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Air Quality Assessment Using Interpolation Technique

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Abstract

Air pollution is increasing rapidly in almost all cities around the world due to increase in population. Mumbai city in India is one of the mega cities where air quality is deteriorating at a very rapid rate. Air quality monitoring stations have been installed in the city to regulate air pollution control strategies to reduce the air pollution level. In this paper, air quality assessment has been carried out over the sample region using interpolation techniques. The technique Inverse Distance Weighting (IDW) of Geographical Information System (GIS) has been used to perform interpolation with the help of concentration data on air quality at three locations of Mumbai for the year 2008. The classification was done for the spatial and temporal variation in air quality levels for Mumbai region. The seasonal and annual variations of air quality levels for SO_2, NO_x and SPM (Suspended Particulate Matter) have been focused in this study. Results show that SPM concentration always exceeded the permissible limit of National Ambient Air Quality Standard. Also, seasonal trends of pollutant SPM was low in monsoon due rain fall. The finding of this study will help to formulate control strategies for rational management of air pollution and can be used for many other regions.

Keywords: air quality; interpolation technique; ArcGIS; IDW

1. Introduction

Urbanization is a major trend all over the world mainly due to rapid growth in population. More than half the population of the world now lives in urban areas. This may be attributed to the continuous increase in global population (Kim, 2005; Huff and Angeles, 2011). Urbanization is affecting air quality at global, regional and local scales (Contini *et al*., 2012; Duh *et al*., 2008; Nemitz *et al*., 2008; Järvi *et al*., 2009). Urban air quality is a complex subject with different socio-economic aspects in different parts of the world and even within a specific region. The population growth is directly correlated to many environmental quality parameters like water and air quality (Alcamo *et al*., 2002; Bollen *et al*., 2009; 2010; Kan *et al*., 2012; Kanada *et al*., 2013; Yennawar, 1978). Nowadays air pollution is becoming a major issue in urban areas especially megacities such as Mumbai, Delhi, and Chennai in India. It has many sources like vehicles, industries, bakeries, domestic sector, load from cremation and hotels. Mumbai is the capital of the state of Maharashtra and is the most populated city in India. Furthermore, it is the financial, commercial and entertainment capital of India with the total population of more than eighteen million people (Census, 2011).

Air quality studies are done with monitoring and modeling techniques (Gulia *et al*., 2015; Kumar *et al*., 2015; Li *et al*., 2011). Air quality modeling requires emission data, meteorological data and surface characteristics for the region, collecting which can prove to be rigorous and tedious. Air quality monitoring is carried out by many authorities to communicate air quality status and this data can be easily collected. The monitoring data is a combination of emission sources and meteorological data which represents air quality status at a point. The objective of this study is to understand the air quality status through the use of interpolation techniques leading to delineating of spatial pattern over a region. The outcome of the study will significantly help in air pollution management, wherein a small dataset can be used for air quality mapping of a larger area. The study has been carried out in three locations within the Mumbai city to analyse air quality. ArcGIS was used to interpolate these values over the Mumbai region for the year 2008. Many communities and regulatory authorities have installed air quality monitoring stations to communicate air quality level or as a part of research and development. National Environmental Engineering Research Institute (NEERI) is a government organisation working continuously to ascertain the critical conditions of environment and suggest control options for the environmental problems. NEERI measures ambient air quality concentration at three locations in the Mumbai region namely Kalbadevi, Worli and Parel. In the present study, concentration data-sets at three locations have been interpolated over the Mumbai region and interpolated spatial and seasonal patterns have been observed that can help in rational management of air quality. The study area "Mumbai city" is depicted Fig. 1 where the three stations Parel, Kalbadevi and Worli are presented. Parel is situated in central Mumbai and represents an influx of huge enterprises in the compounds of the long-gone cotton mills. Kalbadevi is a residential area and an old neighbourhood in Mumbai. Worli is a part of South Mumbai and is one of the original seven islands that constituted the Mumbai city. Now, it has become one of the busiest office areas in the city.

2. Methodology

2.1 Geographical Information System (GIS) and its applications

Geographical Information System (GIS) is an efficient tool to capture, store, manipulate, manage, and analyse various types of geographical data and represent graphical view for easy understanding. ArcGIS software has several inbuilt tools which include many operations such as interpolation techniques, network analysis and spatial analysis. ArcGIS is widely used for modeling and simulation using data processing and various mathematical functions. This tool can help to estimate the levels of air pollution at various locations of the study region. This estimation is very useful to formulate control strategies for air quality management. ArcGIS has been applied in several studies for assessing air quality and exposure (Gulliver and Briggs, 2011; Cinderby and Forrester, 2005; Ketzel *et al*., 2011; Jensen *et al*., 2001; Kumar *et al*., 2016; Maantay, 2007; Marquez and Smith, 1999; Pummakarnchana *et al*., 2005; Sohrabinia and Khorshiddoust, 2007; Vienneau *et al*., 2009; Wang *et al*., 2009; Zhang *et al*., 2008). There are many interpolation techniques available in ArcGIS such as Kriging, Spline and Inverse Distance Weighting (IDW). Interpolation techniques are considered good tools to study spatial and temporal patterns of air quality without requiring data on meteorology and emissions (Candiani *et al*., 2013; Janssen *et al*., 2008; van Loon, 1993). The urban Indian case studies show that Inverse Distance Weighting gives a fairly good performance for the interpolation of the concentration of air pollutants as compared to other interpolation techniques, because the regional and local aspects both are incorporated. The evaluation of IDW interpolation technique for the concentration of ambient air quality in Port Blair

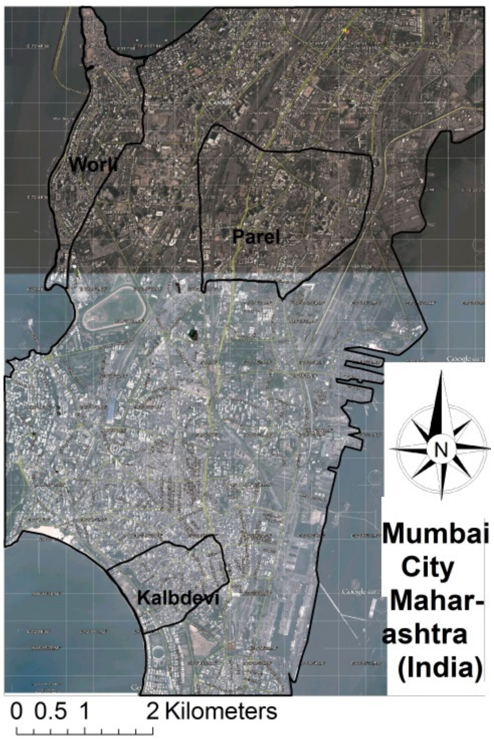


Figure 1. Study area and three monitoring sites: Worli, Kalbadevi and Parel

(India) has been reported by Jha *et al*. (2011). Wong *et al*. (2004) have also demonstrated that IDW gives fairly good interpolation of air quality (Kumar *et al*., 2016). IDW interpolates all values of the points within the sample range as averaging tool and gives better interpolation estimates when the minimum and maximum values of the surface are represented by sample data points. It estimates the value of a point as a basis of a function of two variables: the distance between sampling points and the point at which the value has to be estimated. The concentration of point will have heavier weight if it is proximal to the required point and vice versa. Here, weight is an inverse function of the distance, as demonstrated in the following equation:

$$Z_j = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=1}^{n} W_i} \quad \text{and} \quad W_i = \frac{1}{d_{ji}^{p}} \qquad \text{Eq 1.}$$

where Z_j is the value of concentration at the j^{th} point, W_i is the weight of observed i^{th} point, d_{ji} is the distance from the i^{th} point to the j^{th} point, p is the power and n is total number of points.

A base map was taken and geo-referencing was done to associate with physical earth space in ArcGIS. Shapefiles were created with the help of the geo-referenced map for air quality monitoring stations and for the Mumbai region. The air quality monitoring locations are denoted by point shapefile and area of south-west Mumbai is denoted by polygon shapfile in Mumbai region. Air quality data, monitored by NEERI (Mumbai), was fed in the attribute of point shapefiles on the basis of monthly, seasonal and annual average. Colorimetric method for SO_2, NO_x and gravimetric method for SPM were used to monitor air quality data with the help of High Volume Sampler. The monitoring station runs for twice a week and collect 104 data in a year as per (National Ambient Air Quality Standard) NAAQS. The Inverse Distance Weighting (IDW) was used to interpolate the data of three point shapefiles for the concentrations of SO_2, NO_x and SPM in the study area.

3. Results and Discussion

3.1 Results of monitoring data

Based on monitored data-set of ambient concentration at three locations, it can be concluded that the annual average concentration of SO_2 and NO_x is low while concentration of SPM is consistently high all over Mumbai region for the year 2008. The annual permissible limits of NAAQS by Central Pollution Control Board (CPCB) are 60 μg/m^3 for SO_2 and NO_x and 140 μg/m^3 for SPM (CPCB, 2008).Annual average values of the air quality parameters considered in this study are shown in Fig. 2. The maximum annual average concentrations of SO_2 and NO_x are found to be 10 and 44 μg/m^3 in Kalbadevi amongst the three locations, which are well below the standards. Annual average concentrations of SO_2 and NO_x are close to these values at Parel and Worli: 7 and 36 μg/m^3, respectively. The annual average concentrations of SPM is 251, 253 and 274 μg/m^3 at Worli, Kalbadevi and Parel, respectively, which is above the permissible limit.

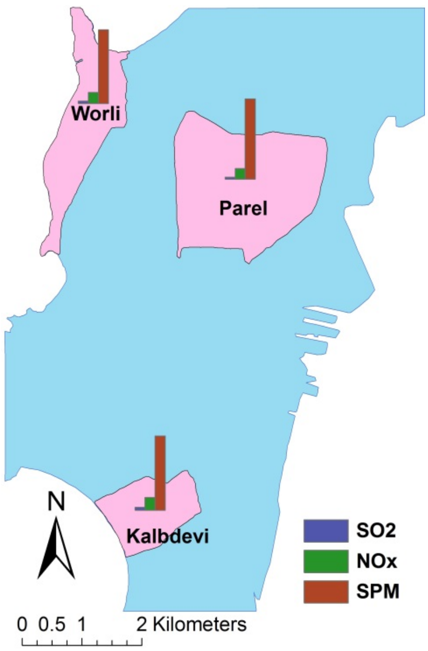


Figure 2. Annual average concentration (μg/m^3) for SO_2, NO_x and SPM as monitored at three locations

Table 1. Annual values for the three stations and permissible limit values for the three pollutants

Monitoring Station	Annual average concentration (μg/m^3)		
	SO_2	NO_x	SPM
Worli	8	38	251
Parel	7	36	274
Kalbadevi	10	44	253
Permissible limit	60	60	140

Table 1 enlists the annual values for the three stations and permissible limit values for the three pollutants, which have been provided by CPCB. The SPM concentration at all three locations is higher than the CPCB standard. Table 2 shows seasonal concentrations of three pollutants at the three stations. The SO_2 concentration is maximum at Kalbadevi from the post-monsoon to winter season which shows industrial emission effect. Worli and Parel have higher concentration for SPM in the monsoon which may be because of resuspension of dust. Kalbadevi and Parel have maximum concentration in the winter. Table 3 shows monthly concentrations of three pollutants at the three stations in which daily standard of air quality of pollutants have been included. Ambient air quality standards are not included in Table 2 because standards are given only on a daily and annual basis. It is evident that SPM exceeds the permissible limit of air quality standard at all three locations while the other two parameters (SO_2 and NO_x) are within limits. The monthly concentration of SPM at all three locations are within limits in the monsoon season because of washout due to rainfall.

Figs. 3 (a), (b) and (c) show bar plots of seasonal average concentration for air pollutants SO_2, NO_x and SPM at the three monitoring sites respectively. Seasons are considered as follows: December and January represent the winter season, February, March, April and May are the pre-monsoon season, June, July, August and September are the monsoon months and the post-monsoon season comprises of October and November. Seasonal average concentrations of SO_2, NO_x and SPM were highest in the winter season, and maximum seasonal concentrations were observed at Kalbadevi for SO_2, NO_x and SPM (24, 76 and 414 μg/m^3, respectively). SPM concentrations were high in each season except during monsoon at Worli and Parel. It may be because these are dense and congested regions where resuspension of particulate matter occurs more. Figs. 4 (a), (b) and (c) represent monthly variations of SO_2, NO_x and SPM, respectively, for the year 2008. The concentration of pollutants was found to start decreasing from winter season to pre-monsoon season and concentrations of all pollutants was least in the monsoon season.

3.2 *Results of IDW interpolation*

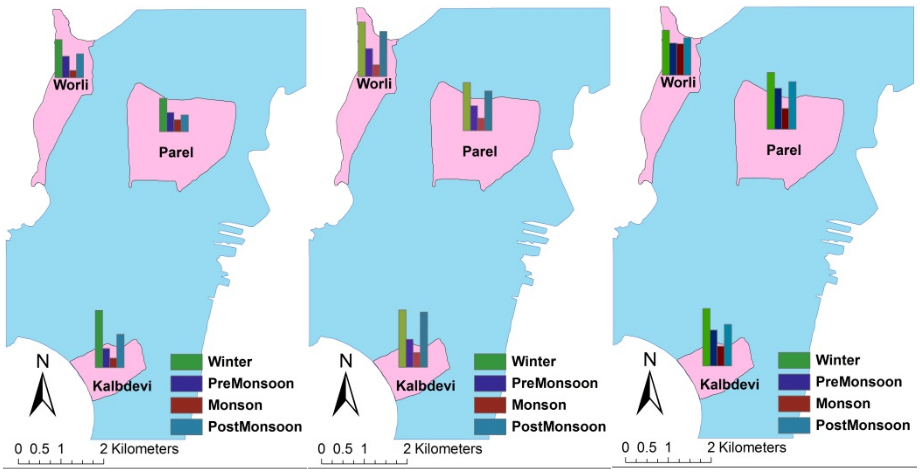
The collected monitored dataset was used in ArcGIS 9.3 to interpolate the concentration data-set of air quality using IDW. Figs. 5 to 9 show the results of use of IDW interpolation technique. Figs. 5 (a), (b) and (c) show contour plots of annual average for air pollutants SO_2, NO_x and SPM respectively. Annual average concentrations of SO_2 and NO_x are maximum at Kalbadevi, but SPM is higher in Parel at 274 μg/m^3. In these figures, spatial patterns indicate that NO_x and SO_2 may be transported from Kalbadevi to Worli and from Worli to Parel, However, in the case of SPM, pollutant may be transported from Parel to Worli and Kalbadevi over the year.

Table 2. Seasonal concentrations (μg/m^3) of three pollutants at the three stations

Locations/	Worli			Kalbadevi			Parel		
Season	SO_2	NO_x	SPM	SO_2	NO_x	SPM	SO_2	NO_x	SPM
Winter	16	70	323	24	74	414	14	62	410
Premonsoon	9	36	231	8	36	259	8	32	296
Monsoon	3	15	226	4	19	142	3	16	151
Postmonsoon	10	58	269	14	71	300	7	51	343

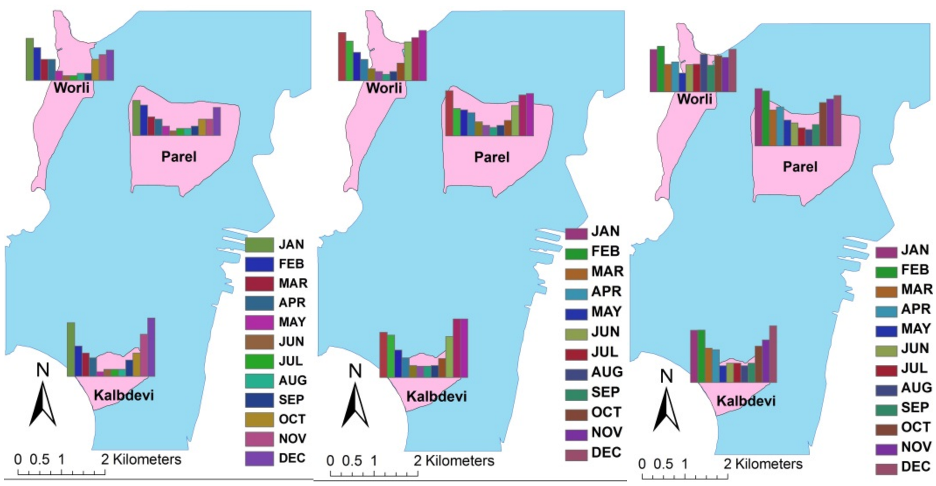
Table 3. Monthly concentrations (μg/m^3) of three pollutants at the three locations

Locations/	Worli			Kalbadevi			Parel			Standard (Daily)		
Pollutants	SO_2	NO_x	SPM	SO_2	NO_x	SPM	SO_2	NO_x	SPM	SO_2	NO_x	SPM
JAN	18	68	322	23	64	397	15	64	436	80	80	200
FEB	14	56	345	13	60	398	13	39	417	80	80	200
MAR	9	40	209	10	39	261	8	37	273	80	80	200
APR	9	30	228	8	28	249	7	33	296	80	80	200
MAY	4	17	142	2	17	127	4	20	196	80	80	200
JUN	2	13	207	3	16	147	2	15	176	80	80	200
JUL	2	9	211	3	16	147	3	12	138	80	80	200
AUG	3	13	285	3	17	127	3	15	125	80	80	200
SEP	3	25	202	7	27	147	4	22	163	80	80	200
OCT	9	55	275	10	58	276	7	43	330	80	80	200
NOV	11	61	262	18	83	323	7	58	356	80	80	200
DEC	13	71	324	25	83	431	12	60	383	80	80	200



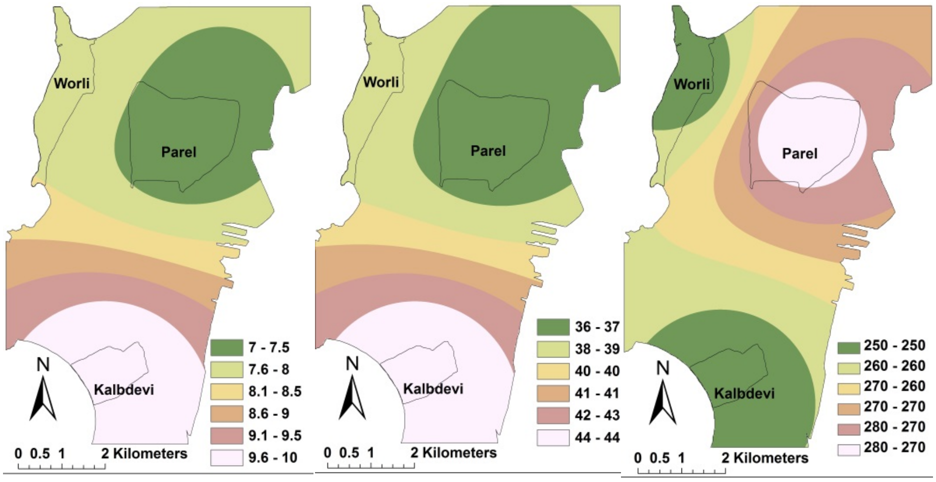
(a) (b) (c)

Figure 3. Seasonal variation of concentration (μg/m^3) of (a) SO_2, (b) NO_x and (c) SPM in 2008



(a) (b) (c)

Figure 4. Monthly variation of (a) SO_2, (b) NO_x and (c) SPM concentration (μg/m^3) in 2008



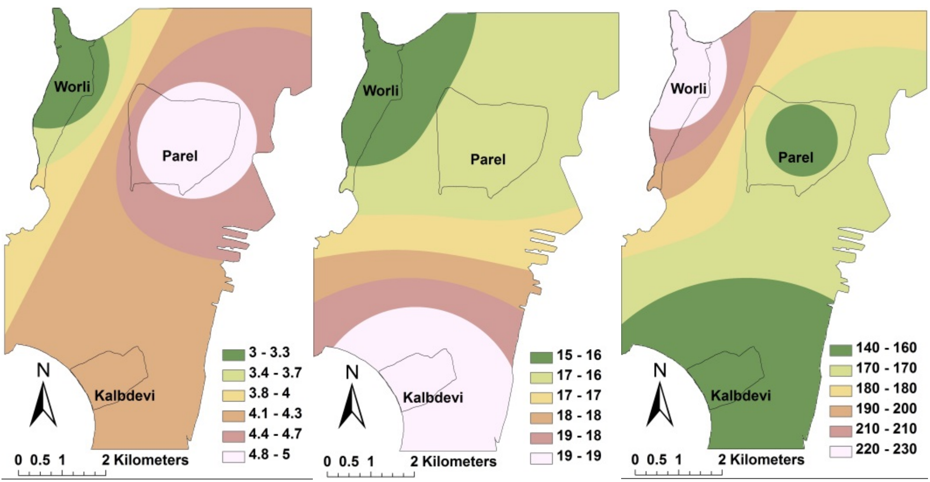
(a) (b) (c)

Figure 5. Annual average concentration (μg/m^3) of (a) SO_2, (b) NO_x and (c) SPM

Figs. 6 (a), (b) and (c) exhibit contour plots of average of monsoon period of the year. This is less for all pollutants, though SPM in Worli and Parel is still higher than the permissible limit of ambient air quality standards. SPM concentration is extremely high at 226 μg/m^3 in Worli for the monsoon period. Here, SO_2 may have been transported from Parel to Kalbadevi to Worli. NO_x may be transported from Kalbadevi to Parel to Worli. However, for SPM, spatial pattern is found to be from Worli to Parel and Kalbadevi.

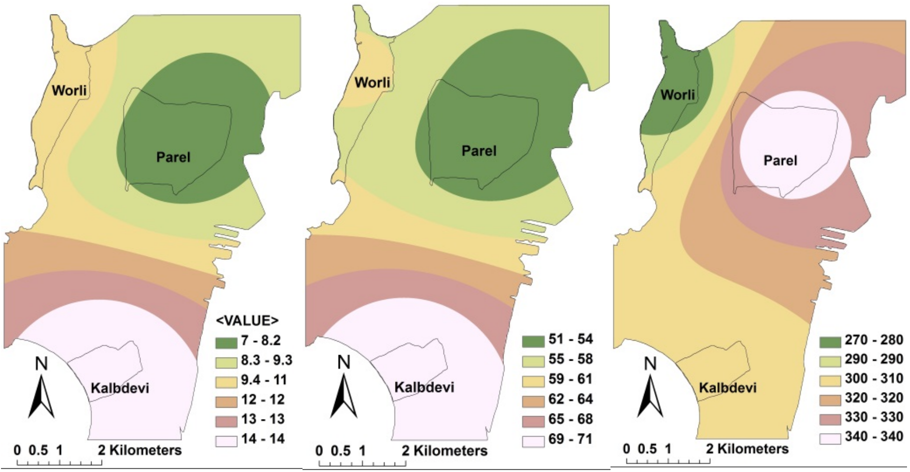
Figs. 7 (a), (b) and (c) are contour plots of average for SO_2, NO_x and SPM during post-monsoon months of the year. SO_2 and NO_x concentrations are as low as 7 and 51 μg/m^3 in Parel. The highest concentrations of SO_2 and NO_x are in Kalbadevi at 14 and 71 μg/m^3 respectively. SPM concentration is high in Parel at 343 μg/m^3 and low in Worli at 269 μg/m^3, though both are higher than the standard limit. Here too, it may be observed that pollutants SO_2 and NO_x may be transported from Kalbadevi to Worli to Parel, but SPM may be transported in the opposite direction.

Contour plots for winter season are shown in Figs. 8 (a), (b) and (c). SO_2 and NO_x are low in Parel at 14 and 62 μg/m^3, respectively. Kalbadevi has a concentration as high as 24, 74 and 414 μg/m^3 for SO_2, NO_x and SPM respectively. Remarkably, here SPM apparently followed the opposite flow direction: from Kalbadevi and Parel to Worli. The concentration of SPM in Worli was 323 μg/m^3, which is low. Here, too, pollutants SO_2 and NO_x had the same spatial pattern of being transported from Kalbadevi to Worli to Parel but SPM may go from Kalbadevi and Parel to Worli.



(a) (b) (c)

Figure 6. Monsoon (June, July, August and September) concentrations (μg/m^3) of (a) SO_2, (b) NO_x and (c) SPM

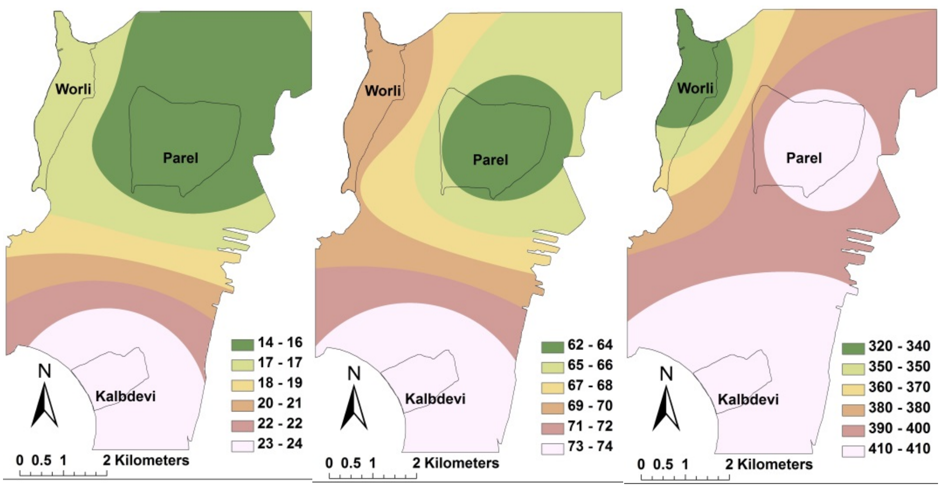


(a) (b) (c)

Figure 7. Post-monsoon (October and November) concentration (μg/m^3) of (a) SO_2, (b) NO_x and (c) SPM

Figs. 9 (a), (b) and (c) show contour plots for the pre-monsoon season. Here, the spatial pattern of SO_2, NO_x and SPM concentrations do not match. For SO_2, Parel and Kalbadevi display fairly low concentrations (8 μg/m^3) which are comparable to the values observed in Worli (9 μg/m^3). For NO_x, Worli and Kalbadevi have the same concentration at 36 μg/m^3, which is maximum. For SPM, Parel showed higher concentration (296 μg/m^3) than Worli (231 μg/m^3). For the entire region, SPM concentration was higher than the permissible limit, except during the monsoon season.

The average wind speed and maximum temperature of every month has been represented in Fig. 10. The maximum wind speed is in the monsoon season, leading to low concentration level of pollutants. The temperature was high and wind speed was low in October, November and December. Fig. 11 shows SPM concentration in terms of monthly average. SPM concentration is low from May to September, which corresponds to the monsoon season in the study area. National Ambient Air Quality Standard (NAAQS; CPCB, 2008) prescribes annual and daily air quality standard 140 and 200 μg/m^3, respectively for SPM but the measured values were higher than that except during the monsoon season at all locations. The concentration is low during the monsoon season and high during the remaining seasons due to precipitation. Rainfall is high from June to September peaking in July, as shown in Fig. 11. The high rainfall washout the pollutants and show lower pollution levels in that period. Temperature, wind speed and rainfall data was collected from Indian Meteorological Department, Mumbai.



(a) (b) (c)

Figure 8. Winter (December and January) concentration (μg/m^3) of (a) SO_2, (b) NO_x and (c) SPM

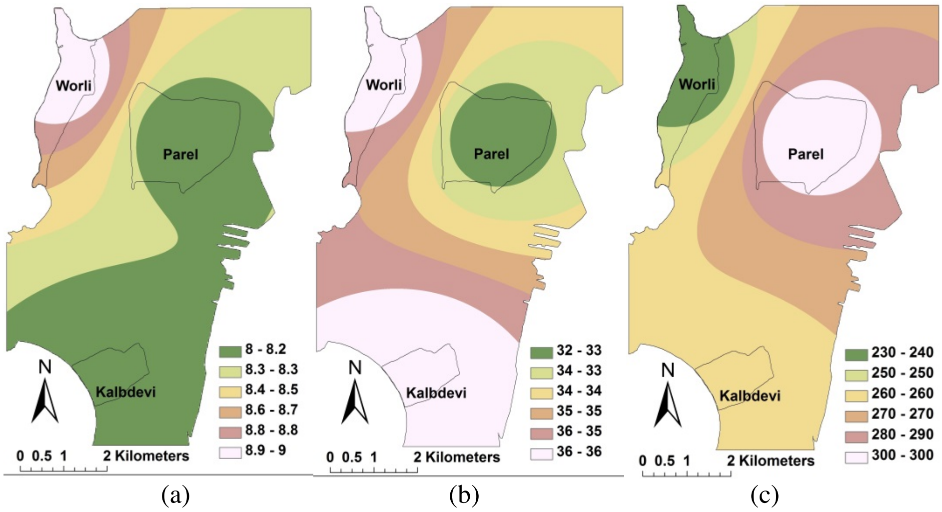


Figure 9. Pre-monsoon (February, March, April and May) concentration ($\mu g/m^3$) of (a) SO_2, (b) NO_x and (c) SPM

5. Conclusions

Interpolation technique of ArcGIS was used for air pollutants such as SO_2, NO_x and SPM for Mumbai region. Inverse Distance Weighting (IDW) tool of ArcGIS was used for air quality assessment with a view to understand the variability of air pollutant concentrations across the city. The analyses have been performed for four distinct seasons: winter, pre-monsoon, monsoon and post-monsoon. The city experiences distinct drop in air pollution during rainy season (monsoon), which spans over four months (June-September). The spatial pattern of annual average, winter and post-monsoon seasons displayed similar pattern for SO_2 and NO_x. The pre-monsoon and post-monsoon seasons showed a similar pattern for SPM. Except these, all showed different patterns for pollutant over the region. All three pollutants showed different patterns in pre-monsoon and monsoon. IDW technique appears to be an appropriate navigation tool for analysis of spatial variation of air quality. It does not require meteorological and emission data, with monitored concentration of pollutants being the only dataset needed. Monitoring data is easy and economical to obtain while collection of emission and meteorological data needs more resources in terms of time and costs.

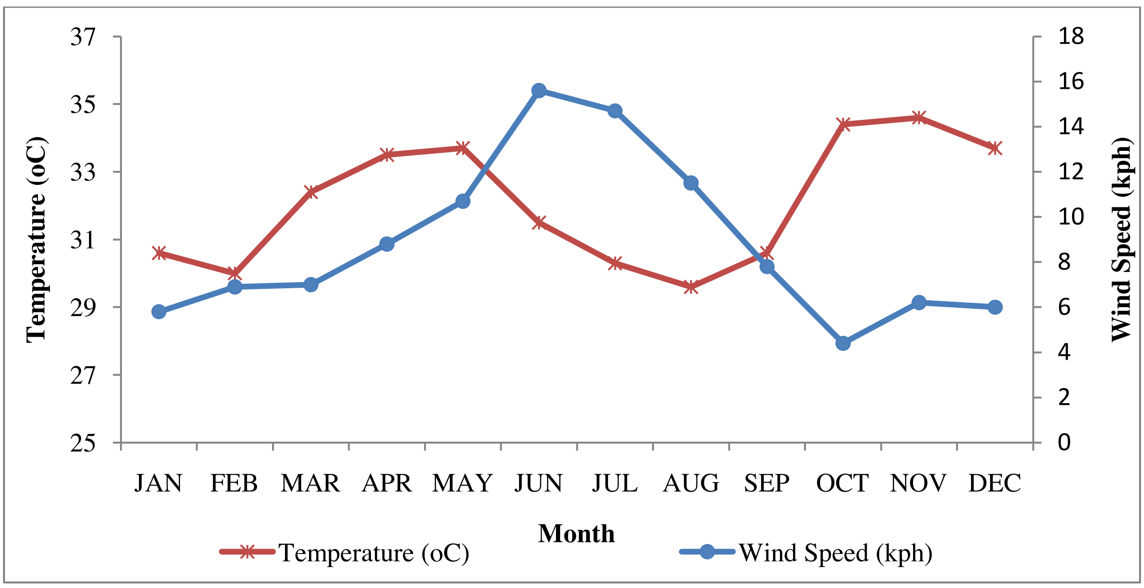


Figure 10. Monthly maximum temperature and average wind speed

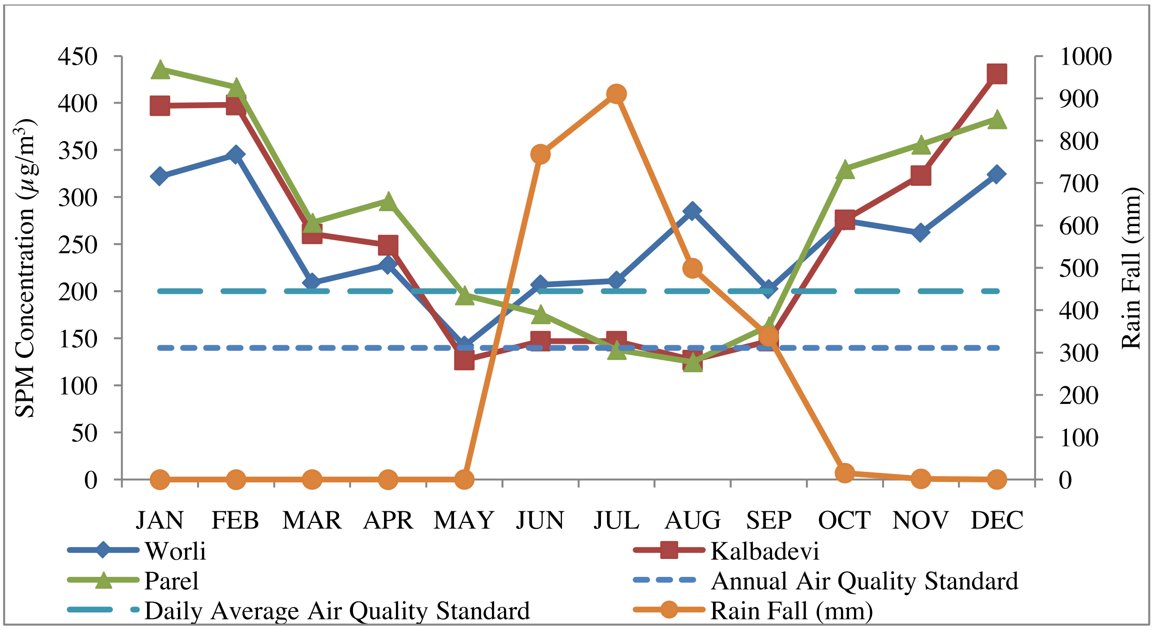


Figure 11. SPM concentrations (average of each month) for three locations of Mumbai compared with annual and daily air quality standard (140 and 200 µg/m^3 respectively)

However, this study has some limitations. For instance, air quality data was available only at three monitoring sites over the entire region and measurement on meteorological parameters was not available at sites. Enhanced air quality monitoring network and inclusion of meteorological parameters will help understand the atmospheric transportation of pollutants, leading to rigorous spatial interpolation and prediction.

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