic model designed for solving the equilibrium auto assignment problem with capacity constraints. The emission model has been developed on the basis of input data and it is able to calculate emission levels of some typical traffic-related pollutants such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x). Emission factors refer to

vehicle grouping based on the knowledge of vehicle model year, fuel type, gross weight, and power characteristics. All these input parameters are very useful for the assessments of air quality as well as for the developed model.

Exposure analysis application

Exposure assessment describes the damages to the human health, plant ecosystems and sensitive areas like hospitals, schools, residential area. Vehicular pollution exposure modeling on human is very spatially complex and temporally dynamic process. The simulation is necessary for simplification and plays a key role in implement exposure modeling (Borrego *et al.*, 2006; Gulliver *et al.*, 2005). GIS provides an effective way to implement exposure modeling. Exposures are estimated for each location, at each time interval, by cross-reference to the pollution concentration raster for that time period as shown in equation 4.

$$E_{ijk} = C_{ij} \times W_k \quad (4)$$

Where E denotes the exposure of an individual during time i, at location j, in exposure environment k. C denotes pollutant concentration during time i at location j and W denotes the weighting factor for exposure environment k, relative to ambient. Modeling exposure uses raster-based calculation. Mapping exposure is carried out using map algebra operation. Exposure profiles are carried out extracting grid values on exposure map along the moving path using combination of several tools in Geomatica10.

Results and Discussion

This paper helps to examine the assessment of vehicular emissions with the help of advanced modern technology based study like GIS. Spatial distribution of urban air pollution concentration is very useful from a technology based assessment. The spatial patterns of pollution resulting from policy or other interventions and provide improved estimates of exposure for epidemiological studies. Delhi has recorded the highest increase per capita road length decrease and more importantly the number of vehicles per km of road has tremendously increased. This indicates the number of vehicles registering has increased fivefold in Delhi. The rapid growth of personalized transport in Indian cities gives rise to serious issue due to increment of air pollutant

problems. In the current scenario, Delhi is facing the highest vehicular emission load. In recent times, Delhi NCR is rapidly modernizing and commercializing. Figure 2 shows the air pollution mostly due to vehicular emissions which contributes 72% and the industrial sector contributes 20% in the megacities of India. This shows that the road transportation has a major role in air pollution. The considerable magnitude of air pollution increases the number of people suffering from respiratory and cardiovascular diseases. That is the major issue which results in premature deaths in India. There is a need to control population growth and vehicular air pollution in the megacities. Special efforts should be made for educating the general mass and local leaders about the adverse effects of a large population and vehicular pollution through specially designed information, education and communication activities. Upgrading the quality of Indian fuel, enforcing higher emission standards and regulating traffic can reduce the pollution caused by the explosion in the number of automobiles in megacities. Those who use personal vehicles should be encouraged to use the public transport system. State transport service should set up better vehicular standards, and more research and development should be encouraged in vehicle technology. Air pollution should not be a responsibility of government alone but mass and local leaders should be encouraged to make dedicated efforts to eradicate the air pollution problems. The policy aimed at overall development should certainly include efforts to control population, private vehicles, and air pollution for better health of the present and future generations.

Conclusions

In present scenario the developing as well as developed megacities are polluting the ambient air and disturbing the natural environment system. It also increases public health issues. It is necessary to learn comprehensive processes and ways to study urban pollution. This paper represents the air quality modeling and evaluating the impact of vehicular pollution with advanced technology. In this study, the integrated modeling approach involving GIS has been used for pollution mapping of vehicular pollutants in megacities. It monitors various temporal scales, which will reduce the cost and time of field surveys. It is most suitable for the local administration in order to forecast alert pollutant levels in air quality area. It also gives the integrated

existing monitoring network measurements and estimates the sensitivity of pollution levels to such variables as traffic flow distribution and atmospheric conditions. The interpretation of satellite data is more complex as compared to in-situ observations. Satellite data sets should be of good quality, easily accessible and reliable for the assessment of air pollution. It is very useful in the model-based approach and the predictions for the epidemiology remain to be seen. The desired future development of GIS requires a switch of emphasis from data and information to knowledge of the atmospheric conditions. The results help in the developments of methods for the study of ambient air pollution and air pollution assessment. GIS has been proved a powerful tool to implement the methods involved in the framework and makes the methods more efficient and flexible. Urban air pollution research will be further developed with increasing concerns of urban planners, developers, health officials and citizens living in the city. The GIS framework is an extension of new methods for the environmental conservation of future.

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