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# Spatial Interpolation of Air Pollutants in Bangalore: 2010-2013

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*Abstract: Air pollutants and their ill effects on the environment and health of populations are well known. However for informed decisions on the protection of the health of populations from elevated levels of air pollution, an understanding of spatial-temporal variance of air pollutant patterns is necessary. Bangalore and other similar developing cities do not have an adequate number of fixed monitoring stations that could provide a complete coverage of the air pollution levels for the entire city. This can be overcome by using geospatial interpolation techniques that provide a complete coverage of the levels of pollutants. The aim of this study is to locate sample points, characterise distribution patterns, map air pollutant distributions using interpolation techniques, highlight areas exceeding standard levels and in doing so determine spatial and temporal patterns of the levels of air pollutants. An air pollution map indicating levels of the variability of the pollutants will aid in the analysis of effects on health in populations due to elevated levels of pollutants.*

## INTRODUCTION

Air Pollution is a growing problem in the world today and the WHO ranks air pollution as the 13<sup>th</sup> leading cause of worldwide mortality [1]. It is believed that pollution due to air quality is more harmful as opposed to pollution caused by either water or land. Air pollution may have mild effects on health such as itchy eyes, sore throat, severe effects such as breathing problems, lung cancer, etc., and inhaling severely polluted air can also result in death.

Currently developing countries face the major brunt of air pollution problems in the world. Asia reportedly is the worst affected with a large number of Asian cities having critical levels of pollution. Asia also houses the world's worst polluted cities and it is estimated that 65% of deaths occurring in all of Asia are due to air pollution [2].

India is a fast growing economy but is burdened by increasing levels of air pollution that pose a serious threat to the environment and the wellbeing of its citizens. In a study conducted in [3], the authors estimated that exposure to ambient air pollution resulted in 627,000 premature deaths and nearly 17.8 million DALYs in India.

Air quality monitoring (AQM) is essential to assess levels of air quality and impact on health. Its goal is to protect human health, the environment and the overall welfare of animal and plant life [4]. A map of air pollution levels for an entire region can assist in the management of air quality and its subsequent effects.

In most developing cities AQM stations are not available to cover the entire area or region, mainly due to the costs involved in setting up of AQMs. But to understand the effects of air quality on health, it is vital to quantify the levels at all locations. The limitations of insufficient monitoring can be overcome by the use of spatial interpolation techniques. Spatial interpolation is a procedure to predict the air concentrations of unmonitored regions based on values at measured locations within the proximity of the monitored areas [5]. Tools such as Geographic Information Systems (GIS) have gained popularity in air quality mapping and analysis. ArcGIS Geospatial Analyst facilitates the creation of a statistically valid prediction surface.

The aim of this paper is to conduct a study in Bangalore, locate monitoring stations in the city, estimate the coverage of these stations by using buffers, use spatial interpolation to determine distribution patterns, obtain statistically predicted values at unmonitored locations and determine hotspots.

## METHODS

### *Study Area*

Bangalore is located at 12.97°N, 77.57°E covering an area of 741km<sup>2</sup> or 286 square miles. Bangalore is the third largest city in India and one of the fastest growing cities in the country, with a population of approximately 8.4 million. It is the nation's leading information technology exporter and is popularly known as the 'Silicon Valley of India' [6]. Bangalore is at an average elevation of 900m (2953 feet) and, as such, the city usually enjoys a more moderate climate throughout the year compared to other cities in India. The temperatures range from an average of 15°C in winter months to a high of 36°C in the summer months.

Air pollution is a growing problem in the city. According to a report by TERI [7], air pollution is said to be high, severe or critical in most areas of the city. The main sources of pollution in the city are the exponential growth in the number of vehicles contributing to almost 50% of the pollution, construction activities, paved and unpaved road dust, domestic pollution and the increased use of diesel generator sets.

Air quality in the city of Bangalore is monitored through the National Ambient Air Quality Monitoring Programme and recorded by the Karnataka State Pollution Control Board (KSPCB) [8] at 6 fixed locations:

- Graphite India Limited, Whitefield Road
- KHB Industrial Area, Yelahanka
- Peenya Industrial area, Regional Office Peenya
- Victoria Hospital, Chamrajpet
- Amco batteries, Mysore Road
- Yeshwanthpur Police Station

In addition, there are many mobile locations distributed across the city [8].

Air pollutants in the city were measured over the study period by the KSPCB in the above locations using Respirable Dust Samplers (RDS) by conventional methods. The sites are representative of the various characteristics of the city, i.e., Industrial, Commercial, Residential and Sensitive areas. Four air pollutants, namely SO<sub>2</sub>, NO<sub>x</sub>, Suspended Particulate Matter (SPM) and

Respirable Suspended Particulate Matter (RSPM/PM<sub>10</sub>), are regularly monitored at all locations.

The monitoring of pollutants is carried out for 24 hours (4-hourly sampling for gaseous pollutants and 8-hourly sampling for PM) with a frequency of twice a week. The KSPCB laboratories are fully equipped with experienced analysts, sophisticated equipment and approved standard test methods to carry out comprehensive analyses of the ambient air [8]. In India, the Central Pollution Control Board (CPCB) coordinates the air quality monitoring network and is responsible for pollution control [9]. CPCB sets the standard that is followed by the State Pollution Control Boards. The locations of the six monitoring stations are shown on the map in Fig. 1.

Most studies obtain recorded pollution levels from the monitoring stations and average it for the whole city. But the nature of particulate matter is such that it is spatially variable, based on various factors such as size of particle, wind, location of structures and other meteorological conditions. One study suggests that the effects of particulate matter should be examined in a ½ mile radius buffer [10]. Averaging the particulate matter values over the whole city based on just 6 monitors will not provide a representative picture of the local pollution conditions.

### ***Buffering***

Buffering can be described as the creation of a zone of a specified width around a point, a line or a polygon. It is also commonly referred to as the 'zone of specified distance' around a coverage feature. These zones or buffers are often used in queries to determine which entities occur either within or outside the defined buffer zone [11]. Buffering point data is the simplest form of buffering that involves the creation of a circular polygon around each point of radius equal to the buffer distance. Applying the ½ mile (800m) radius buffer, the coverage of the monitoring stations for Bangalore was generated (Fig. 2). It is evident from the map that the stations do not provide coverage of the entire city. To obtain the values at unrecorded locations in the city, geostatistical interpolation methods are employed and a continuous surface for the entire city is derived.

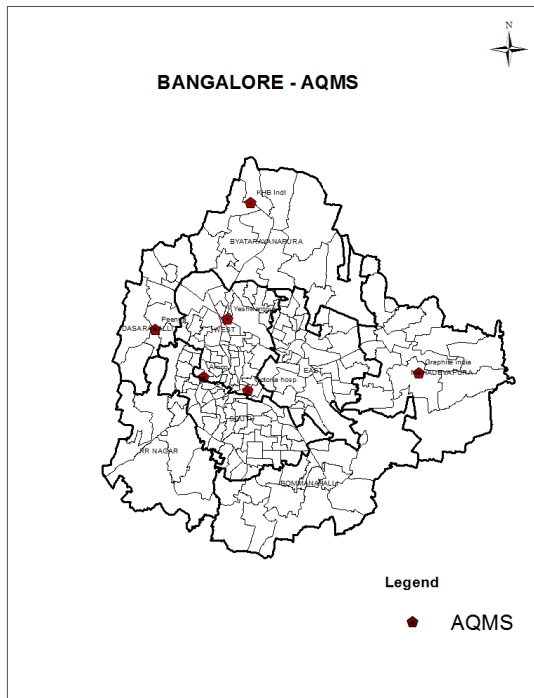


Fig. 1: AQMs in Bangalore

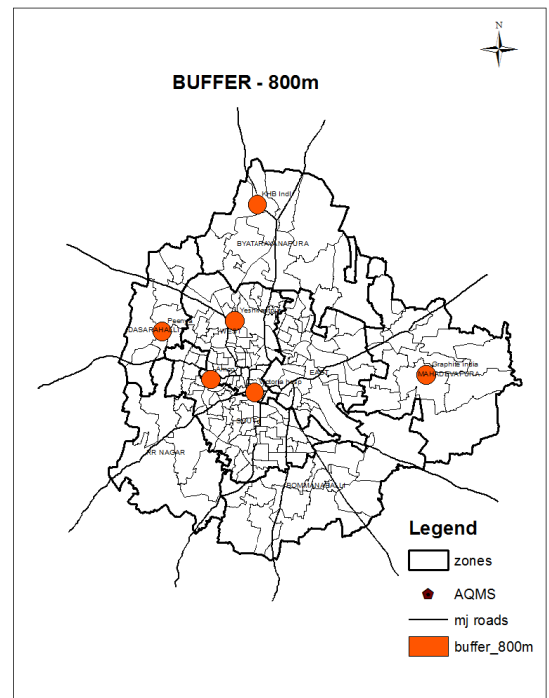


Fig. 2: Buffer of AQMS

**Data**

The data compiled for these 6 stations for the pollutants NO<sub>x</sub>, SO<sub>2</sub> and PM<sub>10</sub> were obtained from KSPCB for the years 2010-2013. That was entered into the database of the GIS for the respective stations. The values for the corresponding years and stations and the trend of the levels are shown in the graph Figs. 3-5.

The standards for the level of pollutants in comparison with WHO standards and US-EPA standards are provided in Table 1.

**Spatial Interpolation Methods**

After inputting all the values, the spatial distributions of these pollutants were determined using Inverse Distance Weighted (IDW)

interpolation techniques. The interpolation techniques based primarily on distance are IDW and Kriging. IDW is computed as a function of the distance between observed sample sites and the site at which the prediction has to be made [12]. As the number of monitors in Bangalore is limited, Kriging is problematic to use since, for a limited number of spatial observations, it can smooth the spatial pattern of pollution levels by not capturing the spatial complexity of the pollutant [12]. IDW is thus more useful in this scenario due to its capability to assign more weight to nearby points than to distant points.

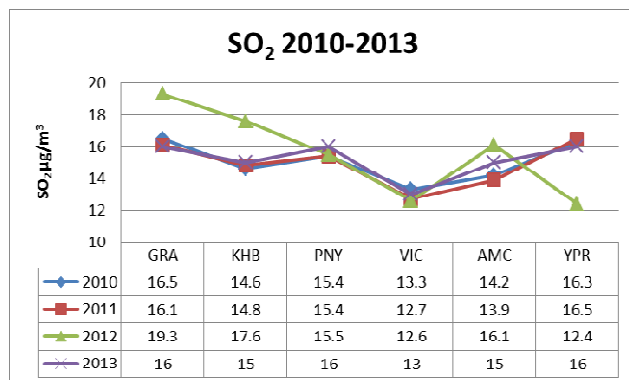


Fig. 3: SO<sub>2</sub> levels 2010-2013

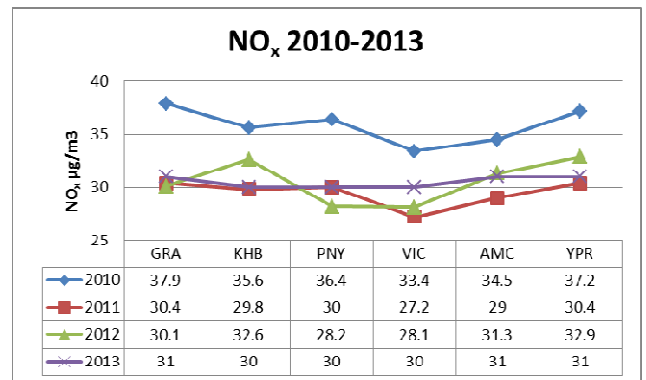
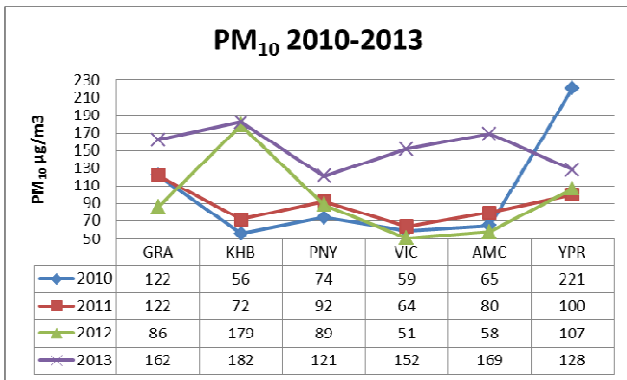


Fig. 4: NO<sub>x</sub> levels 2010-2013

**Table 1: Standards for NO<sub>x</sub>, SO<sub>2</sub> and PM<sub>10</sub>**

Pollutant	Time weighted average	INDIA		WHO	US-EPA
		Industrial, residential and rural areas (µg/m <sup>3</sup> )	Sensitive areas (µg/m <sup>3</sup> )	(µg/m <sup>3</sup> )	(µg/m <sup>3</sup> )
NO <sub>x</sub>	ANNUAL	40	30	40	100
	24 HOURS	80	80	-	-
SO <sub>2</sub>	ANNUAL	50	20	-	80
	24 HOURS	80	80	20	365
PM <sub>10</sub>	ANNUAL	60	60	20	60
	24 HOURS	100	100	50	150



**Fig. 5: PM<sub>10</sub> levels 2010-2013**

## RESULTS AND MAPS

Figs. 6-7 represent the interpolated maps of SO<sub>2</sub> levels for the years 2010-2013. From Table 1 and the maps it can be discerned that SO<sub>2</sub> levels are below the recommended standards in Bangalore. In 2010, the levels ranged between 13.3µg/m<sup>3</sup> and 16.5µg/m<sup>3</sup>, well below the recommended standard of 50µg/m<sup>3</sup>. The highest levels recorded among the four years was in 2012, the highest level being 19.3µg/m<sup>3</sup> but still well below the recommended standard. In 2013, the levels were similar to levels recorded in 2010 with levels ranging between 13µg/m<sup>3</sup> and 16µg/m<sup>3</sup>. The lightest green shade in the maps depicts the lowest levels of SO<sub>2</sub> whereas the darkest green shade denotes the highest level.

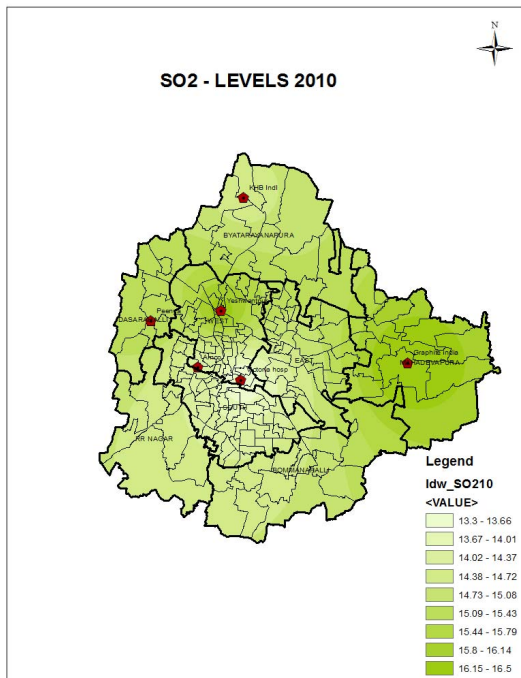
Figs. 10-13 represent the interpolated maps of NO<sub>x</sub> levels for the years 2010-2013. From the table and maps it can be discerned that NO<sub>x</sub> levels are below the recommended standards in Bangalore. In 2010, the levels ranged between 33.4µg/m<sup>3</sup> and 37.9µg/m<sup>3</sup>. In 2011, the highest recorded level was 30.4µg/m<sup>3</sup>. In 2013, the levels in all the areas were between 30-31µg/m<sup>3</sup>. Again, the lightest green shade in the maps depicts the lowest levels of NO<sub>x</sub> and the darkest green shade denotes has the highest level.

Figs. 14-17 represent the maps of PM<sub>10</sub> levels for the years 2010-2013. PM<sub>10</sub> has a wider range of variability in the city. In 2010, the lowest recorded level was 56µg/m<sup>3</sup> and the highest was 221µg/m<sup>3</sup>, almost 3.7 times the recommended standard of 60µg/m<sup>3</sup> and 11 times the recommended WHO

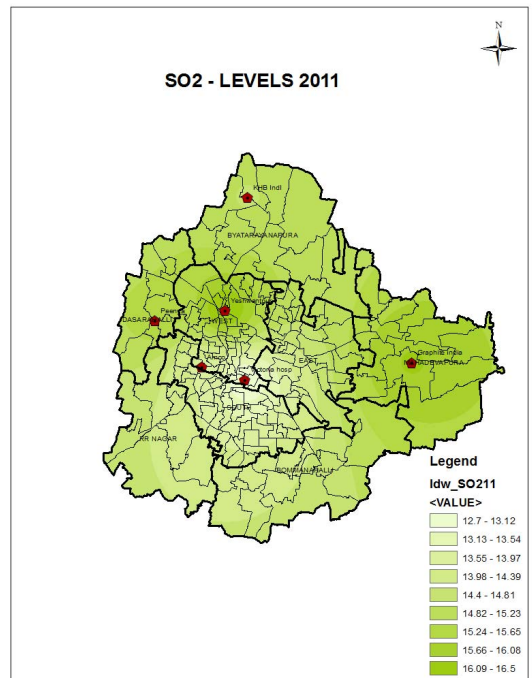
standard of 20µg/m<sup>3</sup>. The darkest red areas have the highest levels of PM<sub>10</sub> pollution.

The areas below 60µg/m<sup>3</sup> in 2010 are determined and only 5 wards out of 198 had levels below the recommended standards. Fig. 18 represents the areas with levels below the recommended standard; 193 wards had levels above the recommended level. Fig. 19 represents areas that exceed twice the recommended standard. In 2011 all 198 wards had levels above the recommended standard, with levels recorded between 64µg/m<sup>3</sup> and 122µg/m<sup>3</sup> across the city.

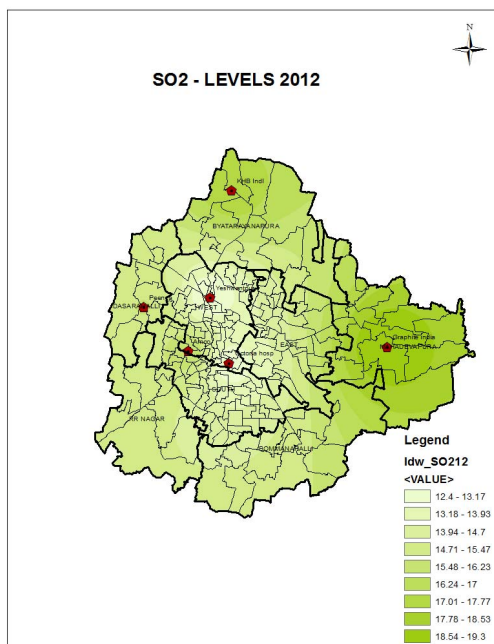
In 2012 levels fell slightly across some areas in the city. Seventeen (17) wards had predicted levels below the recommended standard; the maps showing levels below the recommended standard and areas with twice the levels are shown in Figs. 20 and 21. The year 2013 recorded the highest levels of PM across the city. All stations recorded more than twice the recommended standard with the highest level being 3 times the recommended standard. While the maps in Figs. 14-17 characterise the distribution of PM<sub>10</sub> across the city, care has to be taken in the decision making process with these predicted values as it is necessary to understand the uncertainty of these predictions. PM<sub>10</sub> has a spatial variability due to its nature. In [10] it was suggested that in case of highways with heavy vehicle movement, the variability of the pollutants are limited to 150m. Another study suggested that studies based on citywide air quality advocate that local exposure, and thus individual gradients in air quality, could be very significant [13]. The question then becomes a problem of scale as it is not economically feasible to have an AQM on every block.



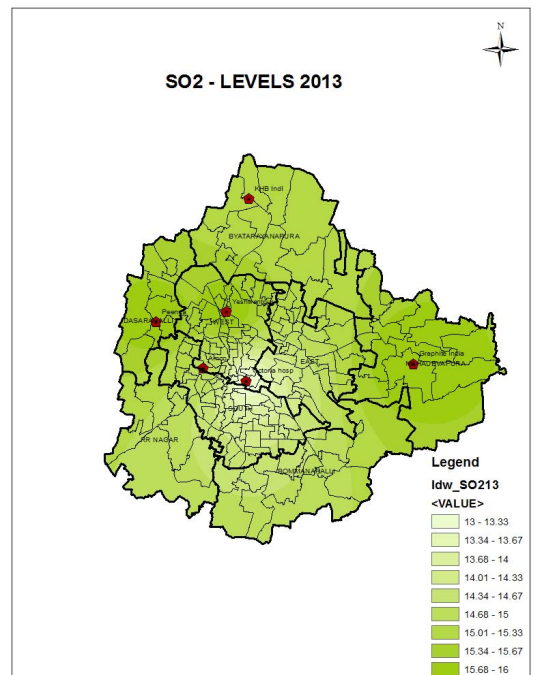
**Fig 6: Interpolated SO<sub>2</sub> – 2010**



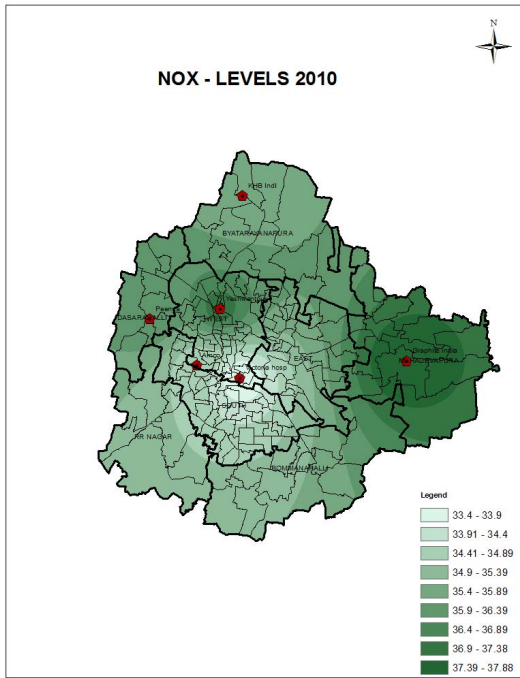
**Fig 7: Interpolated SO<sub>2</sub> – 2011**



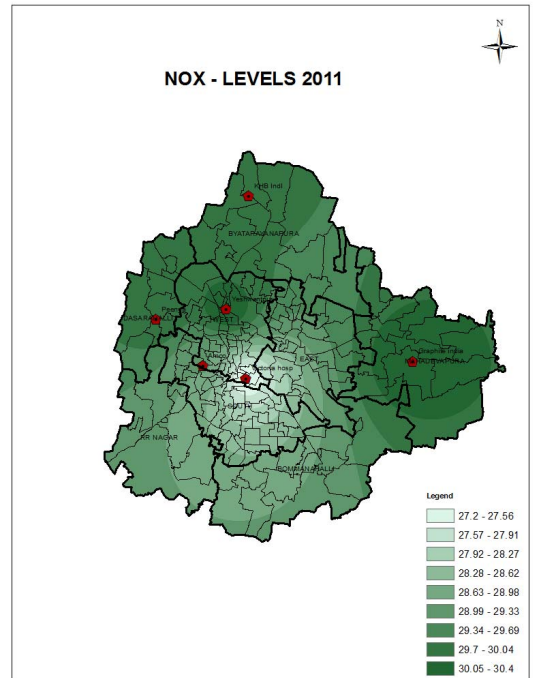
**Fig. 8: Interpolated SO<sub>2</sub> – 2012**



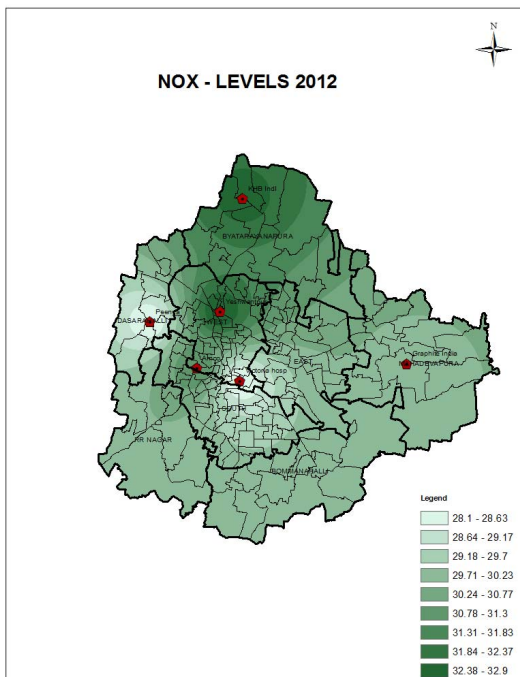
**Fig. 9: Interpolated SO<sub>2</sub> – 2013**



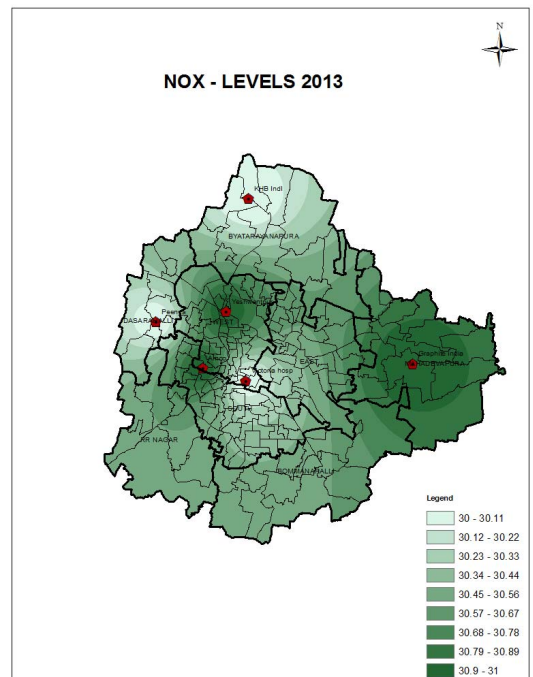
**Fig. 10: Interpolated NO<sub>x</sub> – 2010**



**Fig. 11: Interpolated NO<sub>x</sub> – 2011**

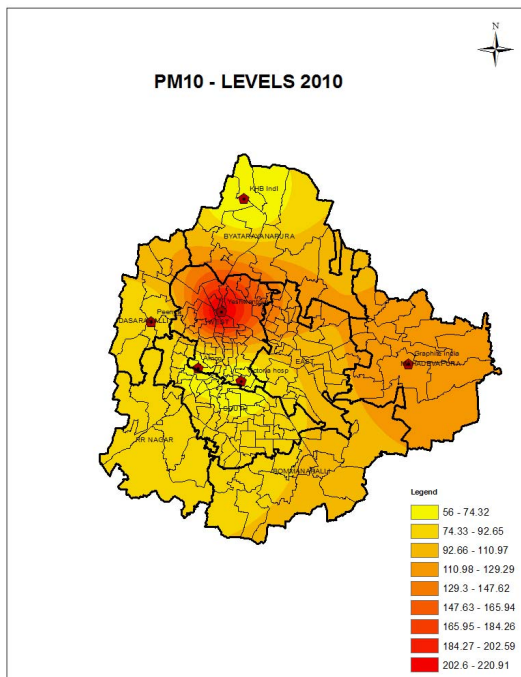


**Fig. 12: Interpolated NO<sub>x</sub> – 2012**

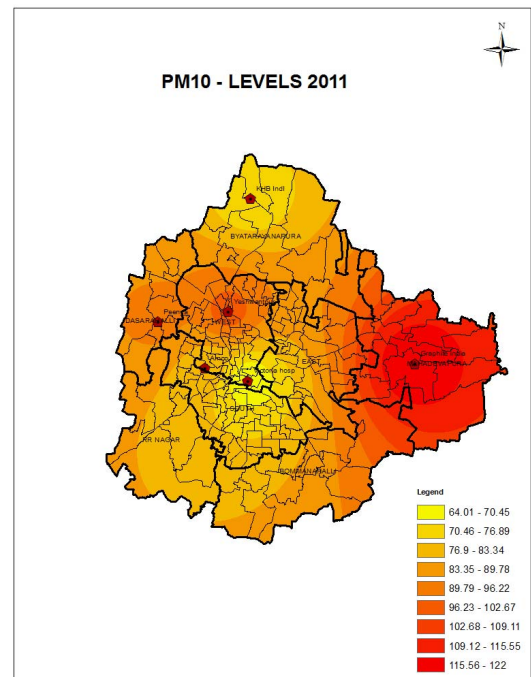


**Fig. 13: Interpolated NO<sub>x</sub> – 2013**

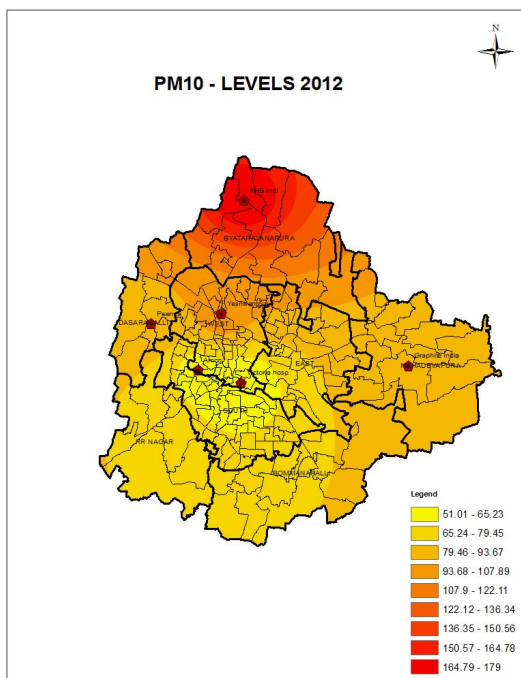




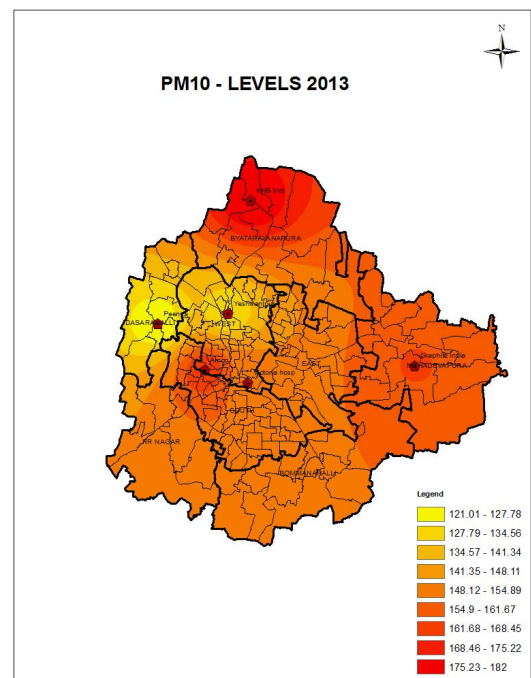
**Fig. 14: Interpolated PM<sub>10</sub> – 2010**



**Fig. 15: Interpolated PM<sub>10</sub> – 2011**



**Fig. 16: Interpolated PM<sub>10</sub> – 2012**



**Fig. 17: Interpolated PM<sub>10</sub> – 2013**

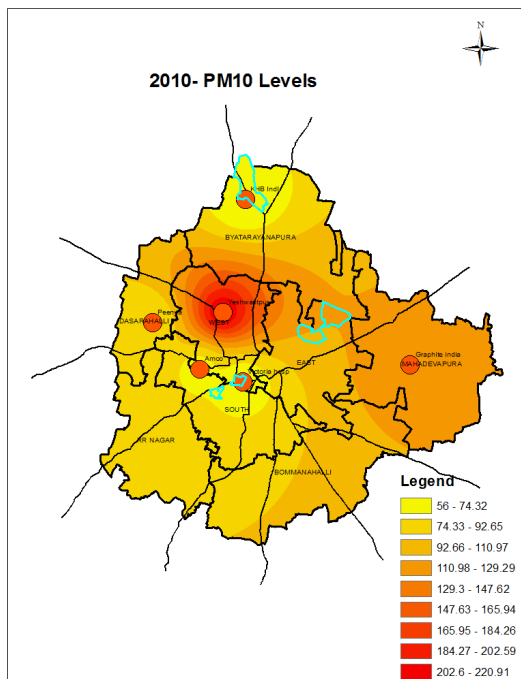


Fig. 10: Wards with PM<sub>10</sub> levels < 60µg/m<sup>3</sup>

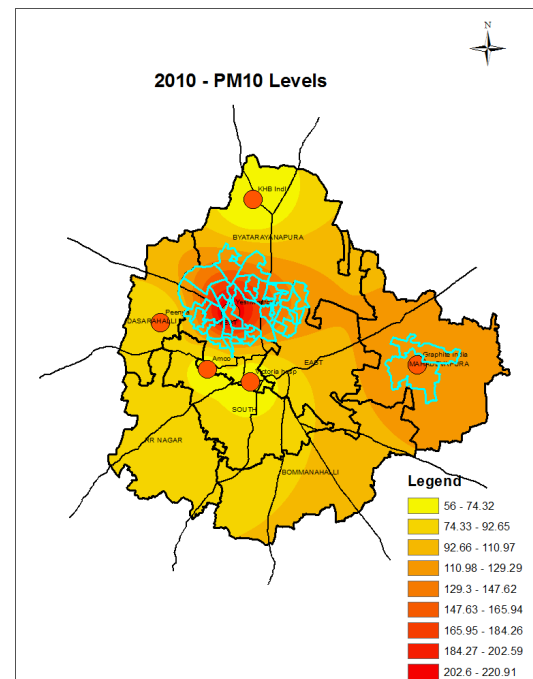


Fig. 11: Wards with PM<sub>10</sub> levels > 120µg/m<sup>3</sup>

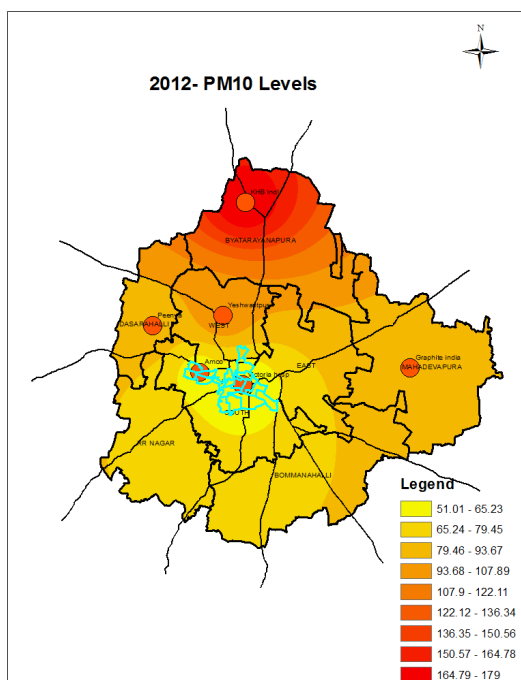


Fig. 20: Wards with PM<sub>10</sub> levels < 60µg/m<sup>3</sup>

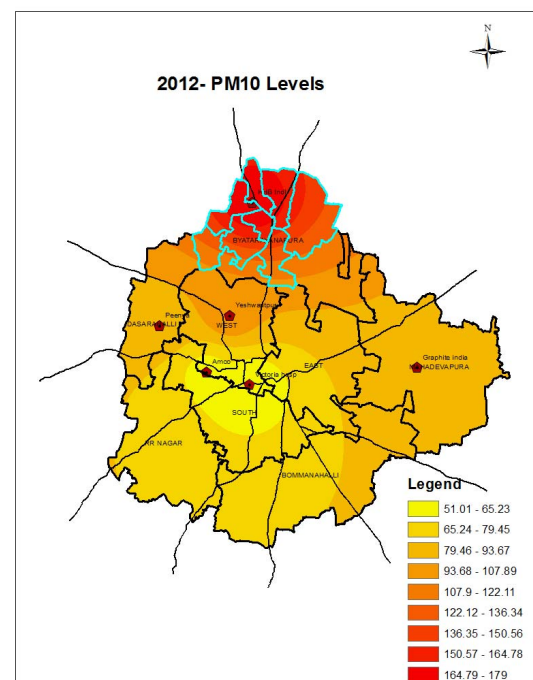


Fig. 21: Wards with PM<sub>10</sub> levels > 120µg/m<sup>3</sup>

## CONCLUSIONS

This paper has utilised the capabilities of GIS to locate the monitoring stations, buffer the zones to show the extent of the pollutant, use interpolation techniques to characterise distributions, perform queries to answer questions and obtain values at every location in the city that

will assist in further analyses to determine levels of pollutants and their effects on health of the citizens.

The paper has demonstrated that IDW can be a powerful tool to determine concentrations of pollutants and that the strong capabilities of GIS can be utilised to determine locations affected by high levels of pollution.

From the maps, it is observed that there is a serious problem with the levels of PM<sub>10</sub> in the city. PM causes decreased lung function, development of chronic bronchitis and premature death. Short-term exposures are associated with increased respiratory symptoms, cardiac arrhythmias, heart attacks, hospital admissions, emergency room visits for heart or lung disease and premature death [14].

The all-cause daily mortality is estimated to increase by 0.2-0.6% per 10µg/m<sup>3</sup> of PM<sub>10</sub> [15]. There are no studies or evidence to indicate safe levels of PM or a threshold below which there are no adverse effects on health. However studies have demonstrated that average life expectancy has increased by reducing levels of air pollution through interventions and reductions in pollution.

In Utah Valley, USA, the closure of a steel mill led to a decrease of 50% of PM<sub>10</sub> levels that resulted in a reduction of hospital admissions by 3 times and admissions for asthma and bronchitis illnesses halved. Furthermore a 15µg/m<sup>3</sup> decrease in levels of PM<sub>10</sub> led to a 3.2% drop in the daily number of deaths [16, 17].

Since the burden of air pollution on health is significant, even at relatively low concentrations, the effective management of air quality is necessary to reduce the health risks to a minimum. Bangalore and other cities in India can benefit from knowledge, communication and decision making on air pollution and health.

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