Air Pollution Dispersion Modeling for Transportation

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Abstract: Transportation sector has become the greatest pollution source in urban area. The objective of this research is to calculate nitrogen oxide (NOx) pollutant concentration emitted due to automobiles. The choice of pollutant is based on the reason that it is primary pollutant emitted from vehicular exhaust. Firstly, transportation survey was conducted to get vehicles activity data such as volume with 6 vehicles classification. Based on transportation survey conducted and emission load calculation, it was observed that the busiest road was Western Express Highway (WEH) and emits highest emission load as 22.172 gm / day. The application of AERMOD for NOx concentration gives an under-predicted value that means about 85 % pollution cause due to automobiles only.

Keywords: AERMOD; Emissions inventory; NOx; Pollutant dispersion; Transportation

1. Introduction

Vehicular exhaust derived pollution can have adverse effects on human health [17]. Such impacts on human health are becoming ever more frequent in developing countries, particularly in China and India, where rapid economic growth, urbanization and improved road infrastructure have led to the severe contamination of air from road vehicles [3]. Mumbai is a prime example of this and is in fact ranked amongst the most highly polluted cities in the world [16]. Over the years Mumbai has seen a gradual shift in passenger and freight movement from rail to road based transport, which has led to a marked increase in fuel consumption by the road sector [11]. Source apportionment revealed that India's transport sector now accounts for up to 90%, 74%, 12% and 22% of CO, NOx, SO_2 and PM_{10} emissions respectively of which road transport dominates with its share [3]. Over the years there have been many different types of dispersion models developed, but despite such development their application in India has been limited. It is therefore the aim of this investigation is to predict present pollutant concentration of NOx, by using AERMOD from a heavily traffic intersection at a busy junction on western express highway in the city of Mumbai (Kherwadi, Bandra).

Vehicular exhausts are obnoxious and occur at ground level. Air quality is direct function of vehicle characteristics and traffic characteristics and any improvement in these two will lead to improve air quality. In Mumbai the PM_{10} levels are consistently high and required to be controlled [5]. Registered motor vehicle population and Percentage growth of vehicles are given in table 1. The emission load due to transportation is given in table 2.

Table 1. Motor vehicles on road on 31st March, 2010 to 2011 in Greater Mumbai

S.N.	Name of Region	Year 2010	Year 2011	% increase or decreases over previous year
1.	Mumbai (C)	593902	601176	1.22
2.	Mumbai (W)	809225	870558	7.58
3.	Mumbai (E)	364671	398577	9.30
	Greater Mumbai	**1767798**	**1870311**	**5.80**
	% Increase or decrease over previous year	5.58	5.80	

[Source: Motor Transport Statistic of Maharashtra 2010-2011]

Table 2. The emission load* due to Transportation in Mumbai city for year 2010-2011

S.N.	Source	SO_2	PM	NOx	CO	HC	Total
A.	Transport (Diesel)	5.96	2.48	34.15	18.12	7.16	67.87
B.	Transport (Petrol)	0.66	0.18	18.20	265.30	39.05	323.39

*MT/ Day (Metric Ton per day); [Source- MCGM (Municipal Corporation of Greater Mumbai)]

The prediction of air quality levels due to road traffic has been found to be difficult, because the emission and dispersion of pollutants depends on many factors like traffic volume, traffic speed and composition of traffic, wind speed, the atmospheric conditions, the acceleration and deceleration of vehicles etc. An attempt is required to be made to model the air pollutants as a function of traffic and roadway parameters so as to get a clearer idea with regards to air pollution caused by road traffic. Thus, it becomes essential to study the effects of vehicles to ambient air quality in Mumbai.

2. Methodology

2.1 Study area

One of the suburban areas of the metropolitan city of Mumbai located geographically on western suburban is Bandra. Its geographical coordinates are 19° 4' 0" North, 72° 50' 0" East. Bandra is a highly coveted location among the suburban Mumbai being a crucial junction for eastern, central and southern part of Mumbai with addition to an important road leading to the domestic and international airports (approximately 4 to 5 Km distance). The average temperature in this region varies from 17° C to 32° C. The average population density in Bandra is 51,275 per square kilometers. Model performance was evaluated through comparison against monitored data for the year 2012. The kherwadi intersection in Mumbai was chosen as the study area for this investigation (Fig. 1). The intersection comprises of 4 links. A 2 x1 km grid comprising the intersection was defined as the simulation domain. Within the domain a pollution monitoring site governed by MPCB is situated 170m from kherwadi junction inside the premises of Government polytechnic. Data from this station was used to evaluate model performance. The four roads of the intersection are numbered as Road 1 to 4, for convenience (Fig.1)

2.1.1 Traffic Characteristics

Kherwadi is one of the busiest intersections in Mumbai. Fig. 2 shows the diurnal variation in traffic at the kherwadi junction. Roads 1 and 2 carry more traffic than Roads 3 and 4. 84% of traffic at the kherwadi intersection occurs between 7 am and 10 pm within which there are two daily peaks. The morning peak occurs between 9 am and 11 am and the afternoon peak between 5 pm and 9 pm. The fleet composition at Kherwadi is dominated by cars (46%). The second largest share is held by three wheelers (16%), two wheelers, taxis, High duty diesel vehicles ,Buses account for a small fraction of the fleet (15%, 14%, 7% and 2%, respectively) as shown is Fig. 3

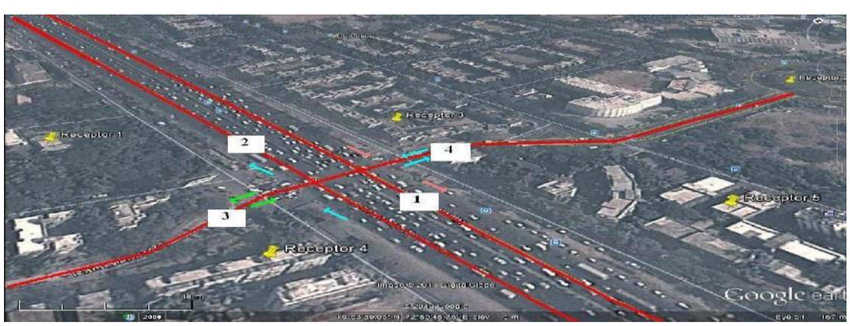

Fig. 1 Schematic of the Kherwadi intersection, Mumbai; 1 = Andheri to Mahim. 2 =Mahim to Andheri, 3 = Ram Mandir Road, 4 = S D Road

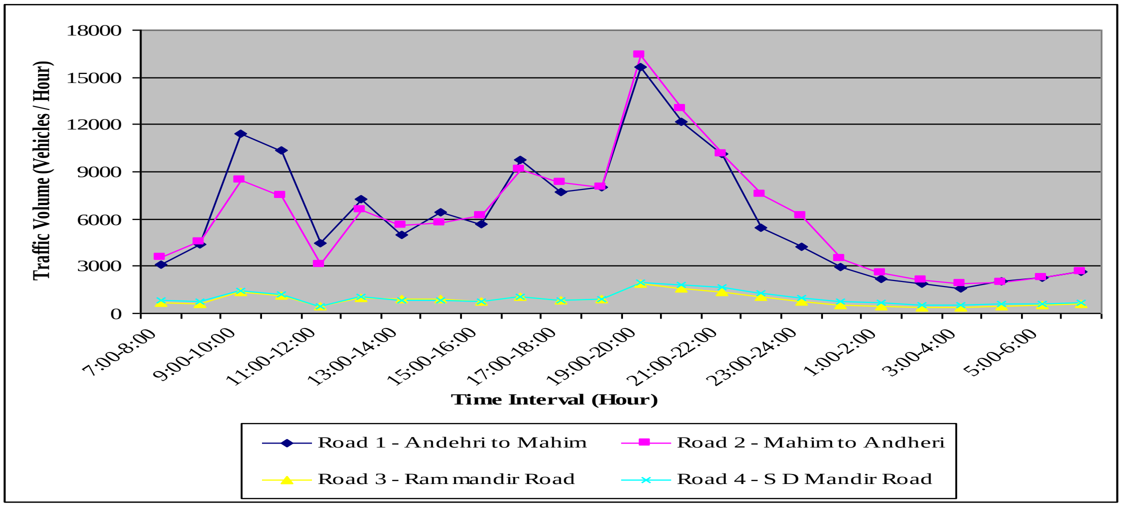

Fig. 2 Diurnal flow pattern of traffic at the Kherwadi junction

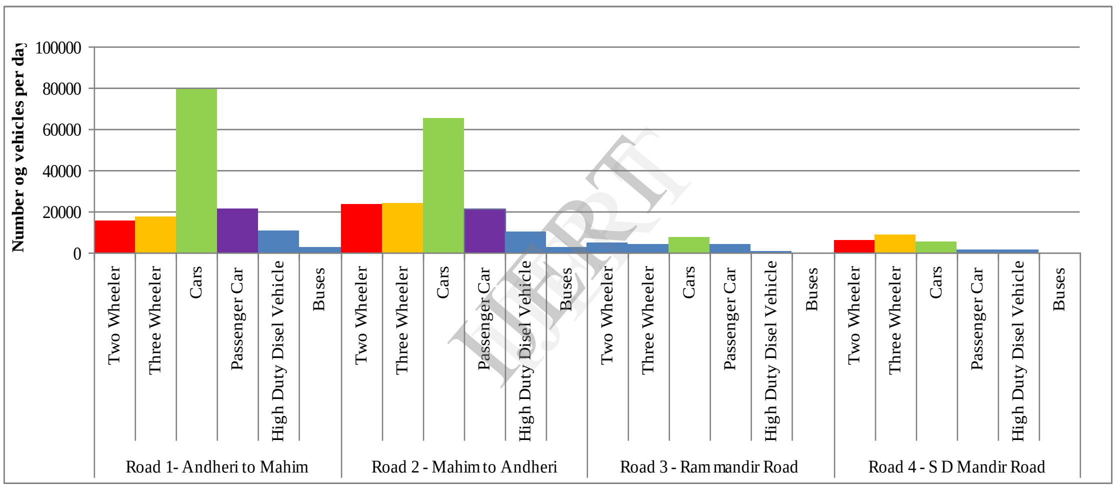

Fig. 3 Vehicle distribution with different categories for four road

2.2 Model configurations and input data

2.2.1 Atmospheric dispersion modeling

The AERMOD is developed from the Industrial Sources Complex Short Term Model (ISCST3) by incorporation more complex algorithms and concepts, i.e., planetary boundary layer (PBL) theory and advanced methods for complex terrains [4]. As with ISCST3, the AERMOD is considered accurate for dispersion modeling at distances not exceeding 50 km from the emission source [4]. The model is composed of three parts: AERMOD Meteorological Preprocessor (AERMET), AERMOD Terrain Preprocessor (AERMAP) and AERMOD Gaussian Plume Model with the PBL modules. The sequences of model operations are shown in Fig. 5. The AERMET processes the hourly surface and upper meteorological data. The dispersion model is the AMS/EPA Regulatory Model (AERMOD), which is a fairly recent and promising model for estimating ambient concentrations of air pollutants [15]

In this study, the AERMOD model is initialized with the View 7.6.0 version (Breeze Environment, 2011). Vehicle sources are considered to predict ambient NOx, PM10 concentrations. Government polytechnic college was considered as receptor.

2.2.2. Emission sources as model inputs

In the modeling exercises, emissions from transportation have been modeled under volume source [15]. The calculation of emission from vehicles is based on the data on emission factor for the specific vehicle type, the distance traveled by a particular vehicle type, number of vehicles and their distribution in the type of the fuel used [13]. The emission factor of different pollutants for each vehicle type have been calculated in earlier studies conducted by organizations such as Central Pollution Control Board [3] and Automotive Research Association of India [2]. Emissions were estimated over a grid network of 2 Km X 1 Km with covering most of the road near receptor.

The emission rate of pollutant j of the vehicle fleet at a road segment can be calculated as follows [13]:

$$Ej = \sum_{i=1}^{n} \mathrm{Eij} = \sum_{i=1}^{n} \mathrm{L.Pi.V.Cij} = \mathrm{LV} \sum_{i=1}^{n} \mathrm{Pi.Cij}$$

Where, L is identified as the length of the road segment. The traffic volume V and the probability distribution fraction Pi. In this research the amount for each vehicle has been carried out, so the probability distribution was not needed anymore. The simple calculation is:

Emission Load (gm / Day) = Vehicle amount (Vehicle / day) * Road Length (Km) * Emission factor (gm / Km / Vehicle)

It has been assumed that there will not be any increase in industrial activities in 2012 and only vehicle source would increase [13]. According to Motor Transport statistic of Maharashtra 2011 amongst the registered vehicles two wheelers were 100 % petrol fuelled, in 3 wheelers 99 % were CNG fuelled and very small percentage petrol fuelled. For cars distribution of petrol, diesel, CNG, LPG was 64%, 29%, 6%, 1% respectively. Similarly for taxis Percentage was 11%, 14%, 2%, 73% respectively. For HDDV all registered vehicles were diesel fuelled and for buses all registered vehicles were CNG fuelled.

Emissions of NOx , from each category vehicle (2wheeler, 3wheeler, cars, taxis, HDDV, buses), in study area have been estimated separately. Further, the total emission in each road has been calculated by adding emissions from each type of Vehicle as shown in Fig.4. Fig.6 shows hourly variation of NOx emission load:

Table 3. Total Emission Load

Road details	NO_X (gm / Day)
Road 1	21.828
Road 2	22.172
Road 3	1.405
Road 4	2.215

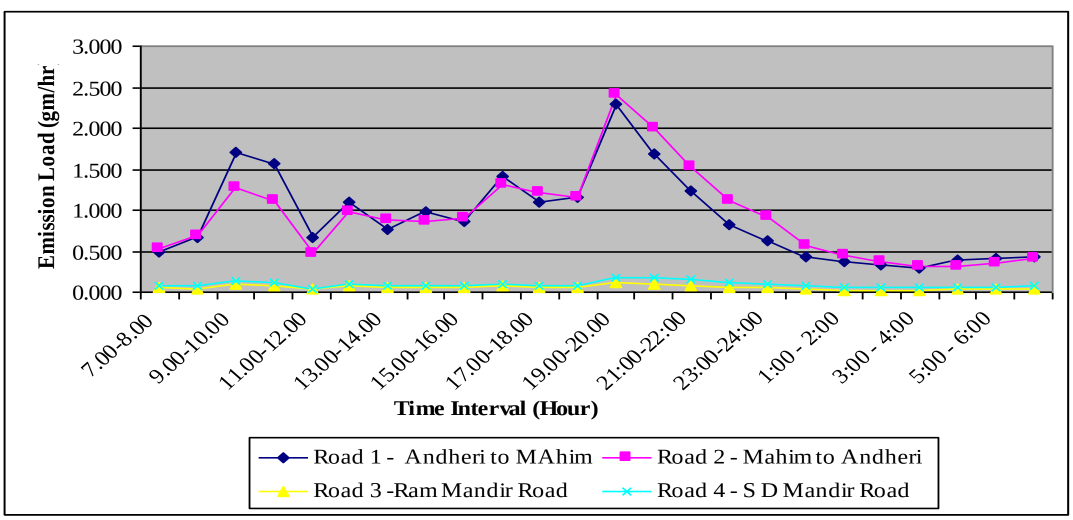

Fig. 4 Hourly Variations In Emission Load For NOx

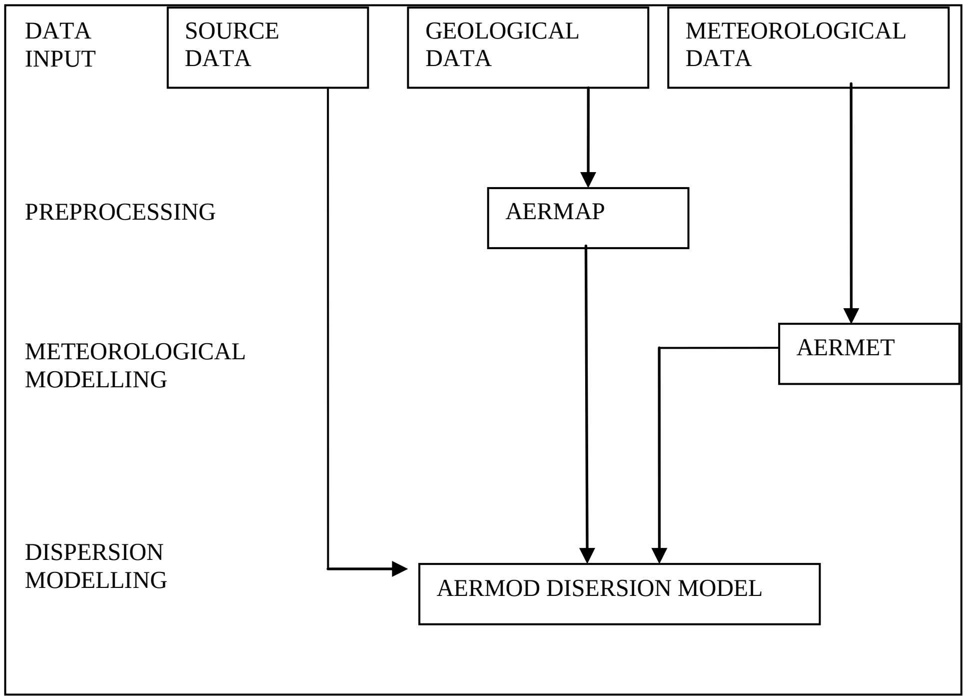

Fig. 5 Data flow in the AERMOD modeling

2.2.3. Meteorological conditions as model inputs

To develop meteorological inputs for AERMOD, AERMET is used to calculate the hourly boundary layer parameters, such as the Monin-Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux, which are necessary meteorological data for running AERMOD. Meteorological data including near-surface measurement and upper-air sounding data are extracting from the Integrated Surface Hourly (ISH) database and the Radiosonde database (RAOB) at the National Climatic Data Center (NCDC) [6] and the National Oceanic and Atmospheric Administration (NOAA) [7], respectively.

2.2.4 Terrain data as model input

A preprocessor program, AERMAP, has been used to process this terrain data in conjunction with a layout of receptors and sources to be used in AERMOD control files. Terrain data is available, in the United States, from the United States Geological Survey (USGS) in the form of computer terrain elevation data files. The data have been standardized to several map scales and data formats. AERMAP produces terrain base elevations for each receptor and source and a hill height scale value for each receptor.

2.2.5 Source and Receptor data

The emission data of volume source has been obtained. Other data like latitude, longitude, hill height scale, X- coordinate, Y-coordinate have been obtained from Google Earth free version provided by U.S.Navy and NASA. The average release height of emissions was assumed as 0.5 meters. Initial lateral dimension have been calculate as 0.93 and 0.46 meters [15].

2.2.6 Observed Monitoring Data

Observed monitoring data has been obtained from the website of Maharashtra Pollution Control Board. MPCB presents this data on public domain website for the purpose of information about air quality. For this study Bandra stations has been selected for comparison.

3. Result and Discussion

AERMOD model has been used to predict the concentration of NOx due to emissions of all types of vehicles from 1 January 2012 to 31 December 2012. The monthly and annual averaged concentrations of air pollutants have been obtained from this model. Validation of models was done by observed data from MPCB for NOx at monitoring station.

3.1 Metrological database

Meteorology (weather and climate) is the key for understanding air quality. The essential relationship between meteorology and atmospheric dispersion mainly involves the wind in the broadest sense. Wind fluctuations over a very wide range of time accomplish the dispersion pattern and strongly influences various other associated processes. Therefore, through studies of these parameters are required for dispersion study. An attempt has been made to assess the wind direction pattern for the Mumbai with using meteorological data collected from NCDC. For this wind rose was plotted for year 2012. Fig. 6 shows annual wind rose diagram as its shows that wind predominately blows from western direction.

3.2 Comparison of observed and predicted concentrations of NOx

Predicted and observed concentration of NOx for monthly average and annual are shown in Fig. 7 and Fig. 8 respectively.

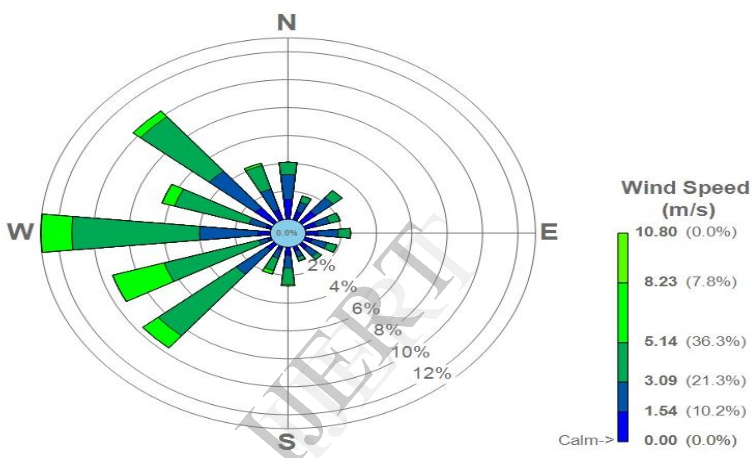

Fig. 6 Yearly Wind Rose Diagram for year 2012

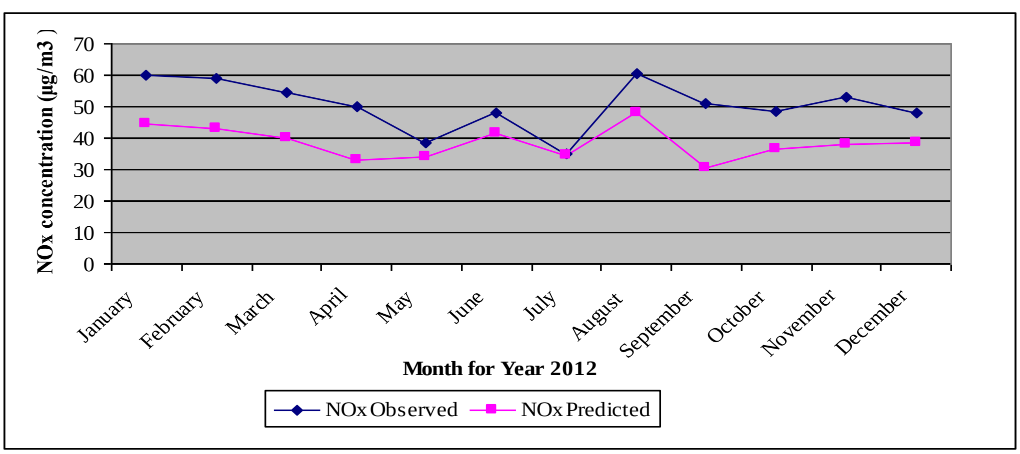

Fig. 7 Comparison of measured and predicted monthly average NOx concentration for year (2012)

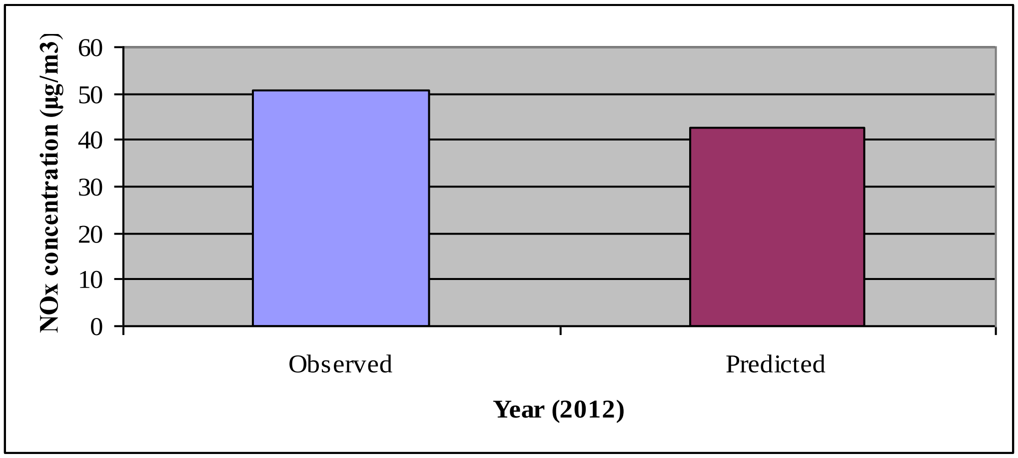

Fig.8 Comparison of measured and predicted annual average NOx concentration for year (2012)

It is observed that in August month, the observed concentration and model predicted concentration of NOx pollutant is maximum i.e. 60.35 $\mu g/m^3$ and 47.84 $\mu g/m^3$ respectively. In January month observed and predicted concentration of NOx is 60.17$\mu g/m^3$ and 44.26$\mu g/m^3$ respectively. From March to May concentration of NOx is decreases from 59$\mu g/m^3$ to 39$\mu g/m^3$. But in June month concentration of NOx pollutant suddenly increases to 48.24$\mu g/m^3$ and predicted concentration is 41.41$\mu g/m^3$. In July, September, October, November, December observed concentrations are 34.97$\mu g/m^3$, 50.76$\mu g/m^3$, 48.45$\mu g/m^3$, 52.93$\mu g/m^3$ and 48.23$\mu g/m^3$ respectively. In July, September, October, November, December model predicted concentrations are 34.27$\mu g/m^3$, 30.56$\mu g/m^3$, 36.47$\mu g/m^3$, 37.81$\mu g/m^3$ and 38.37$\mu g/m^3$ respectively. It is observed that in July month observed and predicted concentration is approximately same.

Figure 8 shows annual average observed and model predicted concentration of NOx. It indicates that observed NOx concentration is 50.52$\mu g/m^3$ and model predicted concentration is 42.54$\mu g/m^3$.

3.4 Discussion

From above results it seems that AERMOD's gives underpredicted values for NOx. The discrepancies in observed and predicted values by AERMOD could be attributed to the uncertainty of emissions from non-road source releases, model sensitivity to wind conditions and link emissions and meteorological input data. These factors are discussed below.

The emissions factors used to calculate total link emissions were constructed by the Automotive Research Association of India [2] and were developed from laboratory dynamometer tests under Indian drive cycle urban conditions. These emissions factors do not take into account real world vehicle speed, evaporative emissions, cold start emissions (possibly not an issue in India due to high ambient temperatures) the influence of brake and tyre ware, vehicle maintenance and the use of auxiliaries (air conditioning, radio etc.). In addition it is highly likely that the Indian driving cycles used to construct the factors were not representative of the heavy congestion that is evident at the Kherwadi junction. The accuracy of model predictions is reliant on input data that is representative of the domain. Model outputs indicate that the best available emissions factors used here are not representative and may have significantly influenced model performance

The uncertainty of emissions sources other than those from vehicle exhausts appears to have been a significant cause of error in predicting pollutant concentrations. The model underpredictions observed values indicate the influence of non-road source releases. The Kherwadi intersection is situated close to the heart of the city and a heavy layer of road dust is evident at the site.

4. Conclusion

On the basis of above results and discussion one can conclude that emission inventory of each type of source is essential for assessing the impact of these sources in Bandra, Mumbai. NOx emission due to vehicles is high 47.62 gm

/day. The observed concentration is more than predicted concentration of NOx i.e.85 % of the pollution cause due to automobiles.

Finally, it seems that levels of NOx due to vehicles are more than the limits of National Ambient Air Quality Standard. It is also justifiable that emission of air pollutants may exceed more with the increase in the number of vehicles. As the emission of air pollutants are directly proportional to the number of vehicles and the concentration of ambient air pollutants is also directly proportional to the emission of air polluting sources. It can also be concluded that a control on emissions of pollutant from vehicular traffic necessitates the control on the new registration of vehicles in Mumbai.

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