



# Comparative emission study by real-time congestion monitoring for stable pollution policy on temporal and meso-spatial regions in Delhi

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## ARTICLE INFO

### Article history:

Received 14 August 2017

Received in revised form

20 November 2018

Accepted 11 March 2019

Available online 25 March 2019

### Keywords:

Air pollution

Pollution checking policy

Spatial and temporal control action

Air quality standard

Vehicular emission

Traffic congestion

## ABSTRACT

Rapid industrialization, urbanization, and motorization lead to hiking of air pollution in various mega cities including Delhi, India. Studies done to analyze pollution suggests that vehicle exhaust emissions are major contributor to the urban air quality along with many other comparable sources. Hence to check instantaneous pollution increment, government aims to reduce vehicle emission. Traditional policies are working at times for holding sudden increase but long-term effects are not seen which need meso-spatial and small temporal policy. For optimizing meso-spatial policies implementation, many intricacies related to moving and stationary sources in near real-time have to be monitored including vehicular emission, itself. Analyzing these moving source emissions on the meso-spatial level is challenging. Therefore, the present study is an attempt to first understand the need of meso-spatial and near real-time checking policy and then leveraging the usage of previous region specific pollutant survey reports to map real-time pollution monitoring parameters. For that, a real-time vehicle monitoring strategy is proposed to map city-wide traffic congestion and emission using crowd-source data of Google Maps. For comparative study of different meso-spatial regions real-time moving source pollutant parameter ' $\mu$ ' is calculated using a factor 'F'. Also, the different effects of congestion on vehicular emission in two different meso-spatial areas of Delhi is presented using comparative case study. Analysis of case study revealed that Anand Vihar area is more prone to vehicle emission variability in case of congestion fluctuation. Further the discussion of short temporal and spatial emission calculation, for weekly pollution evaluation is presented in the paper. This will be helpful to the authorities in formulating technological, institutional and traffic management policies.

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## 1. Introduction

Ambient urban air pollution results from emissions of diverse pollutants originating from different stationary and mobile sources used for both, indoor and outdoor activities. The activities of combustion, construction, mining, agriculture, cooking, smoking, industrial emission, vehicles and the power plants are increasing air pollution. Other less common natural pollutant sources include wildfires, dust storms, and volcanic eruptions. Air pollution consists a complex mixture of chemical compounds in the form of solid

particles, liquid droplets, and gases (Singh et al., 2014). Some of these pollutants are short-lived in the atmosphere (hours to days), while others are long-lived (years). The dispersion and the generation of ambient pollutants are highly affected by local (meso-) meteorological conditions (wind speed, solar radiation, humidity, temperature). Air pollution, not only causes natural resource imbalance, but also results health hazards and millions of deaths per annum. Total pollution mortality counts for India is 1.2 million, this is the highest in the world (Myllyvirta et al., 2016).

In India, for the past two decades, Delhi has witnessed aggravation of air pollutant due to urbanization. After independence in 1947, the city became a major center of commerce, industry, and education. Flouting the land use regulations by dwindling green cover helped catalyzing the problem. City's environment deteriorate because of air pollutants from the burning of fuels, industrial

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factories, construction sites, power plant and vehicular movement. The major sources of air pollutants are vehicular traffic, domestic, industries and thermal power plants. Among them road vehicles are one of the major sources of outdoor air pollution in cities, which produce poisonous gases like CO, NO<sub>x</sub>, and PM (Gurjar et al., 2010; Kumar et al., 2013). In winter, pollution hikes the most, due to typical winter meteorological conditions: cold temperature; lower mixing height of air; calm and no-wind condition. Hence, winter months require major actions to reduce pollution.

Another major cause of instantaneous air pollution is stubble burning of agriculture biomass residue in the neighboring states. It usually happens in the winter season. Recently proposed model to monitor the contribution of burning using a combination of observed and modeled variables of PM<sub>2.5</sub> point to 7%–78% contribution, depending on emission inventory and year (Cusworth et al., 2018). Apart from that crackers pollution due to Diwali festival (generally celebrated in winter season) add on to the pollution. This led to a situation, wherein winter months of November and December 2015 had the maximum number of days falling under severe category of air pollution. With the pollutant rising more than four times the safe standard values, November 2015 had 73% of days in the severe category against 53% in November 2014. Also, December 2015 had 67% of days in the severe category as against 65% in December 2014. In the year 2016, not even a single day could achieve the satisfactory pollutant levels. In the same year 2016 around 1 to 15 November, smog-choked the capital which resulted into decrease in visibility by less than 50 m. As emergency measure the government took an immediate step, by suspending several schools and outdoor activities. This event occurred despite taking some initial measures in early 2016, where Delhi government used odd-even vehicle banning policy.

In practice, these policies are designed to bring change at macro levels (Keeso, 2014). However, the ambient air pollution is resultant of emissions with diverse form of pollutants originating from different stationary and mobile sources. Therefore, the urban air quality is characterized by high spatial and temporal variability due to local (meso-) meteorological conditions like wind speed, solar radiation, humidity, temperature (Levy et al., 2014 a; b). The particle concentrations can quickly change, with steep gradients on short temporal and spatial scales. Also, their chemical composition and physical properties vary considerably. So, to control pollution on the long-term basis it has to be dealt by considering temporal and spatial analysis. This fact is also pointed by Lax equivalence theorem, (“Lax equivalence theorem”, 2018) which states that stability is a necessary and sufficient condition for convergence of a consistent linear finite difference model. In other words, if we take the case of linear finite difference model, it is enough to know that if for a model, a method adopted is stable then this method will sufficiently and necessarily converge the system over a period of time and spatial discretization. Hence, given the method or policy is stable and try to mitigate pollution, if the time step and spatial step of it's implementation is reduced, then it will work to converge pollution, holistically across the system.

To make the checking policy, segregated and consolidated data of air quality monitoring is crucial (Christa et al., 2016). Accurate data helps in taking sustainable measures using the predictive values from the historical data. Using the data, intelligent algorithms, models and monitoring systems identify unique patterns in environmental dynamics and provide accurate forecasting and predictions. It is possible to carry out climate-change analysis using big data which complements environmental impact assessment. For capturing tempo-spatial heterogeneity and identifying pollution hotspots, the metropolitan cities are now equipped with many data grabbing centers. These centers provide near real-time pollutant status. Also, many models have been developed to map

and quantify different pollutant sources. In spite of many such centers in Delhi, the government is struggling to deploy robust real-time strategies on spatial and temporal scales for preventing long pollution exposures. For forming checking policies at spatial and temporal scales near real-time survey and analysis of pollution data as well as information related to source location, speed, area-of-effect etc., is needed. For moving source, mainly vehicles and their related emissions, parameters like congestion, traffic speed, and location are highly erratic. Hence, the database has to be maintained for meso-spatial and temporal period so as to target the key essence that has been missing so far in creating collective knowledge from pollution as well as traffic-condition database which then can be used to promote and trigger a positive change and policies within the spatial regions.

To map moving source parameters, in present paper, authors put forth a monitoring system methodology in form of processed relevant near real-time congestion data and try to establish its significance with emission from another source on a meso-level. A factor ‘F’ is introduced to correct vehicular emission in the meso-spatial region and its usage to calculate a pollutant parameter. Also in spite of traditional methods of congestion and average vehicle speed sensing using hardware, authors have used minimal infrastructure cost methodology with an assurance of better results for the city-wide area. As a step further it is suggested, how to analyze environmental conditions on meso-level using a mix of live-predictive (live traffic information data) and historical data (predictive data of government's reports). Using the information of adopted monitoring system, authors commented on reforms in adaptive checking policy and structural needs that may lead to meso-level pollution control by managing transportation and other causes to prevent air pollution in long run.

Rest of the paper is outlined as follows. Section 2 reports on the need of near real-time pollutant source monitoring. Section 3 discusses congestion impact on pollution and the congestion monitoring system. Section 4 discusses near real-time pollutant availability along with different emission estimation in Delhi. Section 5 describes the system methodology and proposes an architecture for congestion monitoring. Section 6 provide details about the usability of the proposed methodology and define some congestion specific pollution parameters. Further, it also presents analysis and case study. Finally, section 7 reports the conclusions.

## 2. Need of near real-time pollutant source monitoring for stable checking policy

In Delhi, power plant; vehicles; wood fires and industries are the fundamental generator of pollutant particles along with the dust from construction sites, brick kilns. Area, line and point are three categories of sources. These can also be categorized as stationary and moving source. Household cooking, bakeries, restaurants, major construction sites, road dust, and crematoria are area sources. The vehicular commute falls under line source, whereas point sources are industries and power plants. The ballpark result of pollutant criteria, from these sources, calculated out to be NO<sub>x</sub> – 311918 kg/day, SO<sub>2</sub>– 141621 kg/day, CO – 386678 kg/day, PM<sub>2.5</sub>–58733 kg/day and PM<sub>10</sub>–143392 kg/day in Delhi from November 2013–June 2014. More specific spatial distribution map of Delhi is also provided for each pollutant emission to get spatial emission understanding (“Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi”, 2016, pp. 180–191). The main sources of NO<sub>x</sub> are vehicles and domestic emissions. Also, traffic congestion adds to PM<sub>10</sub> and PM<sub>2.5</sub> due to road dust. The data presented for 2013–2014 shows comparatively lesser emission inclination trend in comparison to data available for 2010 (Guttikunda et al., 2013). This can be accounted by application of CNG as a fuel in vehicles. It can also be

seen that the increasing CO content in the Delhi atmosphere is the result of ever-increasing vehicles in the city.

The cargo transfer is done via heavy and light commercial vehicles that work on diesel and petrol. Although these freight vehicles are replaced with the CNG operated vehicle but are still causing the rise of pollution. Hence, focusing only on PM emissions and leaving aside SO<sub>2</sub> and NO<sub>x</sub>, does not give an accurate picture of the sources of pollution. As reported, industrial sources are responsible for nearly 90% of SO<sub>2</sub>, 52% of NO<sub>x</sub> and 11% of PM<sub>2.5</sub> emissions load in Delhi. Most of these pollutants are emitted from the power plants and the sulfate and nitrate particles formed from SO<sub>2</sub> and NO<sub>x</sub> pollution, respectively, are key contributors to the total PM<sub>2.5</sub> pollution. The weight-mapping of these emissions caused by point, line and area source is done by calculating it for particular spatial region of the city. These weights are affected by many factors for e.g. - distance from the point source or the construction sites. Delhi government takes the pain to screen the city on spatial and annual or biennial basis, whenever possible, either by themselves or by commissioning different organization (Central Pollution Control Board (CPCB), 2010; “Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi”, 2016). These reports serve to estimate the possible linkage between area specific emissions and chemicals/parameters involved like PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub> etc. Also, these reports tries to build up the pollutant-source emission relation involving factor like spatial variation of sources.

Further, these reports assist government to frame checking policy and initiate road construction and traffic law enforcement (Belzowski, 2007). The policies adopted are generally holistic in implementation. However, a more condition adaptive view must have to be kept in mind before policy-making for traditional as well as instantaneous pollution hike. For policies framing and implementation, there are various groups with different responsibilities and guidelines. These groups are Policy Planning Group (PPG), Public Transport Group (PTG), Traffic Management Group (TMG), Infrastructure & Development Group (IDG) and Environment Group (EG) (“Delhi Urban Environment and Infrastructure Improvement Project”, 2001). Various policies are analyzed and framed by governmental research group (Brief, 2018). Short, medium and long-term actions are taken into consideration, comprehensive plans and orders for policy implementation were sent to neighboring state governments for review and adoption after scrutinized by Supreme Court (“DRAFT Comprehensive Action Plan for Air Pollution Control”, 2017).

As part of short action checking policy to stop instantaneous hike and critical conditions, in Delhi, in winter of 2015, first odd-even phase was implemented and following which the second phase was implemented in April. After the odd-even program was completed various research groups provided reports presenting the outcome, tabulated in Table 1. Some reports stated the success, some stated that the effect of the policy can't be judged by restricted data set while others implied that the odd-even scheme failed in most of its objectives. However, all reports point that the policy led to increase of average speed and minimize congestion. A study using aerosol optical depth in Delhi (CSE, 2016) throw light

on the point that AOD parameter was improved in Delhi after the implementation of the odd-even scheme but on the contrary in areas bordering the capital the aerosol effect was worsened by showing an increase of 35%. Also, banning vehicles (odd-even) over full Delhi region for 15 days causes significant inconvenience to the citizen. These studies expose a need of stable pollution checking policies to manage and suppress instantaneous pollution hike for making environment system robust. According to Lax-equivalence theorem, which pivot it to the idea that if the method (pollution policy) make system (region) stable on small tempo-spatial basis then pollution will converge for full system in long run. Hence, real-time congestion data analysis and their co-relation to pollution parameter is needed for framing policy, such that it is tempo-spatial stable and doesn't causes major discomfort to road users.

However, the complex mess between category/source causing the pollutant, and the pollutants itself, make it hard to understand the woven relation that changes in real time. Therefore, temporal and local area study denotes a deeper approach for analysis of pollutants as it improves the picture for near real-time. In a region, the pollution is due to its own generated pollutants by different stationary and moving sources and the transported pollutants. Knowledge of predicted emission by stationary sources along with the varying vehicle moving sources provides a better and more scientific approach towards monitoring. For analysis of the varying vehicle moving sources and their related pollution emission, street level congestion of different regions can be of much use. That can be employed by traditional models to predict more realistic near real-time source specific emission. Also, limited research is available that intends to use near real-time speed or congestion data that assist to frame strategic solutions.

### 3. Congestion impact on pollution and live traffic monitoring system discussion

National Capital Territory (NCT), Delhi, being big urban conglomeration with total area of 1483 km<sup>2</sup>. Out of which urban segment was 685 km<sup>2</sup> (46.2%) in 1991. From 1991, the population growth of Delhi led to 9.42 million population in 1991 to 28 million in 2017. Increased population caused exponential growth of road traffic, from 0.841 million vehicles in 1985 to 10.756 million vehicles in 2018. This traffic increment was far more than sustained by roads which were incrementing at 4.53% per year in Delhi. Report cited that road density in Delhi is around 155 km per 100,000 population and about 80 vehicles per km. At intersections, the cycle time ranges from 120 to 180 s. This leads to long queues, especially in the peak hours. Mix traffic with personal vehicles, buses, trucks, three-wheelers, two-wheelers, including animal-driven carts and pedestrians, keep growing as diverse economic groups and workforce population rises. Ongoing construction of metro network in various locations, damaged roads, repairing roads all contribute to severe traffic congestion in the city (Phukan, “Traffic Congestion in Delhi: Causes, Outcomes and Solutions”). Congestion lead to idling of vehicles due to long jams, less traffic flow speed, long waiting time at traffic lights and sporadic flow. All this led to more fuel

**Table 1**  
Odd-Even Policy (in terms of pollution reduction).

	Effective	Can't say about policy effectiveness	Not-Effective
Phase 1	CSE (2016) Greenstone et al. (2017)	Urban emission (2016) (CPCB, 01 to 15 Jan, 2016) Goel et al. (2016)	Mohan et al. (2017)
Phase 2		(CPCB, 15th to 30th April, 2016) Sharma et al. (2016)	Mohan et al. (2017) Greenstone et al. (2017) Kreindler (2016)

wastage as vehicle engine consume more fuel while driving in sporadic slow traffic. 24% of idling is reported in Delhi which leads to additional emission and hence additional air pollution levels on road (Goel et al., 2015b).

Many researchers and government agencies are working on the problem. Past studies try to point out the quantitative assessment of the pollutant emitted in Delhi urban area (Mishra and Goyal, 2015). However, some of the literature tries to describe the pollutant emission on basis of income groups of residing population in different areas of city (Singh et al., 2014). Studies are also aimed to find out relation between air pollution and traffic (Galatioto et al., 2014). The on-road driving speed has a significant effect on emission factors for estimating moving and idling emissions. Many studies have demonstrated a non-linear relationship of vehicular speed with emission factors (Goel et al., 2015b). Analytical studies are also conducted in Delhi, which establish a correlation for estimating possible average emission rates with changing driving cycle and speed patterns for 3Ws (3-wheelers) (Grieshop et al., 2012). The sociological behavior of populace also plays vital role in available road usage which can contribute to congestion. Monitoring system in form of geographical information system are used to map emissions for assessment of air pollution epidemiology and air quality policy framing. Realistic, locational and dynamic modelling needs data as well as source emission model to map parameters for a given site (Briggs, 2005).

Emission from more predictable stationary source can be estimated using models and then displayed on GIS. However, for moving sources parameters related to both their position and movement, independently as well as fleet movement in context of the system are needed. Hence, the emission from vehicles and the related dust emission generated by them need vehicle movement detail in near real-time. Previously, monitoring model was used for vehicular emission (NO<sub>2</sub>) using regression-based complex model by sampling data from 80 passive sites on the basis of weighted-traffic-volume-factor for high-density housing and industrial land (Briggs et al., 2000). Due to dynamic nature, accurate high resolution GIS are needed for traffic emission study and control. These GIS system that plots real-time absolute emission estimate needs additional information on speed profiles (Gühnemann et al., 2004). Therefore, floating car data using GPS and other sources like vehicle loop detector and sensor node communication infrastructure are discussed in literature. Usage of MMP (mobile monitoring platform using zero emission vehicle) and video processing is also used for vehicular emission mapping (Fruin et al., 2008). Speed profiling along with other needed parameter are infrastructure-intensive and complex.

In lieu of infrastructure with cost scalability limitation, there are many infrastructure free vehicular networks. However, for practical city-wide survey huge processor resources for data mining and very good user accessibility is needed. This is done by many services like Google and Bing. After processing various mixed algorithms the results are presented using API (Application program interface). Live traffic status is provided by Google in form of an average time to travel, in accordance with congestion between origin and destination, or it might be color tracks in their map services. The estimation for the time of arrival (ETA) or time of travel for a matrix of origin and destination is reported by Google, Distance Matrix API. This API is also used by a report to predict ETA in the different part of Delhi during odd-even vehicle banning time period (Goel et al., 2016). Authors have used this API to map congestion adaptive traffic light cycle time for road intersections in Delhi (Mishra et al., 2018) and (Mishra et al., 2018a). However, for modelling, a wider picture of traffic across city is needed, so this API is of little use for that purpose.

Another Google maps API is JavaScript API. It has vast variety of API functionality for map editing. Traffic Layer API (“Google”, 2018)

functionality of this API gives the option to get the live traffic in four colors. The red color on track means highway traffic is moving at less than 25 miles per hour and could indicate an accident or congestion on the route. Orange lines on the map mean traffic is moving faster, from 25 to 50 miles per hour, while green lines mean traffic is flowing freely along at 50 miles per hour or more. Gray lines mean there's no traffic information available at the time and a dark brown (red-black) line refers to extremely slow or stopped traffic. But this color-speed mapping is a relative value and can be different for different roads with different design-speed. If traffic on city streets is considered then the speed limits are much lower than on highways. Therefore the colors take on more of a relative meaning, although red or dark brown (red-black) lines mean a lot of slow going and general congestion. Orange is a little better but still not the best for city travel, and green means traffic condition is good. Therefore, color mapping is totally a relativistic representation. Google map presents the congestion in color form with the zoom provided. The zoom level fed into the API manages to show the highway or the highway plus the joint street roads, with respect to low or high zoom value respectively.

#### 4. Near real-time pollutant data availability and source specific emission

Almost every type of pollutant's source is available in Delhi. These sources emit different chemicals of which National Ambient Air Quality Standard (NAAQS) has categorized the air pollutants into 12 parameters out of which principal pollutants are PM, CO, NO<sub>x</sub>, Lead, Ozone and Sulphur Dioxide. Data analysis is done using various models and the results are disseminate for public awareness via different platform. There are various government bodies Public Sector Units (PSU), NGOs, SMEs that collect the data by using various independent hardware resources. Data on near real-time basis is provided in form of reports after scrutiny. Through strategic installation of networked instrument, across the city develop a dense data-grid of networked centers. This helps in understanding the phenomena of pollution and climate change at macro level (Kumar et al., 2015). The methodology and models for parameter calculation used by these organizations are also different from each other. Some of them try to publish the past as well as real-time data by performing real-time measurements, while other use predictive models loaded with meteorological data for forecasting the predicted values.

There are several agencies that collect and display information in raw format. Delhi Pollution Control Committee (DPCC - equivalent to a state pollution control board) operates 6 continuous monitoring stations. The data from the stations are available online (Real time ambient air quality data, DPCC). Central Pollution Control Board (CPCB - part of the ministry of environment, forest, and climate change, Government of India) operates approximately 560 manual and 60 continuous monitoring stations across Indian cities. Out of which 10 are in Delhi (CPCB-Central Pollution Control Board). Indian Institute of Tropical Meteorology (IITM - an autonomous body under the ministry of earth sciences, Government of India) operates up-to 10 continuous monitoring stations and report ‘PM’ pollution data and AQI in real time, through their web portal and mobile apps in Delhi and other Indian cities (“SAFAR - India”, 2018). The USA embassy operates one ‘PM2.5’ monitoring station and the data archives are accessible as a simple excel file for anybody to download and use (U.S. Mission India, “Air Quality Data Information”, 2018). Various other groups, independent institutions and non-government organizations like, India Open Data Association (IODA) (“India Open Data Association”, 2018) and ‘The India Spend’ operating many low-cost particulate matter sensors and reporting the data as AQI in real time. Although the archive

data from DPCC, CPCB, and IITM are hard to access either due to data removed after some time or due to unavailability. However, there are online portals such as AQICN and Plume Labs which are accessing the data from DPCC, CPCB's real-time data portal website in real-time and converting it into an Air Quality Index (AQI). Along with posting them on their web portals and mobile apps as they tend to store the raw data in their archive to make them available for later use ("OpenAQ", 2018).

#### 4.1. Different emission estimation models in Delhi

In the backend of the monitoring system traditional emission estimation models are used. Emission models map different emissions to different originating source and give a source specific emission value. After source specific estimation, raw pollutant data is analyzed by monitoring system to get spatial source specific emission inventory. Further, these models have various location specific parameter input to quantify pollutant on spatial level. The location specific holistic view of moving and stationary source are very crucial to calibrate these models. Hence source specific models and in context discussion for Delhi are enlisted.

##### 4.1.1. Industrial emissions

According to economic survey of Delhi (2017–2018) there are 8,75,000 industries. Major fraction of these industries is contributing to deteriorating air quality of the city.

$$E_{i,j} = \sum (C_{i,j} \times EF_{i,j}) \quad (1)$$

The expression mentioned in Eq. (1) is used to estimate the emissions given by (Mohan et al., 2012) in which, 'j' represents the year and 'i' is the type of fuel used (such as High-Speed Diesel, Light Diesel Oil, Compressed Natural Gas and Furnace oil).  $C_{i,j}$  represents fuel per year (gm/year),  $E_{i,j}$  represents industrial emission rate (gm/year) and  $EF_{i,j}$  is used as emission factors for the fuel used. Reports of (GNCTD - Government of NCT of Delhi, 2010) and (DPCC, 2002) provides the fuel consumption data whereas emission factors can be obtained from (Central Pollution Control Board (CPCB), 2010).

##### 4.1.2. Household emissions

Census of India (2011) shows a population hike of 1.4 crores to 1.7 crores from the year 2001–2011. This population consisted of different income groups which are likely to use different kind of fuels to complete their basic needs and wants. The fuel used are coal, crop waste, dung cake, kerosene and firewood for the low economic domestic household region and firewood, kerosene and liquefied petroleum gas for bakeries and restaurants. The coal used in the furnaces, including the smoke and ash-emitting tandoors, are also a major cause of pollution. There are approximately nine thousand hotels/restaurants in the city of Delhi, which use coal (mostly in tandoors). The Particulate Matter (PM) emission in the form of fly ash from this source is large and contributes to air pollution. The crop waste and dung cake are used as fuel in poor households kerosene and firewood are used as secondary fuels whereas LPG is the primarily consumed fuel in the urban areas due to its high efficiency.

$$E_i = \sum (EF_{ij} \times F_j) \quad (2)$$

The expression for pollutants estimation is given by Eq. (2) (Mohan et al., 2012).  $F_j$  denotes fuel usage and is dependent on fuel type,  $E_i$  denotes emission per compound and  $EF_{ij}$  emitted compounds 'i' per unit fuel 'j' consumed. The emission factors can be obtained from (Central Pollution Control Board (CPCB), 2010).

##### 4.1.3. Powerplant

Thermal power plants has become one of the major pollution source in Delhi ("India's first-ever environmental rating of coal-based power plants finds the sector's performance to be way below global benchmarks", 2015). Delhi accommodates four electricity generating plants, viz., Gas fired – Indraprastha Gas turbine and Pragati power station, whereas coal-fired Rajghat and Badarpur thermal power station. Badarpur thermal power station is situated in the southeastern part, whereas other three are located near central Delhi besides the bank of River Yamuna. There are 16 coal-fired units (2,824 MW) within 50 km from the center of New Delhi, and 114 units (26,874 MW) within 500 km. Depending on wind direction and other atmospheric conditions, these power plants and other large coal-burning industries can make a very significant contribution to Delhi's air pollution. Even more alarmingly, nine more coal-fired units (5,530 MW) are under construction and 36 units (28,040 MW) are in pipeline within the 500 km radius of the capital. On full operation, these plants have a capacity of producing more than double the air pollution that is being produced by the existing coal-fired plants (Myllyvirta et al., 2016). The modifications, done for fuel use and gross generation provides the basis for power plant emission calculation (Gurjar et al., 2004).

$$\begin{aligned} \text{Gross generation (GWh)} &= \text{plant load factor (\%)} \\ &\times \text{capacity (GW)} \times 24 \times \text{days} \end{aligned} \quad (3)$$

$$\text{Fuel use (kt)} = \text{gross generation} \times \text{fossil fuel use per GWh} \quad (4)$$

Estimation of emission is done using Eqs. (3) and (4). It can be observed from Eqs. (3) and (4) that estimation of emission is done by multiplying the emission factors with corresponding fuel. The data concerning emission factors are provided by (Central Pollution Control Board (CPCB), 2010), operating hours from (DPCC, 2002). Fuel consumption of gas and coal capacity and plant load factor type of data is obtained from (CEA, Annual Report, 2010).

##### 4.1.4. Vehicular pollution

Vehicle emission is a major contributor and it keeps varying due to dynamic nature of vehicles. It is highly dependent on different type of vehicle present in the fleet. Motorized two-wheelers like scooters, small capacity motorcycles, and mopeds constitute 70% of the personal vehicle fleet and are more common and major contributor to vehicle emission due to their low initial cost (Guttikunda et al., 2014). In past, vehicular emission rates have hiked as much as 72%. Vehicles in major metropolitan cities are estimated to account for 70% of CO, 50% of HC, 30–40% of NO<sub>x</sub>, 30% of SPM (2.5) and less than 10% of SO<sub>2</sub> of the total pollution loads, of which about two third is contributed by two-wheelers alone (Goyal et al., 2006). International vehicle emission (IVE) model provided by USEPA was developed to estimate the spatial and temporal emissions. Further correction factor based on driving variables, fuel type (gasoline and diesel), humidity, altitude, and temperature, classification of the vehicle are suggested in IVEM Correction Factor Data 2008 (Goyal et al., 2013).

Age mixture-composition of the fleet is necessary to determine fleet's average emission rates. As vehicles become older, their emission behavior deteriorates due to the aging of catalytic converters. Emission also increases due to deterioration of emission control system of the vehicles, in addition to other factors such as road and driving conditions. Also, change in technology over years makes new vehicles less polluting than their older counterparts. For instance, during last one decade, three exhaust emission

standards have been introduced in India. These are the Bharat Stage II, Stage III and Stage IV (Indian counterparts of Euro II, III and IV) mandated from 2003, 2005 and 2010 onwards, respectively. This implies that vehicles bought during this decade will have varying emission factors for different years. Therefore, considering these variations a new benchmark was defined with a slightly different model to calculate vehicle emission (Goel et al., 2015b). Detailed trends and evolution of the total emissions from 1990 to 2030 with technology and emission standards in Delhi are also presented in study (Goel and Guttikunda, 2015a). For macroscopic analysis of speed, vehicle characteristic and vehicular emission for pollutant type  $k$  (where  $k \in \{CO_2, NO_x, VOC, PM\}$ ) in a network of given link 'l' the expected total emissions (in gram) in road network during the desired calculation period is approximated as  $E[TE^k]$ . This is presented in simplified version of previous model of Panis et al. (2006) and is described in Osorio & Nanduri (2015):

$$E[TE^k] = \sum_{l \in L} \left[ \max \left\{ E_0^k, C_1^k + C_2^k E[V_l] + C_3^k E[V_l]^2 \right\} * E[T_l] * \lambda_l * \Delta T \right] \quad (5)$$

where in Eq. (5),  $L$  is set of all link in the network,  $E[T_l]$  is the expected travel time on link  $l$ ,  $\lambda_l$  is the arrival rate to link  $l$ ,  $\Delta T$  is the total duration of desired calculation time,  $E_0^k$ ;  $C_1^k$ ;  $C_2^k$  and  $C_3^k$  are average vehicle parameters, and  $E[V_l]$  is the expected vehicle speed on link  $l$ .

#### 4.1.5. Dust as a pollutant

The pollutants from construction, road dust, mining processes and deserted areas are essentially the source of dust based pollutants. Road dust mainly adds to  $PM_{10}$  and  $PM_{2.5}$ . Pollutants that emit from unpaved roads vary with the degree of traffic. Emissions straight from the vehicle also cause particulate emissions, like the wear and tear of breaks and tires caused by vehicle moving on the cemented roads (Nagpure et al., 2012). Construction of roads and residential areas are considerable source of dust emission. Also, on sunny days, the heavy metals are carried by the hot wind that causes degraded view and rigorous pollution. The re-suspension of dust contribute as much as 30% of ambient  $PM_{10}$  concentration in Delhi. The empirical function for resuspension rate are available due to various sources. Estimated re-suspension of dust on roads can be done by USEPA model (USEPA, 2006). For Delhi region, the average road dust re-suspension rates is 5.6 g per vehicle-km traveled for feeder roads, 5.9 g for arterial and ring roads, and 10.4 g for main roads, based on the vehicle density, mix of vehicles, silt loading, and vehicle speeds, for each road type (Guttikunda and Giuseppe, 2013a). A more generalized empirical formulae with mean weight of vehicle fleet is used for Delhi and a very good area wise spatial distribution of road dust pollution for Delhi can be seen in report "Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi" (2016, pp. 182–184).

#### 4.2. Overall emission calculation

For air pollution estimation, emission from different sources are usually expressed as the mass of pollutant per unit mass of raw material, volume, distance traveled or duration of the activity (e.g., grams of particulate emitted per kilogram of coal burnt). A representative parameter generally used for spatial average value is emissions factor. It attempts to relate the quantity of pollutant released and so it has to be referred for comparison. In most cases, these factors are simply averages of all available data of acceptable quality and are generally assumed to be representative of long-term averages for all facilities in the source category. The general

equation for emissions estimation is given by Eq. (9). Where,  $E$  = Average predictive emission;  $A$  is Activity rate;  $EF$  is Emission factor and  $ER$  is Overall emission reduction efficiency, (%). Also, ' $A_i \times EF_i = E_i$ '. However, aggregated concentration of greenhouse gases (GHG) can also be calculated, which is an equivalent parameter, as stated in Eq. (6). GHG footprint is a measure of human activities impact on the environment in terms of the amount of greenhouse gases produced ( $CO_2$  and non- $CO_2$  gases). Ramachandra et al. (2015) worked on calculating different CHG values of different greenhouse gases for major cities of India. The method for calculation is multiplying fuel consumption by the corresponding emission factor to calculate emission of each greenhouse gas and then average to give holistic CHG value.

$$E = \frac{\sum_{i=1}^n (A_i \times EF_i \times (1 - ER_i/100))}{n} \quad (6)$$

### 5. System methodology and architectural overview of proposed method

The method proposed involves the ideology of analyzing the pollution on meso-level by dividing air pollution equally among the small areas and particularly not focusing on eliminating from large areas. Adopted methodology works on the problem by dividing the road traffic (moving source) and related pollution monitoring on small scale so that pollution checking policy can be adopted on meso-level for small temporal period. The spatial controlling of pollution will help to cut short pollution by neutralizing it in small regional environment and avoid accumulating it. In order to do regional analysis city-wide area has to be split into different regions according to major road infrastructure. Also, grid cell map has to be prepared in terms of square boxes for discrete data analysis and reporting (Guttikunda and Goel., 2013b). For regional partitioning, Delhi traffic police divided Delhi in 53 traffic circles of jurisdictions ("Know Your Traffic Circle", 2018). For discrete data analysis, square grids are spread over Delhi region, as demonstrated in Fig. 1. The

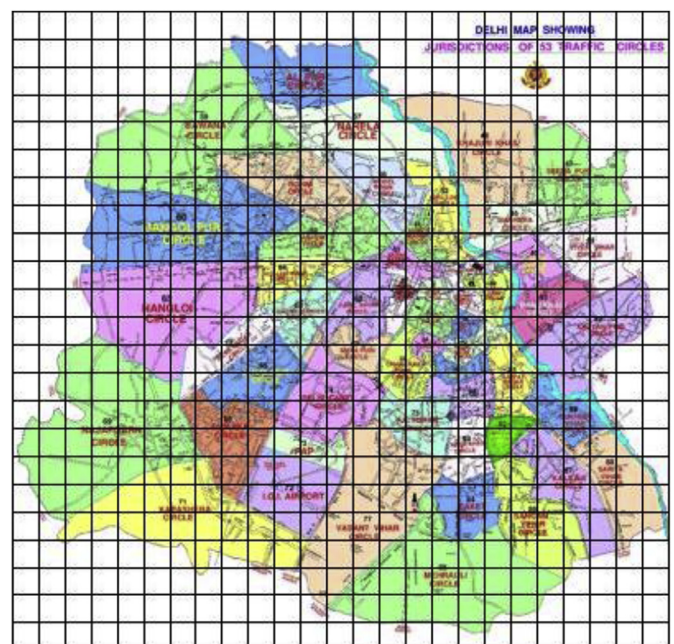


Fig. 1. Grid map of Delhi showing 53 traffic circles.

stationary pollution sources can be easily located and analyzed for near real-time emissions using different model discussed in section 4.1. However for monitoring moving sources (vehicles) and congestion caused by it, a different approach is required. For studying vehicular parameter, each square grid is analyzed using Google map API. The pitch is decided by analyzing factors considering street and highway which can be adjusted by setting the zoom value in the map. Further, clutters like water bodies, parks, building structures, local roads etc. are extracted out.

For aiming at area-wide traffic flow information by analyzing big data and patterns discovery to establish inferences, Fig. 2 illustrates the process of acquiring traffic flow data. Using the Google map service API, an aerial flow web crawler has been developed. The crawler takes a print-screen and saves it for applying image processing technique to figure out the color track, in terms of pixel count. These color tracks are representative of speed range and the congestion value. After processing each image, flow intensity based congestion value database is created in 'excel' sheet in accordance with the specific date and time for the selected area of the city (group of tiles) and all the images are saved in a 'zip' file for further scrutiny. For performing congestion status check of the specific tile at a given zoom, an algorithm was developed to estimate congestion value. The principal involves mapping data of speed flow color tracks by taking an image using 'Google Map API' tile with a fix or suitable zoom which is centered at the center coordinate of the tile. For efficiently using an image to estimate congestion value, clutters are removed and image processing is done to calculate the ratio of pixels of 4 colors and then by using congestion value algorithm, the congestion value has to be defined.

The algorithm developed in the present paper considers the ratio of each color using Eq. (7). The ratio is multiplied by 0.25, 0.50, 0.75 and 1.00 respectively for green, orange, red and dark brown and summed up to estimate congestion value. It can be comprehended from the congestion value that higher the value more will be the congestion. The different color weightage multiplication factors are so considered to maintain linearity between the congestion color representation and calculated congestion value. Theoretically, the congestion value must vary in between the range of 0.25–1. However congestion value in India (Delhi) varies between 0.25 and 0.60 (depending on crowdsourcing data and spatial data availability). As per the aforementioned discussion, the congestion value can be calculated by Eq. (8).

$$\text{Ratio of a color} = \frac{\text{Number of pixels of particular color}}{\text{Submission of total colored pixels}} \quad (7)$$

$$\begin{aligned} \text{CONGESTION VALUE} = & 0.25 * (\text{Ratio of green color}) \\ & + 0.50 * (\text{Ratio of orange color}) \\ & + 0.75 * (\text{Ratio of red color}) \\ & + 1.00 * (\text{Ratio of dark brown color}) \end{aligned} \quad (8)$$

### 5.1. Programming analysis and implementation level details

For getting the real-time data from Google we use "Google map API" that provides traffic layer of the desired location with a given zoom value. To get live data the Google server is contacted at regular intervals. For this, a key was obtained from Google for individual Google account. The program proposed in the paper creates an HTML file with help of Google RoadMapAPI. The "Style-dMapType class" function provided in API helps to eliminate clutter like parks, local roads, water bodies, buildings etc. and the result is shown in Fig. 4 at zoom 14 for the Google API. HTML file contains coding of HTML, JAVASCRIPT and CSS. After eliminating clutters, the API was left with the highway of that area. Another function of Google API, i.e. TrafficLayer() gives live traffic of the road encoded in form of 4 colors. This lead to a processed '.html' file with color codes to determine the traffic at a particular location, the HTML file is hardcoded in the function of javascript as demonstrated in Fig. 3 (a). To scrape the real-time data, python was used. Using polygon object of python, a large square was coded that contains the whole Delhi region. Function shift\_lng and shift\_lat shifts the given coordinates by a fixed amount, the algorithm is based on the principle theory of latitude and longitude.

Web crawler algorithm works by tracing the area bounded by 4 coordinates. The scraping with a given zoom starts from right corner and end at the left of the area bounded by given coordinates. After reaching to extreme left the scrapping window shifts down and then start from left towards right, this pattern of snake-like motion goes on till the end of area. The 'contains' function, shown in Fig. 3 (b) checks if the given coordinate is inside the

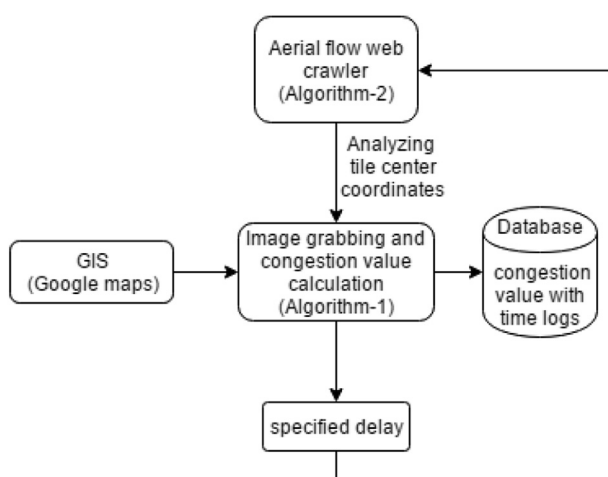


Fig. 2. Traffic flow acquisition methodology through a GIS map web crawler.

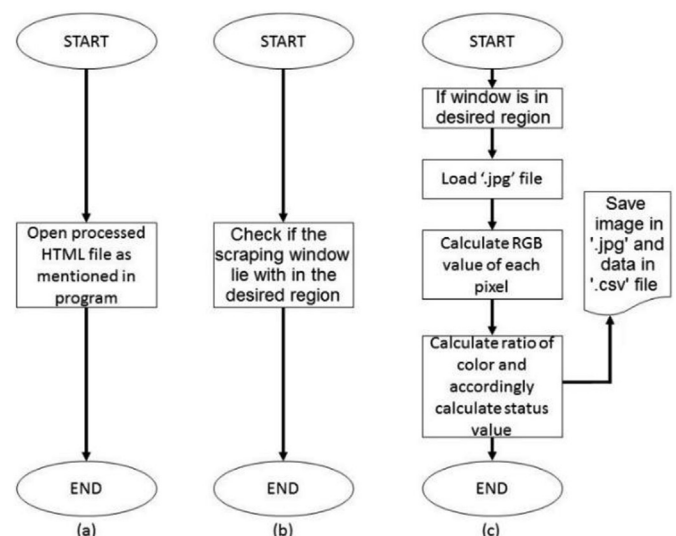


Fig. 3. (a) Sub-algo.1 (b) Sub-algo.2 (c) Sub-algo.3.

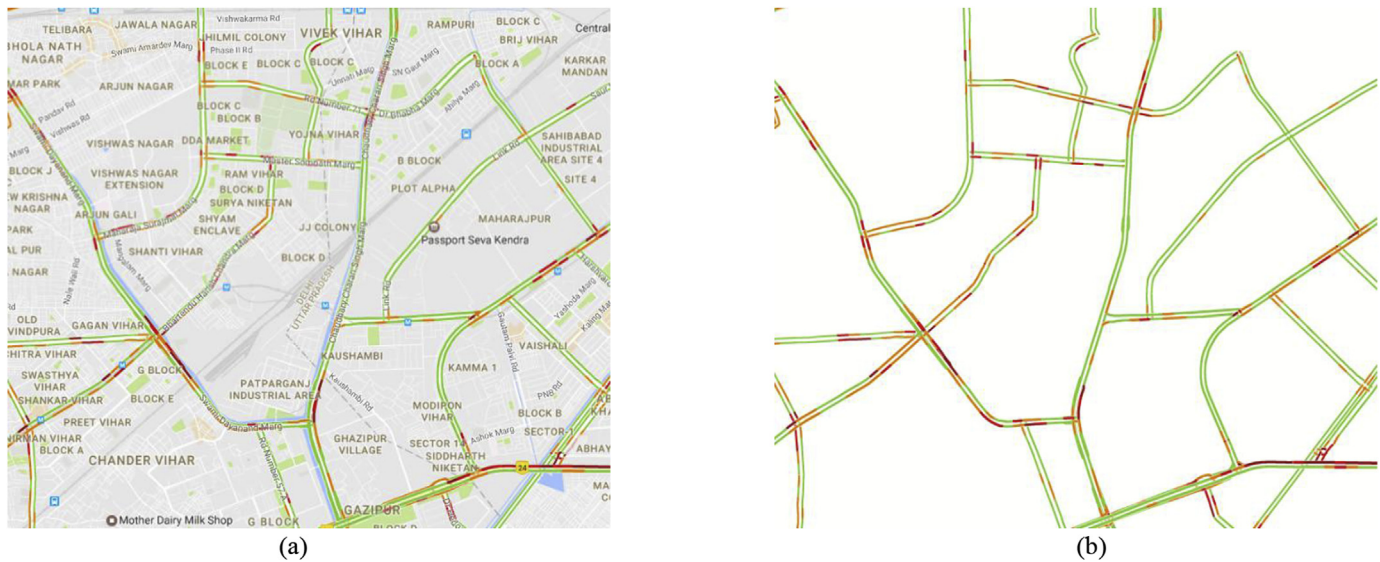


Fig. 4. (a) Images of unprocessed HTML file (b) Images of processed and clutter removed HTML file.

polygon i.e. Delhi region. For this, there are two ‘while’ loop deployed in ‘contain’ function to check if scraping window lies inside the desired area. The ‘status’ function returns the relative color coding found in the image passed in the function, as shown in Fig. 3 (c). The ‘app’ function is the main driver function and takes a screenshot and sends it to the ‘status’ function to get the values. The data is saved in . csv file. For each HTML scenario established by main ‘App’ command, the image processed congestion value for the group of tiles is saved along with the current date and time logs which are stored in a database. This process is repeated after every specified delay time. For calculating the number of pixels of different color, the R, G, B value of each pixel has to be noted and compared to the range of values for RGB corresponding to green, orange, red and dark brown. For finding the range of threshold to set the value in Sub-algo.3, different sample image are loaded and analyzed in MATLAB which are presented in Table 2.

```

Algorithm: Main ‘App’ function
DELAY = ‘xx’ seconds;
/**for each iteration like 4 time a day set it accordingly**/
Switch ();
Do open web browser with the code from sub-algo 1;
Case ‘1’; Sub-algo. 2
{ Check if scraping window is in required region;
  If (yes) {Run Sub-algo. 3
    {Print the screen;
    Do the data logs and save screen;}
  }
  If (no) {Crawl the scraping window;
    Check if window is in required region;
    { If (yes)
      {Return case ‘1’;}
    If (no)
      {Return case ‘2’;}
    }
  }
}
Case ‘2’; Sleep DELAY;
Repeat
  
```

## 6. Applications and case studies

### 6.1. Usability of proposed methodology

The weight-factor for emissions-sources may vary a little or may remain fixed as cited by recent study or survey. However, for vehicular emission case is different. Therefore congestion status for comparative analysis between the regions of the whole area is needed. In a study conducted by CSE, India (Center for Science and Environment, “Decoding Google map information on travel time to understand travel speed and congestion in Delhi”, 2017) used Distance matrix API of Google to relate air pollution increases with congestion. The result shows that a decrease in average morning peak hour speed from 28 km/h to 25 km/h during evening peak, result in elevated nitrogen dioxide levels by 38 percent. These studies map accurate real-time, non-relative, ETA by manual origin-destination (O-D) input for each stretch of road. However, for getting an automated relative value without manual O-D input, authors used Java Map API which also uses the same crowd-source data as of distance matrix API. However, in this study authors intend to compare two areas, either with themselves or with bigger area in which they lie, for policy reform on temporal basis. Hence, absolute value is not needed and a comparative value will suffice for the study. For comparative spatial analysis of vehicular and related emission, a good parameter can be ‘vehicle proportionate area specific moving source emission’ denoted by ‘ $\mu$ ’ in Eq. (9)

Table 2  
Range for RGB values of different color of Google maps.

COLOR PRESENTED IN GOOGLE MAPS	RANGES FOR RGB
GREEN	R (125–195), G (172–232), B (58–185)
ORANGE	R (180–255), G (90–190), B (0–110)
RED	R (140–220), G (0–65), B (0–65)
DARK BROWN	R (75–160), G (0–80), B (0–90)



$$\mu = \left( \frac{\text{Vehicle in an area}}{\text{Total vehicle in area of comparison}} \right) * (\text{Vehicle related emission of both areas by recent report}) \quad (9)$$

$$F = \frac{\text{average congestion value of Area1}}{0.5(\text{average congestion value of Area1} + \text{average congestion value of Area2})} \quad (10)$$

$$F = \frac{\text{average congestion value of Area1}}{A + B} \quad (11)$$

where,

$$A = \frac{\text{colored pixel of Area1}}{\text{colored pixel of Area1} + \text{colored pixel of Area2}} (\text{average congestion value of Area1})$$

$$B = \frac{\text{colored pixel of Area2}}{\text{colored pixel of Area1} + \text{colored pixel of Area2}} (\text{average congestion value of Area2})$$

For mapping emission using the proportionate congestion, authors introduced a comparative factor 'F'. It removes intricacies of modelling needed for exact calculation. Analysis of congestion is done on daily basis (3 runs per day). Afterwards a week congestion value for 'F' can be calculated by simple averaging. Using these 'F' value a comparative more accurate pollutant caused by vehicular and dust emission can be mapped either for a given instant or for weekly average pollutant values. As only these two emissions are linked to vehicular congestion. For comparative consideration between areas, pollutant emission due to traffic emission and due to dust is multiplied by factor 'F'. Then the new emission 'F\*(average ratio of each particular pollutant caused by vehicular or dust emissions only for a given area)', will give more exact real-time mesoscopic emission due to each activity. The factor 'F' is estimated using an expression presented in Eq. (10). A more accurate value of 'F' can be taken by considering the weighted average of congestion value in accordance with road length availability in 2 comparing regions. The total color pixel will be directly proportional to available road length in an area. For comparative 2 area study, the value of F in accordance with road length is given in Eq. (11). This factor 'F' considers the essence of relative near real-time congestion between two areas. The value of 'F' lies around '1' mapping if one area has more congestion than another and when multiplied with comparative emission cause by sources related to the vehicle, will give real-time comparative value of two regions. Using 'F', the near real-time proportionate vehicle congestion (P.V.) for region-1 can be written as in Eq. (12).

$$P.V._1 = \frac{F_1 * V_1}{F_1 * V_1 + F_2 * V_2} \quad (12)$$

where,  $F_1$  denotes factor of region – 1,  $F_2$  denotes factor of region-2,  $V_1$  denotes number of vehicles in region-1 and  $V_2$  denotes number of vehicles in region-2. Also, the real-time total vehicular and related emission for both the areas can be written as

$$\left( F_1 * \left( \sum \text{Moving source emission} \right)_{\text{region-1}} + F_2 * \left( \sum \text{Moving source emission} \right)_{\text{region-2}} \right)$$

'Here, 'Σ Moving source emission' is " $V_{CO} + V_{SO_2} + V_{NO_x} + V_{PM_{2.5}} + V_{PM_{10}} + D_{PM_{2.5}} + D_{PM_{10}}$ " as reported in the recent areal pollution

due to various pollutant. Where,  $V_{CO}$  is for vehicular CO,  $V_{SO_2}$  is for vehicular SO<sub>2</sub>,  $V_{NO_x}$  is for vehicular NO<sub>x</sub>,  $V_{PM_{2.5}}$  is for vehicular PM<sub>2.5</sub>,  $V_{PM_{10}}$  is for vehicular PM<sub>10</sub>,  $D_{PM_{2.5}}$  is for dust PM<sub>2.5</sub>, and  $D_{PM_{10}}$  is for dust PM<sub>10</sub>. Hence, for calculating near real-time 'μ' Eq. (13) is formulated.

$$\mu_1 = P.V._1 * \left( F_1 * \left( \sum \text{Moving source emission} \right)_{\text{region-1}} + F_2 * \left( \sum \text{Moving source emission} \right)_{\text{region-2}} \right) \quad (13)$$

Quantities of region-1 can be interchanged with quantities of region-2 to calculate P.V.<sub>2</sub> and 'μ<sub>2</sub>'. Also, if needed, 'μ' can be calculated and compared for separate pollutant as well. However, submission of average values of different pollutants due to moving source is considered for further discussion. Also, Instead of multiplying factor 'F' directly to moving source or related emission, this factor can be used in the model itself to calculate more correct near real-time predictive emission value for the comparative analysis of policies. For vehicular emission, this can be calculated by considering multiplicative factor 'F' in  $E[V_i]$  and  $E[T_i]$  in Eq. (5). There is no need to change  $\lambda_i$  as it's essence is already considered in  $E[T_i]$ . Also, for dust emission multiplicative factor 'F' can be considered for the road-dust caused by vehicle emissions.

To take a more holistic view, weekly emission analysis report can be made and used as presented in Fig. 5. A week can be considered as single cycle period. As most of the general life activities repeat cyclically over a period of week. Further it is a significant time, neither too big and nor too small, to implement a policy on spatial basis. Weekly analysis and predictive emission of chemicals/parameter corresponding to the upcoming week can be calculated by feeding the previous week's (near real-time) average values. Which are calculated and stored for each respective day of the previous week. There are 2 ways for calculating predictive emission. If the direct source emission data (as calculated by different models given in section 4.1) is available for a given

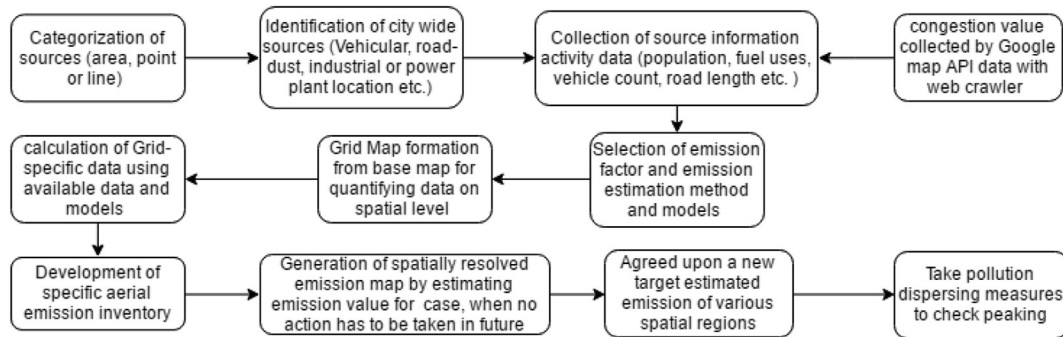


Fig. 5. Stepwise methodology adopted for study and for making weekly reports.

mesoscopic region. Along with the weighting impact factor over the area, the traffic congestion corrective mapping can be done directly. Else, if the pollutant data is available then it can be mapped back to its source for taking source specific majors and actions. Mostly the API or monitoring center gives pollutant related data and not the source related data. The average predictive emissions of chemicals/parameters involved are mapped with respect to cause-of-emission i.e. sources in accordance to weighting factor or the ratio of a given mesoscopic region to overall Delhi. As stated in a study by Ramachandra et al. (2015), if most recent real-time data is not available then national GHG inventories have to be used for quantification of sector-wise greenhouse gas emissions. In case of unavailability of country-specific emission factors, default IPCC guidelines data of emission factors has to be used.

Calculating the data of different sources and predicting changes in physical meteorological parameters like temperature, wind, rain, and fog help to prediction emission for upcoming week by varying 'A<sub>i</sub>' in Eq. (6). Experts use tools like the Rose-Diagram and other methods to find near real-time variability in 'A<sub>i</sub>'. The variability caused by moving sources can be taken into account by involving factors relating to their position in the model of source specific emission calculation. After that a more exact near-future, average comparable predictive emission can be calculated for upcoming week by inputting average of previous week data with or without policy change that will affect 'ER'. The factor 'F' is solely dependent on emission related to vehicular emission or the emission, partially caused by dust emission. Therefore, it is possible to calculate the future predicted pollution parameters value for next upcoming week, when no change has been done in policies. This data will be extremely helpful for monitoring and sensitivity analysis of policy adoption on meso-spatial level for short time period. After comparison an agreed upon targeted pollutant value for an area, different policies have to be evaluated before implementation. Accordingly, the managing policies are adopted to maintain it for different emission source using the same Eq. (6) but this time 'ER' change is done in accordance with policy change also.

In order to maintain the agreed upon estimated emission of spatial region, various governmental policies can be formed for meso-spatial regions. These policies may include technical or non-technical solutions. Technical solution involves vehicle technology improvement (2-Ws with Multi-Point Fuel Injection (MPFI) system or equivalent: wef, January 2019 in Delhi), fuel quality improvement (Ultra Low Sulphur Fuel (<10 PPM); BS-VI compliant: wef, January 2018 in Delhi), De-SO<sub>x</sub>-ing and De-NO<sub>x</sub>-ing at Power Plants and reducing Sulphur content in Industrial Fuel (LDO, HSD). The increment of mass transit systems such as Delhi Metro and DTC bus service wherever necessary. Hence this possesses a possibility of shifting people from private mode to Public Transport and NMT. Technical measures include construction of urban road & flyover

projects wherever necessary, defining different Pollution-Under-Control (PUC) certificates in accordance with vehicle emission quality and allowing them to travel in different regions according to need. Non-technical policy involves temporal emission value setup for different industries, scraping old polluting vehicles, tax or charges for private noncommercial vehicles, encouraging zero-emission vehicles (ZEVs) usage, subsidies for clean vehicles parking charges & fine, route diversion of non-commercial private vehicles, implementing odd-even vehicle banning policy at spatial region, encouraging carpool awareness campaigns, water spraying, plantation, reclamation, managing crop residue burning.

## 6.2. Local area case study

For a deeper approach a comparative spatial study is needed, as mentioned, which resulted in selection of area-1 and area-2 for the better optimization at the local level. For selecting these regions, we first run our code for 1 week, 3 times a day in morning; afternoon and evening, to collect the congestion value for overall Delhi which lies within 0.25–0.6 and, the average lies around '0.296379889'. After that, we analyzed the area with high average peak congestion considering the source of pollution. Along with areal importance congestion consideration leads to selection of two area for pollutant level study, they are R.K Puram in southern part whereas Anand Vihar in northeastern part of Delhi. Both of the regions lie in the urban area of Delhi.

Anand Vihar is situated at the Delhi – U.P. border where the inter-state bus terminal is operated. Hundreds of diesel-belching interstate buses entering the terminal make the air in the area worse than the rest of Delhi. Registered vehicle for areas around Anand Vihar is 431681 for December 2016. The nearby Ghazipur landfill, which receives 2,200 tons of garbage every day, often catches fire in summers. NCR towns like Ghaziabad and Sahibabad have many small industries, which vitiate the air further. These areas have turned into a construction factory, the first round took place when people moved in the 1990s and early 2000s. Now, these houses are being broken and rebuilt, there are dust and debris all around. The people living in Anand Vihar and around make enough wages to use better fuel for domestic purposes but some poor living in the area can be accounted for using low-quality fuel like firewood, cow dung cake, kerosene etc. Anand Vihar is majorly affected by pollution in Vivek Vihar, Gandhi Nagar, and Mandavli circle out of 53 traffic circles in Delhi. Also, Anand Vihar proximity to ISBT, Sahibabad and Patparganj Industrial area makes it more prone to pollution caused by commercial activity (Nath, "Anand Vihar exposed to worst pollution", 2016).

R.K. Puram in Delhi comprising of 12 sectors, is sandwiched between Ring Road and Outer Ring Road, through which thousands of diesel trucks and other commercial vehicles move after 10 p.m.

every night. Vehicles registered for area around R.K. Puram are 189964 as on December 2016. Delhi Metro (DMRC) construction work at Moti Bagh, RK Puram, Munirka and Vasant Vihar, in addition to a construction of flyover at Rao Tula Ram Marg near Malai Mandir Road, adds to the pollution levels. Several restaurants that use open-air clay ovens or tandoors in their premises are contributors to the pollution. By evening, the smoke from these tandoors affects the nearby areas. R.K. Puram is a central government employee's residential colony in South West Delhi so it is expected that major population living with decent earnings and use more refined fuels for domestic purposes whereas minor part of the population can also be identified as using low-quality fuels. R.K. Puram area is majorly affected by R.K. Puram circle and the adjacent circles such as Chanakayapuri, Defence Colony, Hauz Khas, Vasant Vihar, and Delhi Cantonment out of 53 traffic circles in Delhi (Times, "Surviving Delhi's three most polluted neighbourhoods", 2016).

In Fig. 6 (a, b) the graph plotted are for factor 'F' by considering different equations, congestion average (CA) graph is plotted using Eq. (10). While, weighted average graphs are 'WA1' (comparison between 2 areas i.e. Anand Vihar and RK Puram) and 'WA2' (comparison between 2 area i.e. any one of Anand Vihar or RK Puram and the overall Delhi) for RK Puram and Anand Vihar respectively, are plotted using Eq. (11). For extracting the data to calculate factor, the algorithm was executed 3 times a day, i.e. morning; afternoon and evening and for 3 days. Then a comparison was made with pollution trends presented in Fig. 7 (a, b). The pollution data is also collected for same, 3 times a day as that of congestion factor data. The data represented in Fig. 7 (a, b) is the pollutant data as presented by CPCB in near real time on their monitoring site (CPCB-Central Pollution Control Board). Both the pollution measuring stations of CPCB are located in the center of corresponding areas and the data is the sum of all the sources in those corresponding regions. As reported on average, by annual studies, vehicular emission should be a part of this whole emission. Further, for calculation of ' $\mu$ ', on average, as reported by data of recent study is taken. Calculation of 'proportionate vehicle ratio' is done using the data of registered vehicle which is '431681' for Anand Vihar and '189964' for RK Puram as of December 2016 ("Transport Department", 2016). For moving source and related pollutant data (vehicular emission and road dust) in Kg/day is taken from ("Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi", 2016, pp. 180–184) for an area of 32 km<sup>2</sup> around Anand Vihar and RK Puram. The data is tabulated in Table 3. The average and real-time ' $\mu$ ' calculation is done by using Eq. (9) and Eq. (13) for each area in comparison to each other. The values of ' $\mu$ ' in Kg/day is presented in Fig. 8.

The average congestion, which is related to average speed and not the traffic density of R.K. Puram, day 1 afternoon is more

than that of Anand Vihar. However, for day 2 Anand Vihar was more congested than RK Puram whereas on day 3 the situation was reversed. For day 1 and 2 average congestion values difference are subtle but for day 3 it is good. The same trend is observed for weighted average according to road length available. But if we discuss for an area in comparison to overall Delhi, then both areas values are more than '1' with a single dip in value for morning of day 1 also with the highest for the afternoon of day 3 (day 3 was Monday) in RK Puram. The overall congestion trend of day 1 is similar to that of day 2 for Anand Vihar with a little bit of similarity in Rk Puram too. The trend can be analyzed by checking dip at sampling point 2 and 5 of Fig. 6 (a) and peak at sampling point 2 and 5 of Fig. 6 (b). But for day 3, there is major dip and peak in trends for both the places, respectively.

Although the data of pollution curves for Anand Vihar have a higher average than that of Rk Puram due to various reasons discussed along with approximately 2.3 times vehicle registration than of RK Puram. For instance, PM 10 average is higher in Anand Vihar region due to landfill and other more prevalent sources of Anand Vihar. After analyzing ' $\mu$ ' it can found out that the rise of pollution due to congestion in Anand Vihar region is worse than that of pollution rise in RK Puram region. This fact is highlighted as the extra shoot of ' $\mu$ ' for Anand Vihar is 1.5–3.5 times than that of RK Puram for some of the readings. In afternoon, there is a dip in congestion for all 3 days in Anand Vihar region, however, there are peaks of congestion, in afternoon for all 3 days in RK Puram region. Same type of trends can be easily seen for graph of ' $\mu$ ' in Fig. 8. Vehicular emission mainly contributes to NO<sub>x</sub> and PM. Also, the pollutant due to vehicular emission gets accumulated all over the day and in the night they get stabilized or dispersed. It is not wise to directly relate emission of Fig. 7 with congestion factor 'F' but prediction of some relationship between the relative increment and decrement is possible. Therefore, taking care of 'F' trend it can be seen in Fig. 7 that NO<sub>x</sub> hardly builds up during the daytime in Anand Vihar but for RK Puram there are peaks of NO<sub>x</sub> for, both day 1 and 2, up till night time. If lesser relevant pollutant, 'PM 2.5' is considered then due to vehicular emission, the graph of PM2.5 shows the same trend as expected except day 1 of Anand Vihar with an increasing trend in the night. For Day 1 and 2, the congestion of both areas is quite comparable so nothing can be said about relative variation (from average) of vehicular emission for both the days. However for 3<sup>rd</sup>-day occasionally congestion is more in RK Puram than Anand Vihar and the difference in 'F' is the most. Hence for 3rd day the relative variation of ' $\mu$ ' from average is largest for both RK Puram and Anand Vihar. Hence it can be stated that NO<sub>x</sub> and PM2.5 which led to maximum increase in RK Puram is mainly due to vehicular emissions. Also, for some Anand Vihar's

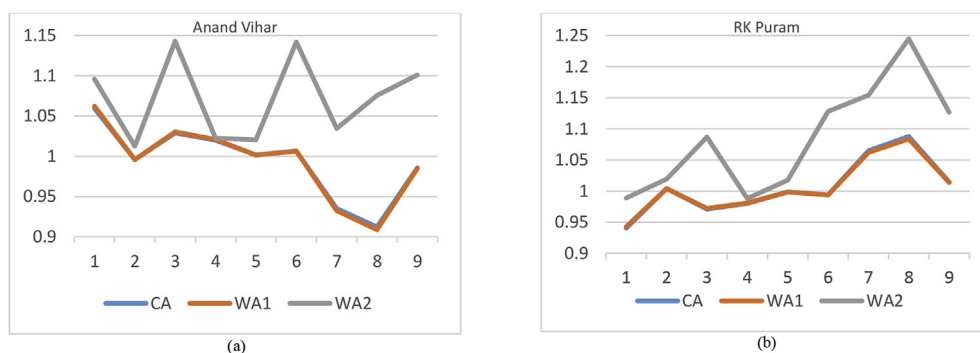


Fig. 6. Graph plot of factor "F" over a time interval of three days, 3 times a day. Vertical axis – Factor, horizontal axis – number of data sample collected. (a) Anand Vihar (b) R.K. Puram.

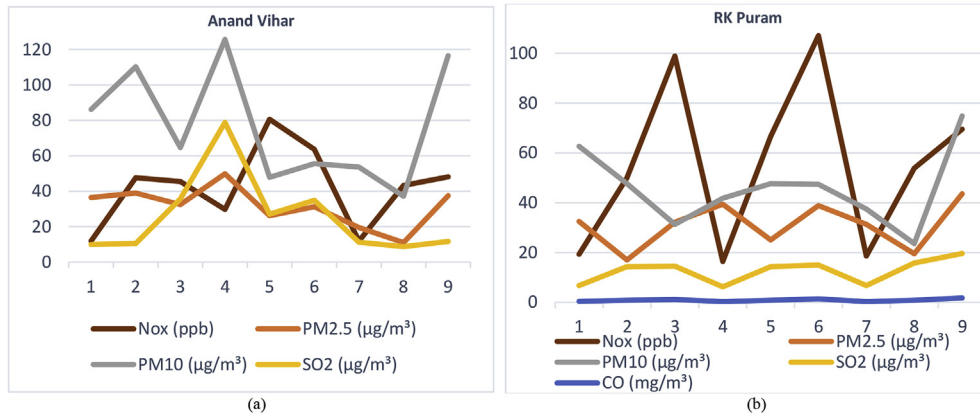


Fig. 7. Graph plot of different, average pollution values, over a time interval of three days, 3 times a day. Vertical axis – pollutant level, horizontal axis – the number of data sample collected. (a) Anand Vihar (b) R.K. Puram.

Table 3  
Pollutant for moving source for different regions of 32 km<sup>2</sup>.

	Vehicle-PM10 Kg/day	Vehicle-PM2.5 Kg/day	Vehicle-NO <sub>x</sub> Kg/day	Vehicle-SO <sub>2</sub> Kg/day	Vehicle-CO Kg/day	Dust-PM10 Kg/day	Dust-PM2.5 Kg/day	Avg. sum of all poll. Kg/day
RK Puram	727.83–1428.99	664.68–1297.92	7776.61–14966.5	56.68–95.20	18223.49–29048.06	8540.51–15108.71	2115.05–3799.44	18716.285
Anand Vihar	304.84–500.53	386.43–620.39	3376.46–5584.38	27.06–47.58	8131.56–14143.84	1242.35–1885.01	461.11–721.03	51924.835

real-time readings, variation is comparable to some reading of RK Puram. For ex., variation in 8th real-time reading than that of average for Anand Vihar is equal to 1st reading of RK Puram. This proves the importance of presented work of real time monitoring and mapping.

The comparative plot of ‘F’ for independent area with overall Delhi (WA2) shows that both area are congested with respect to overall Delhi and with higher average value in Anand Vihar. Further, Anand Vihar area is more prone to solid waste burning, soil dust, diesel generators, construction and paved road dust. Apart from this, due to Anand Vihar bus terminal and proximity to ISBT, movement of traffic is relatively higher than other parts of Delhi. The average congestion values show that overall traffic jams and low speed trends are higher in both Anand Vihar and RK Puram areas with some peaks in RK Puram occurring occasionally. Simply, pollution is more in Anand Vihar despite occasional and comparably low congestion than RK Puram that cause high relative variation of emission. Which shows that Anand Vihar is more prone to emission increment with congestion. Hence, corrective policy

measure can be taken more accurately to make Anand Vihar area more robust to congestion change. Traffic fleet in Anand Vihar area have higher percentage of commercial vehicles like trucks and private diesel buses than that of R.K. Puram which comprises of private vehicles (Cars and 2Ws) and CNG driven DTC buses. However, for night time, R.K. Puram is also flooded by commercial vehicles like trucks due to heavy vehicle permit after 10 p.m. Government agencies can estimate emission values of various pollutant using the different models and data available to them for different regions and take preventive regional and temporal measures on weekly basis to control pollution. For example temporal odd-even vehicle banning policy can be implied in Anand Vihar area and adjoining traffic circles, setting up a new bus terminal near the metro route alongside GT road like Loni road that leads to Rajnagar extension will reduce the rush on ISBT. Immediate and enhanced action to stop smoke emissions from Ghazipur, improving the waste management efforts, improving parking facilities by revising parking fares will benefit both the areas on a whole.

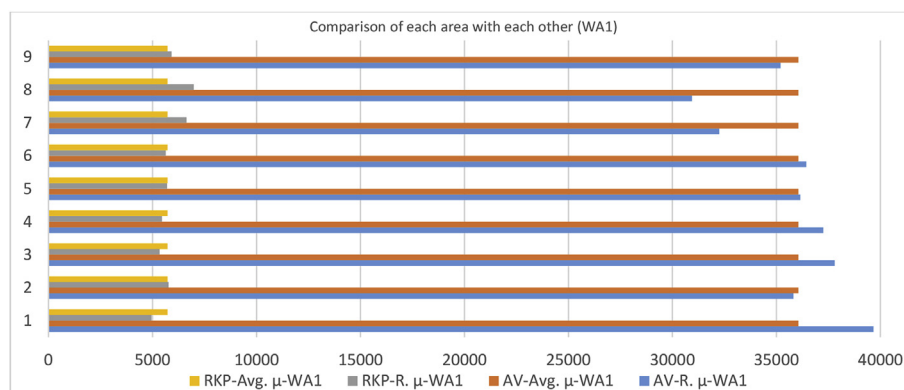


Fig. 8. Calculation of  $\mu$ , using average data (as in recent report) as well as real-time data for both regions (RKP- RK Puram and AV- Anand Vihar) in comparison to each other.

## 7. Conclusion

This study attempts to introduce the impact of pollution crisis over national capital, Delhi. Discussion of previous studies; available knowledge base near-real-time pollutant data; policies and regulations enforced by the authorities to control the sub-spatial and temporal pollution were highlighted. It was observed that the short-term measures for whole area adopted by the authorities are not efficient in the long run. Therefore, the present paper demonstrates a methodology to analyze the total emissions by dividing the NCT area of Delhi. Amongst the different emission sources viz. vehicular, power plants, industries, household and other factors in Delhi, vehicular emission and the related dust emission are the most unpredictable. To map average emission to near real-time emission on meso-spatial scale, a methodology is proposed to use structured Google traffic knowledge data in the form of Factor 'F' to relate comparative congestion of two areas and the vehicular emission. A parameter ' $\mu$ ' is also discussed which represent 'vehicle proportionate areal emission of moving source'. The calculation of 'F' and real-time ' $\mu$ ' is done considering comparison for two major areas of Delhi i.e. Anand Vihar and RK Puram with each other. The real-time emissions of pollutants in these two areas were noted and analyzed against the Factor 'F' for 3 days. The analysis shows that as the congestion increases the pollutant due to vehicular emission prevails in the meso-environment. Comparative analysis of emissions and 'F' factor, for 3rd day, points that if occasionally less congested area becomes more congested then pollutants due to vehicular emission are more prevalent. The case study proves Anand Vihar area is less robust and prone to more emission variation due to congestion change. Also, the study pointed the use of Factor 'F' in traditional models to analyze the effectiveness of policy for managing comparative meso-environment neutrality. This may help to provide an advanced modelling, monitoring, and analysis system for environmentalists, planners, and decision-makers on the spatial basis to combat pollution hikes in Delhi. Using the same, future work can be addressed by leveraging convolution-based neural networks for manual and automatic feature extraction. This can be done using raw emission data, considering global; propagation specific and local specific features of sources, to automatically generate an urban knowledge graph for more flexible decision and policy making.

## Acknowledgments

Authors would like to thank all anonymous reviewers for their comments and insights.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2019.03.122>.

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