Study Comparing Urban Air Pollution

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Abstract: Using the US-EPA regulation dispersion model AERMOD and the emission loads provided by the CPCB and NEERI, the level of air pollution in Mumbai, one of India's major cities, was compared to the results projected. In order to compare the levels of two air pollutants, PM10 and NOx, during the year 2012, two monitoring stations, Sion in central Mumbai and Bandra in western Bombay, were used. The results for the Sion and Bandra monitoring sites indicate that the current observed PM10 concentrations are higher than the projected amounts.

However, in the instance of NOx, it was discovered that the observed values at Sion and Bandra were lower than the projected concentrations. According to a comparison of the study's findings, the city's development initiatives, plans, and policies to reduce air pollution have succeeded in slowing the growth of NOx but failed to do the same for PM10. With the aid of air pollution modelling, this study will offer researchers and planners/decision-makers a different perspective on how to concentrate on the efficacy of the adopted plans and policies.

Keywords: AERMOD; planetary boundary layer; emission rate; dispersion models; air quality map.

1 Introduction

Present scenario

The observed quantities of NOx at Sion and Bandra, however, were discovered to be lower than the projected concentrations. The study's findings show that while development initiatives, plans, and policies to reduce air pollution in the city have slowed the pace of increase in NOx, they have not been able to slow the rate of increase in PM10. By using air pollution modelling, this article will give academics and planners/decision-makers another way to concentrate on the success of adopted plans and policies. The World Health Organization has modified its air quality recommendations, giving a universally applicable standard for air quality and lowering the risk of pollution-related illness (UNDESA, 2006). Urban areas' vehicular emissions of pollutants are widely acknowledged to be a source of long-term health impacts (Molina and Molina, 2004). But this expansion comes at a significant, and frequently rising, economic and social cost in the absence of a proper environmental policy and action plan. Sickness and death rates, productivity losses, missed chances for education and other forms of human development, as well as lost production, can all be used to quantify the serious effects of air pollution on public health (UNEP, 2005).

Urban air pollution not only has detrimental local effects but also has regional and international implications. The current state of the air quality in major Indian cities necessitates the creation of detailed action plans for enhancing the non-attainment cities and towns (Athalye, 2010). The problem with air quality is deterministically described by air pollution modelling. Depending on the study's breadth, it might also offer recommendations on how to adopt mitigation measures as well as an analysis of the factors and causes (emission sources, climatic processes, physical and chemical changes) (Daly and Zannetti, 2007).

The urban scale modelling systems designed using such models are being increasingly employed in developed countries to reliably provide urban air quality forecasts for protection of public health, policy formation purpose, etc. (Otte et al., 2005; Menut et al., 2005; UKPF, 2006). Air pollution modelling is the method that quantifies deterministic correlation between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of efficacy of strategies. This makes air pollution models vital in regulatory, research, and forensic applications (Builtjes, 2003). Very few cases of application of air pollution dispersion models in urban air quality management are currently available with consideration of entire urban area (TERI, 2005; IES, 2005; Athalye et al., 2006, CPCB and NEERI, 2010; Kesarkar et al., 2006) in India. However the softwares used in available studies are now obsolete like ISCST-3 (US-EPA, 2003).

About AERMOD

AERMOD is a steady-state plume dispersion model introduced in 2006 as a regulatory model to replace ISCST3 (US-EPA, 2008). In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal planes of reference. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function (PDF). In addition, in the CBL, AERMOD treats 'plume lofting', a portion of plume mass, released from a buoyant source, rises to and remains near the top of the boundary layer before becoming mixed into the CBL. AERMOD also tracks any plume mass that penetrates into the elevated stable layer, and then allows it to re-enter the boundary layer when and if appropriate. For sources in both the CBL and SBL, AERMOD treats the enhancement of lateral dispersion resulting from plume meander (US-EPA, 2004a). The AERMOD consists of two pre-processors viz. AERMAPand AERMET with the dispersion model.

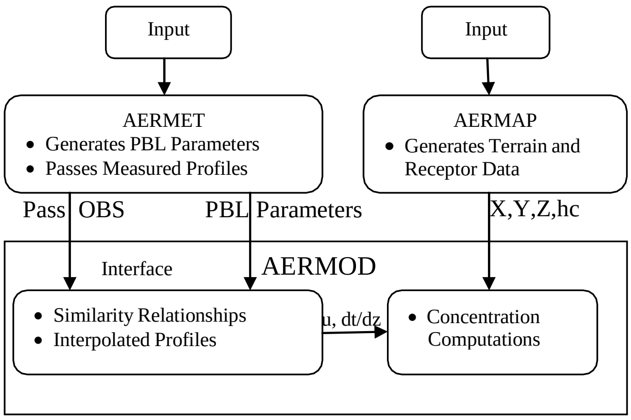
Meteorological pre-processor – AERMET

AERMET is used to process meteorological data and surface characteristics to calculate boundary layer parameters required by AERMOD. One of the major improvements that AERMOD brings to applied dispersion modelling is the ability to characterise the planetary boundary layer through both surface and mixed layer scaling. It constructs vertical profiles of required meteorological variables based on measurements and extrapolations of those measurements using similarity (scaling) relationships (US-EPA, 2004a). AERMET uses three-stage processing. The first stage extracts (retrieves) data and assesses data quality. The second stage combines (merges) the available data for 24-hour periods and writes these data to an intermediate file. The third stage reads the merged data file and develops the necessary boundary layer parameters (US-EPA, 2004b).

Terrain pre-processor – AERMAP

AERMAP uses terrain data for the modelling area to calculate a representative terrain-influence height associated with each receptor location in the study area. The grid data is supplied to AERMAP in the format of the digital elevation model (DEM) data (USGS, 1994). The terrain pre-processor can be used to compute elevations for both discrete receptors and receptor grids.

Figure 1 Data flow in the AERMOD modelling system



Source: US-EPA (2004a)

The assumption has been made that terrain will affect air quality concentrations at individual receptors. Hence, AERMAP first determines the base elevation at each receptor and source (US-EPA, 2004c). The run stream file is divided into five functional 'pathways'. These pathways are identified by a two-character pathway ID placed at the beginning of each run stream image. The pathways and the order in which they are input to the model are as follows (US-EPA, 2004a):

- CO – for specifying overall job control options
- SO – for specifying source information
- RE – for specifying receptor information
- ME – for specifying meteorology information
- OU – for specifying output options.

2 Material and methods

Inputs for AERMAP

Study area: Mumbai is a capital of Maharashtra state in India comprises of 468 km^2 area. City is surrounded by coastline on western, eastern and southern sides. Average elevation of Mumbai is from 10 to 15 metres (CPCB, 2010a). Base map has been used from the website of Google earth. Terrain data has been taken from United States Geological Survey (USGS) in the form of computer terrain elevation data files acquiring 1:24,000-Scale (7.5-minute) DEM with following specifications (ASTER and GDEM, 2011):

Figure 2 Mumbai city: study area (see online version for colours)

Source: Google Earth (2013)

Table 1 Technical specification of DEM files

Tile size	3,601 × 3,601 (1 × 1)
Pixel size	1 arc-second
Geographic coordinate system	Geographic latitude and longitude
DEM output format	GeoTIFF, signed 16-bit, in units of vertical meters, Referenced to the WGS84/EGM96 geoid Special DN values
	–9,999 for void pixels, and 0 for sea water bodyCoverage
	North 83 to South 83, 22,702 tiles

Inputs for AERMET

Hourly meteorological data has been collected from National Oceanic and Atmospheric Administration's (NOAA) and National Climatic Data Center (NCDC) (2013) for Santacruz station and considered as representative for whole Mumbai city. The obtained meteorological data from NCDC differs in frequency of measurements/observations, units, etc. For calculation of missing meteorological data, the procedure adopted by Texas Commission on Environmental Quality (TCEQ, 1991), Texas State Implementation Plan has been followed. The Albedo, Bowen ratio and surface roughness length were set to default, as 0.14, 1 and 1, respectively as minimum. For upper air meteorological data default option has been used.

Observed monitoring data

Observed monitoring data has been obtained from the Maharashtra Pollution Control Board (MPCB, 2013). In this study, Sion and Bandra stations have been selected for comparison as they represent the Mumbai city. The Continuous Ambient Air Quality Monitoring stations have been engaged to collect data from these locations.

General methodology

The commercial interface of AERMOD formulated by BREEZE version 7.6.0 has been sused in this study. The report entitled 'Air Quality Assessment, Emissions Inventory and Source Apportionment Studies: Mumbai' prepared by Central Pollution Control Board and National Environmental Engineering Research Institute of India has been used to get emission loads (CPCB and NEERI, 2010) in the study area. Depending on the availability of data modelling has been carried out for the year 2012 and air pollutants viz. Particulate matter of 10 µm size and Oxides of Nitrogen – prominently contributed by vehicular population (28.22% increase in 2010–11 compared to last year) (Motor Vehicle Department of Maharashtra, 2010–2011) and development activities in the city. Considering 2007 as a base year and sources like point sources, area source, line source (vehicular source) and road side dust, the emission loads have been given and projected for 2012 for selected grids of Mumbai city in above mentioned report. Projections are based on the growth rates considered for population, industries, area sources and vehicular sources computing strengths for the base year 2007. Additional data collection and analysis carried out to check the growth rates for particular sectors like vehicular data, industries registration data in background. It was observed that the growth rates are not following the previous trends because of some plans and policies. Some of the uncertainties that may arise in the projections are because of:

a Many plans and policies changed with respect to time which leads to differentpattern of emission loads.

b Many industries in the area are asked and pressurised to relocate or change to cleanerfuel. This will lead to lower the contribution of point sources.

c At the same time number of vehicles is increasing with high rate; contributing moreloads from line sources.

d In the area sources many unorganised sectors like construction activity, street venders and open eat outs are practically difficult to quantify and project for future,even though they are contributing in air pollution.

In this study, the map of Mumbai city has been divided into 147 numbers of effective grids of size 2 × 2 km each covering terrestrial boundary of Mumbai. The grid size kept same for this study as mentioned in the report by CPCB and NEERI. Some uncertainties may arise like:

1 model-based

2 inter-relations of grids with respect to air pollutants

3 sub-grid variability are not considered.

Each grid has been treated as an area source only. The CPCB and NEERI's report has published the emission loads and respective grids formed on the Mumbai image. The same image used for present modelling and geo-referencing has been carried out by overlying on the base map. This effort has been taken to ensure that the grid size and location will remain same for both the studies. AERMOD input file consists of emission rate data (as gm/sec/m^2) calculated from the projected emission loads for the respective grids; considering an area of the grid. Assuming that all the major emission sources have been considered in this study, the output of AERMOD does not include the background concentrations of pollutants or those transported from sources outside the study area. The 71 receptor locations have been selected including 17 sensitive receptors comprises of hospitals, academic institutes and government buildings. Figure 3 represents grids as an area sources and receptor locations in Mumbai, India. Two locations, Sion and Bandra have been selected for which actual monitoring was carried out by Maharashtra State Pollution Control Board with the help of Continuous Ambient Air Quality Monitoring Station. The comparisons of obtained model concentrations and observed monitoring concentrations have been presented in a graphical manner.

Validation

For the validation of software, modelling has been done for Bandra, in Mumbai over an area of 16 km^2 (four grids of 2 km × 2 km) using only one dominant air pollution source (vehicular emissions) for the year 2012. The area selected for validation study is totally urbanised area of Mumbai. As per literature (CPCB, 2010b), vehicular source is the major contributor of NOx and up to some extent for PM_{10}. In this area, open burning is not allowed, and landfill site in not present at least for 12 kms radius. Being an unorganised sector; construction activity and eat outs are not considered in this part. Also, it is a constraint of time and data availability to consider all the sources. Vehicular source can be quantified straightforwardly with higher confidence level. The validation part includes actual measurement of number of vehicles travelling daily, categorising them. Using vehicular emission factors given by Automotive Research Association of India, modelling has been carried out. The modelling results have been compared with the observed data provided by MPCB, monitored by Continuous Ambient Air Quality Monitoring Station. The modelled data shows 90.78% and 84.20% accuracy for PM_{10} and NOx, respectively. Table 2 shows annual average concentrations of model predicted and observed results for PM_{10} and NOx.

Figure 3 Area sources and receptor locations in Mumbai (see online version for colours)

Source: Google Earth (2013)

Table 2 Model predicted and observed results

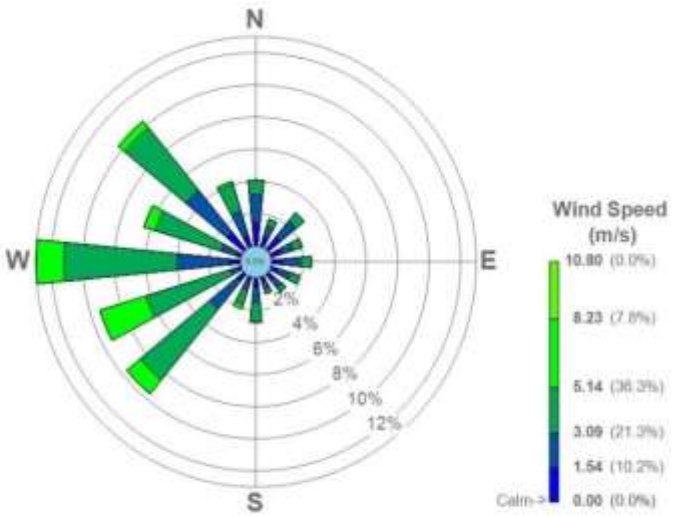
Air pollutant	*Model results (µg/m³)*	*Observed results (µg/m³)*
PM_{10}	114.71	126.35
NOx	42.54	50.52

3 Results and discussions

Meteorological results

Pollutant dispersion is very sensitive to the wind direction relative to the intersections of roads and obstacles (Venegas and Mazzeo, 2012). An output file of AERMET provides boundary layer parameters like mixing heights, friction velocities. Figure 4 represents South-West as prevailing wind direction of Mumbai considering annual average measurements.

Figure 4 Annual Windrose for the year 2012 (see online version for colours)



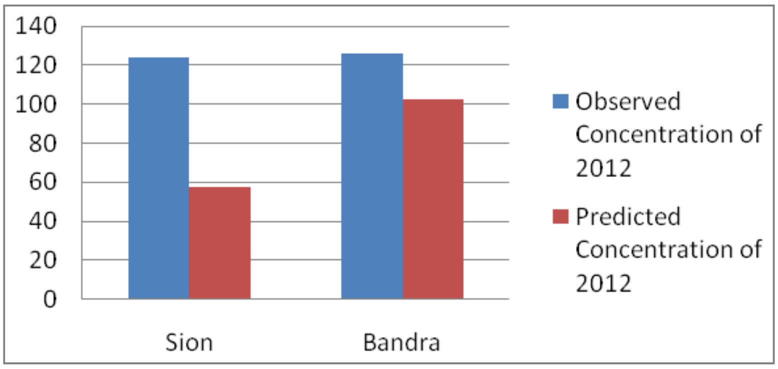
For PM_{10}

Obtained model concentrations of PM_{10} have been compared with observed concentrations of the year 2012 as presented in following figures. Figure 5(a) presents comparison of model results of 2012 and observed results of 2012, considering annual average concentrations of PM_{10}. Figures 5(b) and 5(c) show comparison of observed results of 2012 with model results of 2012, considering monthly average concentrations of PM_{10} for Sion and Bandra. Further to that Figure 5(d) presents comparison of observed results of 2012 with observed results of 2007 considering annual average concentrations of PM_{10}.

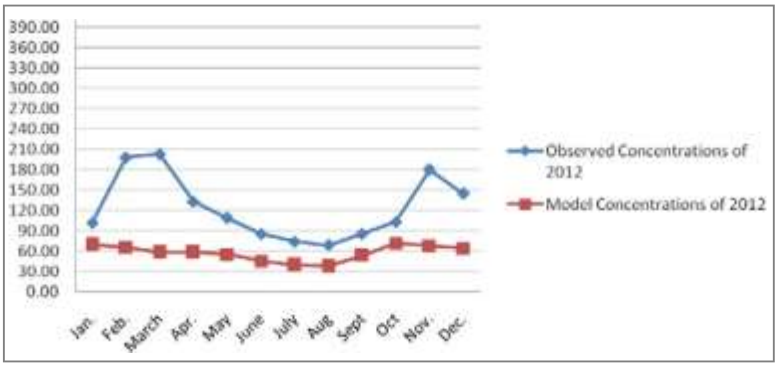
For NOx

Obtained model concentrations of NOx have been compared with different years' observed concentrations as presented in following figures. Figure 6(a) presents comparison of model results of 2012 and observed results of 2012, considering annual average concentrations of NOx. Figures 6(b) and 6(c) show comparison of observed results of 2012 with model results of 2012, considering monthly average concentrations of NOx. Further to that Figure 6(d) presents comparison of observed results of 2012 with observed results of 2007 considering annual average concentrations of NOx.

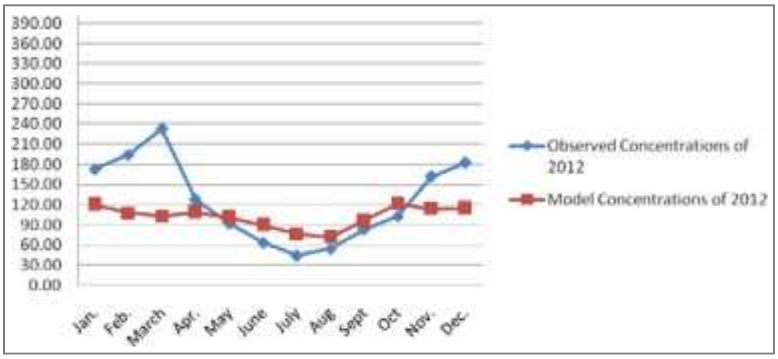
Figure 5 (a) Model results of 2012 Vs Observed results of 2012 (Annual average) (in µg/m^3) (b) Observed results of 2012 vs. model results of 2012 for Sion (Monthly average) (in µg/m^3) (c) Observed results of 2012 vs. model results of 2012 for Bandra (monthlyavg.) (in µg/m^3) (d) Observed results of 2007 vs. observed results of 2012 (annual average) (in µg/m^3) (see online version for colours)



(a)



(b)



(c)

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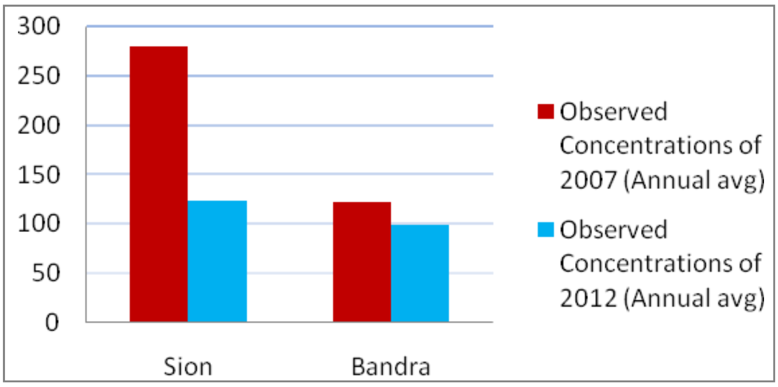


(d)

From Figure 5(a), observations can be made that the observed concentration of PM_{10} for the monitoring locations of Sion and Bandra are more than the predicted concentrations. While in case of oxides of nitrogen, [Figure 6(a)], the scenario is totally opposite making observed concentrations lesser than the predicted concentrations for the same monitoring locations. Figures 5(b), 5(c), 6(b) and 6(c) represent predicted concentrations and observed concentrations for monthly average concentrations of PM_{10} and NOx. The winter season of Indian meteorology gives higher concentrations of PM_{10} and NOx.

Figure 6 (a) Model results of 2012 vs. observed results of 2012 (Annual average) (in µg/m^3) (b) Observed results of 2007 vs. observed results of 2012 for Sion (monthly average) (inµg/m^3) (c) Observed results of 2007 vs. observed results of 2012 for Bandra (monthly avg.) (in µg/m^3) (d) Observed results of 2007 vs. observed results of 2012 (annual average) (in µg/m^3) (see online version for colours)

(a)

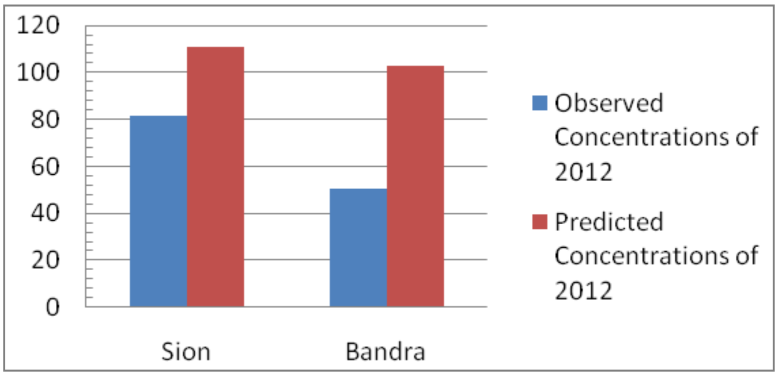
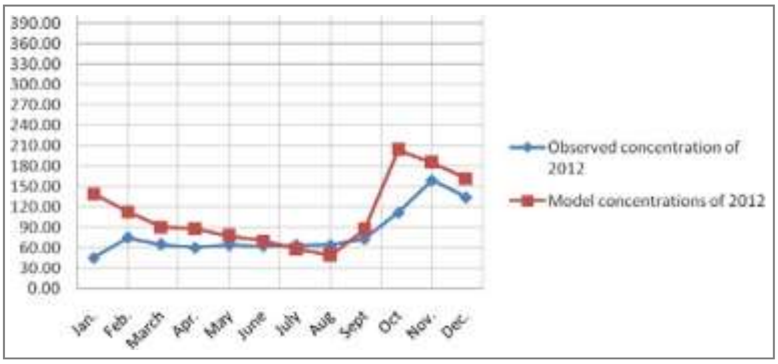
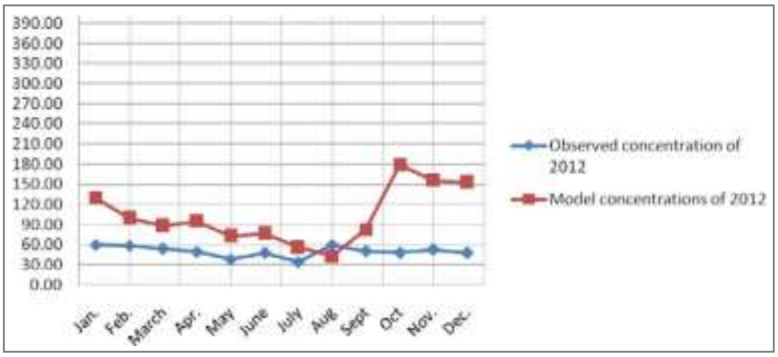


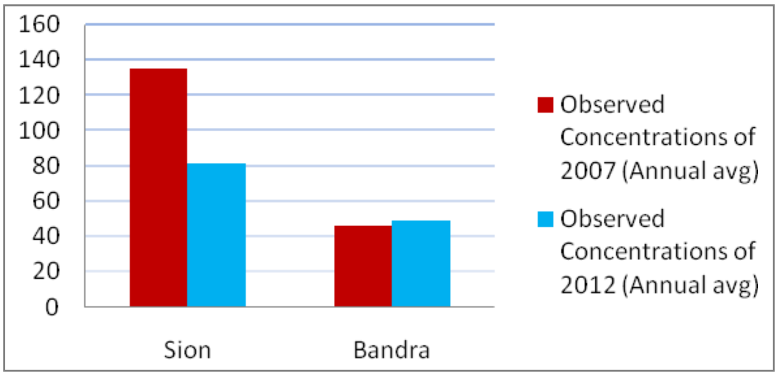
Figure 6 (a) Model results of 2012 vs. observed results of 2012 (Annual average) (in µg/m^3) (b) Observed results of 2007 vs. observed results of 2012 for Sion (monthly average) (inµg/m^3) (c) Observed results of 2007 vs. observed results of 2012 for Bandra (monthly avg.) (in µg/m^3) (d) Observed results of 2007 vs. observed results of 2012 (annual average) (in µg/m^3) (continued) (see online version for colours)



(b)



(c)



(d)

Results illustrate higher variations for PM_{10} at Sion and NOx at Bandra may be because of development pattern for the respective areas and uncertainties involved in projections of the emission loads from 2007 to 2012. Sion is the area in Mumbai where major construction activities are taking place from last few years as visually observed. Also, many slum areas and unpaved roads were observed in Sion making more contribution for PM_{10}. At Bandra number of vehicles is comparatively more because of being a commercial complex (Bandra-Kurla complex for more than 5,000 offices) and presence of two airports within 5 kms of range lead to higher variation in the NOx values.

Statistical analysis

Evaluation of model performance was carried out through the comparison of observed and predicted results of model for both the sites. Statistical analysis was based on; index of agreement (IA), fractional bias (FB), normalised root mean square error (NRMSE), geometric mean bias (MG) and the geometric mean variance (VG) in accordance with the guidelines given by USEPA (2010). An MG value < 1 indicates model over prediction, whereas MG > 1 indicates under prediction (Righi et al., 2009; Namdeo et al., 2012). In ideal conditions (predicted match observed values); FB and NRMSE should be zero and IA, MG and VG should be one. According to the Kumar et al (1993) performance of a model can be deemed acceptable if: NRMSE ≤ 0.5; $-0.5 \leq$ FB ≤ 0.5; $0.75 \leq$ MG ≤ 1.25; and $1 \leq$ VG ≤ 1.25.

Table 3(a) Statistical analyses for observed and predicted results

Site	*Parameter*	*IA*	*FB*	*RMSE*	*NRMSE*	*MG*	*VG*
Sion	PM_{10}	0.50	-0.73	22.46	0.17	2.26	1.94
	NOx	0.76	0.30	12.45	0.11	0.83	1.04
Bandra	PM_{10}	0.58	–0.21	15.95	0.08	1.58	1.23
	NOx	0.11	0.68	19.04	0.75	0.31	3.82

Table indicates that model performed adequate for the NOx at Sion and PM_{10} at Bandra. But it showed poor performance for PM_{10} at Sion and NOx at Bandra according to the criterion given by Kumar et al (1993). This may be because of the area specific uncertainties involved in the projection of emission loads and practical constraint to quantify PM_{10} at Sion and NOx at Bandra from varying and unorganised sector.

Maximum concentrations (1st high) of modelling

The 1st highest concentrations of PM_{10} and NOx obtained during this modelling to know the short term exposure peaks of the pollution, presented in following tables.

Table 3(b) Particulate matter – 10 µm size (PM_{10}) (µg/m^3)

Station	*1-Hr*	*8-Hr*	*24-Hr*	*Month*
Sion	601.992	364.411	220.690	121.722
Bandra	345.014	212.013	129.841	71.926

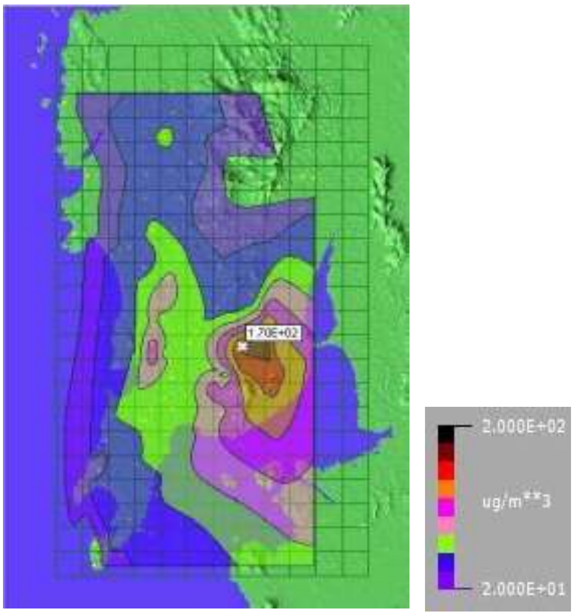
Table 3(c) Oxides of nitrogen (NOx) (µg/m^3)

Station	*1-Hr*	*8-Hr*	*24-Hr*	*Month*
Sion	1220.103	539.899	317.209	178.944
Bandra	1201.467	771.444	363.564	203.880

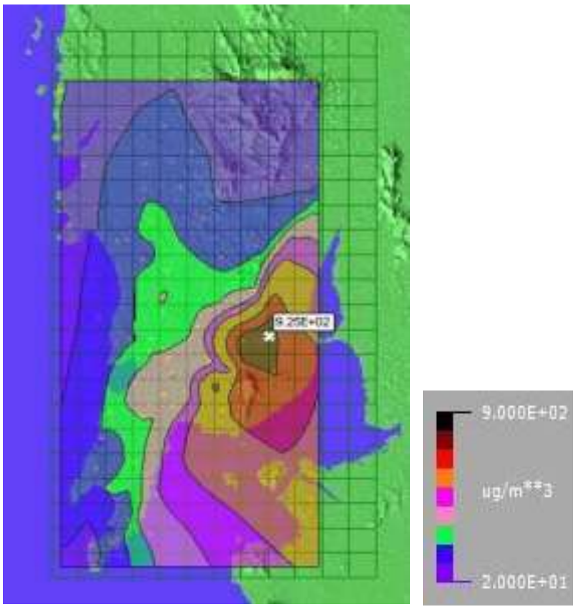
Air quality maps

The air quality maps have been prepared for PM_{10} and NOx using BREEZE 3D Analystsoftware, version 2.4.

Figure 7 (a) Air quality map for PM_{10} with annual average concentrations (b) Air quality map forNOx with annual average concentrations (see online version for colours)



(a)



(b)

Mahul (an industrial area) has been identified as critically polluted area for PM_{10} and NOx annual average oncentrations. Core area of Snajay Gandhi national park situated near Borivali has been identified as least polluted area in the city. The air quality maps shows that many sensitive receptors which consists of foremost hospitals in the city are falling under the area where PM_{10} and NOx concentrations exceeding the National Ambient Air Quality Standards of India.

4 Conclusions

Maximum (1st high) concentrations [Tables 3(b) and 3(c)] suggest that short term exposures are also at alarming levels. It can be concluded that the developmental activities, plans and policies to control air pollution in the city have failed to control increase in the rate of PM_{10} while it brought good results to decrease in NOx concentrations when compared to the emission loads as predicted by CPCB and NEERI report. The developmental activities, increased number of vehicles, projects implemented by the Mumbai Metro Region Development Authority (MMRDA, 2013) and stringent Indian fuel standards (MORTH, 2008) are some of the likely justifications for above observations. MMRDA is implementing projects like Mumbai Urban Infrastructure Project (MUIP), Mumbai Urban Transportation Project (MUTP) (MMRDA, 2013) and Industry location policy. Construction work included in these projects may be responsible for the increase in PM_{10} concentrations. However, these projects (which include construction of roads, flyovers, subways, highways, etc.) with the help of stringent vehicular fuel standards [implementation of Bharat Stage IV in 2010, (MORTH, 2008)] brought good results to control rate of increase in NOx concentrations compared to predicted concentrations. Study emphasises on to conduct monitoring of criterion air pollutants, emission inventory, source apportionment studies and to form a realistic, technically feasible and economical action plan to control air pollution in the city. It is advisable that, the sector wise contribution and uncertainties are the crucial points for a comparative study of an urban area which should be considered before decision making.

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