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Urbanization and Air Quality – Bengaluru, India

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Abstract— Urbanization and Air pollution are one of the biggest challenges the world is facing at present. The study mainly focuses on urbanization and air pollution of Bengaluru urban area, India, which is one of the fastest growing metropolitan cities in the world. The world is facing rapid urbanization and increase in the number of mega cities from 3 to 31 during 1975 - 2016. Air pollution is crossing the national ambient air quality standards in most of the urban areas. The same can be observed in Bengaluru at present. Decade 2001–2011 marked a population growth rate of 47.18% for Bengaluru urban agglomerate reaching a population of 9,621,551. It has a vehicular population of 7,028,067 and 13 Industrial areas in and around Bengaluru urban area at present. Ambient air quality parameters like SO_2, NO_2, Particulate Matter 2.5 ($PM_{2.5}$), Particulate Matter 10 (PM_{10}) and Air Quality Index (AQI) for 15 sampling stations of Bengaluru urban area covering industrial area, mixed urban area, sensitive areas were analyzed for the year 2011-2016. The PM_{10} concentration at 14 locations has crossed the national ambient air quality standard (60.0 µg/m^3) by 30%-120%. The $PM_{2.5}$ concentration at 9 locations has crossed the national ambient air quality standard (40.0 µg/m^3) by 3%-45%. The concentration of SO_2 is within the national ambient air quality standards (50.0 µg/m^3). The concentration of NO_2 at one station has crossed the national ambient air quality standards (50.0 µg/m^3). The concentration of Pb varies between 0.1–0.3 µg/m^3 at 13 locations. NH_3, Pb and CO concentrations in ambient air are within the limits of national ambient air quality standards (100 µg/m^3, 0.5 µg/m^3 and 2 mg/m^3). The ambient Air Quality Index of 15 sampling stations were in Satisfactory (51-100) and Moderate (101-200) range. During the nationwide strike, 22%-41% of reduction in the concentration of SO_2 and 38%-77% of reduction in the concentration NO_2 was observed. Industrial emissions, vehicular emissions and construction activities are identified as the major source of air pollution. The wet precipitation samples collected at Bengaluru during the 2013 monsoon season reported a pH of less than 5.6 and the presence of metals such as Fe, Mn, Zn, Al, Cr, Ni, Cd, Pb and Cu. Concentration of Fe was 0.27 mg/l in some of the wet precipitation samples and 0.01-0.41 mg/l in the harvested rainwater samples collected from the building roof catchment. This maximum concentration is higher than the acceptable drinking water standards. The source of metals was identified as particulate matter in atmosphere. It is an alarming situation.

Keywords—Urbanization, Air pollution, Harvested Rainwater, Metals

I. INTRODUCTION

In 2007, global urban population surpassed the global rural population (World Urbanization Prospects 2014). In 2016, an estimated 54.5 % of the world's population lived in urban areas (The World's Cities in 2016). A proportion of it is expected to increase to 66 % by 2050 (World Urbanization Prospects 2014). Urbanization of Bengaluru has lead to decline of wet lands and green spaces by 78% vegetation, 79% water bodies and 925% increase in paved surfaces (built-up and roads), Floods due to conversion of wet lands in to residential layouts, decline in groundwater table from 28m to 400-500m in 20 years and Heat islands – increase in the temperatures than the surrounding area [33] and [37]. Vegetation is a source to reduce the air pollutants in the atmosphere as reported by [21], [17] and [16]. The waxy, spiny or hairy leaf surfaces helps to reduce the air pollutants such as NOx, CO_2, SO_2 and particulate matter. United Nations, sustainable development goals 2016 has mentioned that 6.5 million people dying annually from air pollution and 92 per cent of the world's population living in places where levels have exceeded recommended limits. One in nine of total global deaths are from exposure to indoor and outdoor air pollution. This study is in line with urbanization and air pollution of Bengaluru urban area [25].

II. MATERIALS AND METHODS

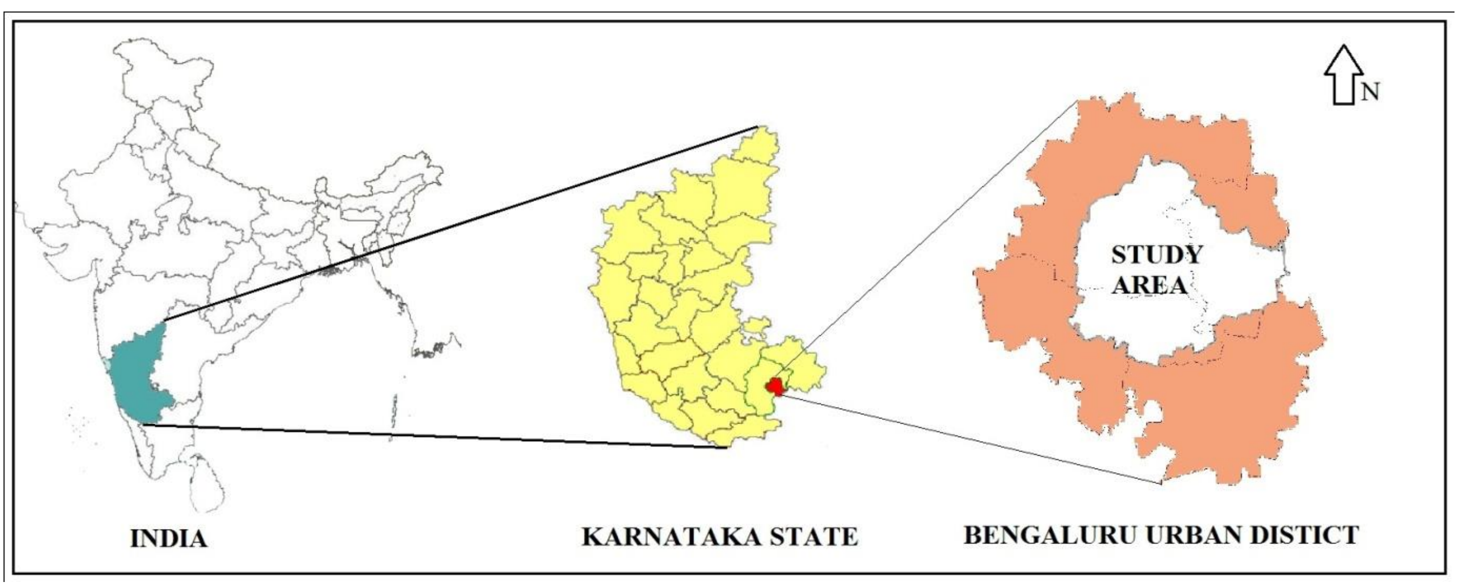
A. Study Site

Bengaluru is a rapidly growing metropolis with a population of 9,621,551 (Census 2011) [11], this garden city is the capital of the southern Indian state of Karnataka. Situated at an altitude of 921m (3021 feet) above mean sea level, it is approximately 450 km from the Bay of Bengal and the Arabian Sea and approximately 700 km from the Indian Ocean. It is of 855 mm (Karnataka State Natural Disaster Monitoring Centre, 2014) [20]. The study area as shown in

Fig. 1 and sample collection stations listed in Table 1 consists of different types of land use such as residential, commercial, industrial, mixed urban (residential, rural and other areas), sensitive etc. It is the core urban area of Bengaluru urban district consisting of 198 wards as shown in Fig. 1.

Sl.	Stations	Land use	Sl.	Stations	Land use
1	ITPL (International Tech Park Ltd.) Graphite India	Industrial	9	Victoria Hospital	Other areas (Sensitive)
2	KHB (Karnataka Housing Board) Industrial area Yelahanka	Industrial	10	Indira Gandhi CHC (Community Health Centre)-NIMHANS (National Institute of Mental Health and Neuro Sciences)	Other areas
3	Peenya Industrial Area	Industrial	11	City Railway Station CAAQM (Continuous Ambient Air Quality Monitoring) station	Other areas
4	Peenya Industrial Area (Gymkhana)	Industrial	12	Saneguruvanahalli CAAQM (Continuous Ambient Air Quality Monitoring) station	Residential
5	Yeshwanthpura	Other areas (Commercial)	13	Kajisonnenahalli	Rural
6	AMCO Batteries Mysore road	Other areas (Commercial)	14	TERI (The Energy and Resources Institute) Domlur	Other areas
7	Central Silk Board	Other areas (Commercial)	15	Banaswadi Police Station	Other areas (Residential)
8	DTDC (Door To Door Courier), Victoria Hospital	Other areas (Sensitive)	16	--------	-------

Table 1: Sampling Stations



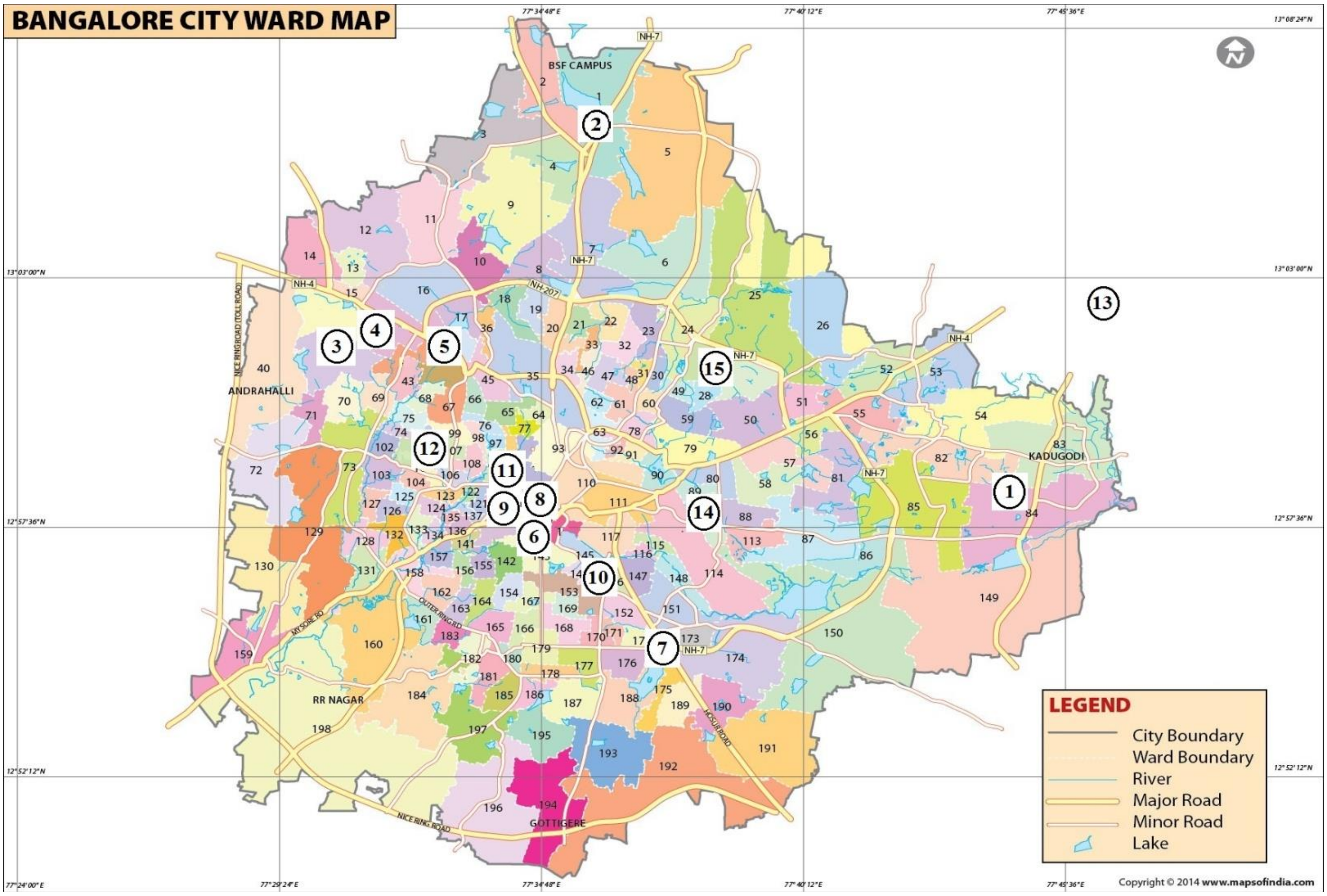


Fig. 1. Bengaluru Urban Area and Sampling Stations

III. SAMPLING

Selection of sampling stations (Table 1 and Fig. 1), sample collections and analysis are carried out by Karnataka State Pollution Control Board (KSPCB) and Central Pollution Control Board (CPCB). Karnataka State Pollution Control Board is a government authority of Karnataka state, INDIA, monitoring air, water and industrial wastewater quality throughout the state. Ambient air quality sample collections are carried out as per National Ambient Air Quality Standard (NAAQS) 2009. 13 nos. of sampling stations are selected based on the type of land use such as residential, mixed urban, industrial area, sensitive areas and strategic locations. Two sampling stations are Continuous Ambient Air Quality Monitoring (CAAQM) station, being monitored for 24 hrs and 365 days. Ambient air quality sample reports for all the sampling stations from 2011 to 2016 are collected from Karnataka State Pollution Control Board (KSPCB) [19] for this study.

IV. RESULTS AND DISCUSSION

The 2011 census [11] has reported 47.18% decadal growth of Bengaluru city as shown in Fig. 2. The population has almost reached 10 million as reported by "The World Cities 2016". A city will be named as "Mega city", once it crosses 10 million populations as per "World urbanization prospects". The density of population is defined as the number of persons per square kilometer. The density recorded as per 2011 Census is 4,381 persons per sq.km [11]. From a density of 180 persons per sq. km. in 1901, it has increased to 4,381 by 2011. Area has increased from 69 km^2 in 1949 to 741 km^2 in 2010 [34], [35] and [36].

World Urbanization Prospects, 2005 and 2016 [47] has reported the rapid increase in the number of mega cities having population above 10 million. In 1950, Tokyo and New York were the only two mega cities. By 2016, it has increased to 31 numbers. Of these cities, 24 are located in the "global South". India includes five megacities, while China has six. The various mega cities since 1950 to 2016 from the world are provided in Table 2. A rapid increase in the number of mega cities is reported between 1975-2000 and 2005-2016. Bengaluru urban sprawl shows that there has been a growth of 632% in urban areas of Greater Bangalore across 37 years

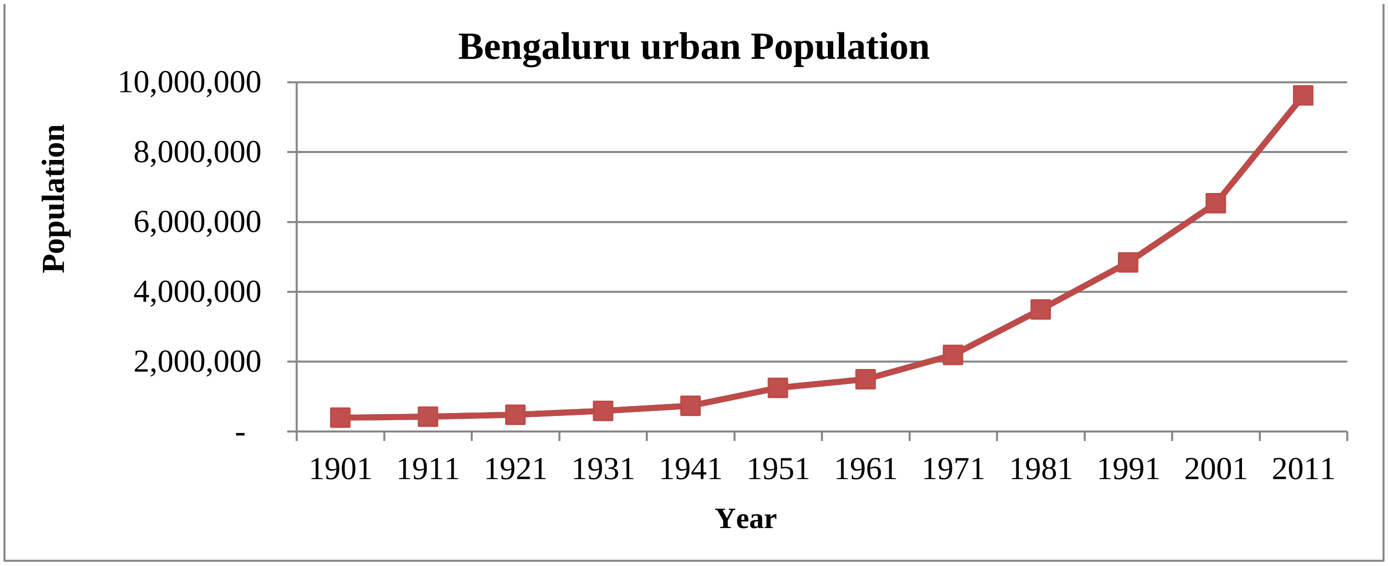


Fig. 2. Bengaluru Urban Area Population Growth

(1973 to 2009) resulting in 76% decline in vegetation cover and 79% decline in water bodies, conversion of land has resulted in its ability to absorb rainfall, concentrated high population densities resulting in high level of anthropogenic activities, growth depends on growth agents like IT corridors, Industrial units etc., newly built-up areas consists of small scale industries, IT companies, multi storied buildings, private houses etc., within a decade [35].

The Bangalore Water Supply and Sewerage Board (BWSSB) [8] is responsible for providing water supply to Bengaluru city area of 800 sq. km. At present BWSSB is supplying treated Cauvery river water to Bengaluru city under the Cauvery Water Supply Scheme (CWSS) Stage I, II, III & Stage IV Phase I & II with total installed capacity of 1310 MLD. In 2012, CWSS Stage IV, Phase II was commissioned. But still BWSSB is able to cover 575 sq. km. BWSSB [8] is working with the government authorities for additional water requirement for the remaining 225 sq. km towards the commissioning of Cauvery stage V, Phase I and II schemes. Most of the nations in the world are experiencing urbanization today in a rapid pace. Bengaluru is at the 29th place with population more than 10 million during 2016. The growth trend of Bengaluru when compared with other mega cities (Census 2011) indicate Bengaluru moving towards rapid urbanization. In urban areas, most of the population and communities live in cities [14]. A diminution of the rate of urbanization in the older industrial countries is being compensated for by an increase in the rate in the underdeveloped areas [14]. Urban areas provide Job opportunities; improved living standard, access to advanced technology, infrastructure, etc., this can be observed in all mega cities. Urbanization has significant impact on air quality [27], [24], [32], economy, environment [6], climate [49] and Bio-diversity [44], [13] and human health [28].

Urbanization needs a very detailed planning considering various criteria with multiple dimensions [27]. Urban planners, Government authorities, Policy-makers in developing countries should seek multiple ways of enabling forms of urbanization that contribute to economic growth, increase in jobs, environmental sustainability, and so on, rather than pursuing accelerated urbanization.

World Health Organization (WHO), 2016 [46] reported the PM_{10} and $PM_{2.5}$ annual mean concentration of some of the urban cities from different regions of the world for the year 2008-2015. It is shown in Fig. 3 and 4. The regions are as follows: Afr: Africa; Amr: America; Emr: Eastern Mediterranean; Eur: Europe; Sear: South-East Asia; Wpr: Western Pacific; LMI: Low- and Middle-income; HI: High-income.

The EMR HI, Sear and EMR LMI regions have the highest PM_{10} concentration levels and Amr HI, AMR LMI and EUR HI regions have the lowest concentration of PM_{10} compared to other regions of the world. The top three cities with highest concentration of PM_{10} are reported in Riyadh, Doha and Delhi as shown in Fig. 3. The Wpr HI, EUR HI and AMR HI regions have the lowest $PM_{2.5}$ concentration levels and EMR HI, Sear and WPR LMI regions have the highest.

Rank	City	Pop. in 1950	City	Pop. in 1975	City	Pop. in 2000	City	Pop. in 2005	City	Pop. in 2016
1	New York	12.3	Tokyo, Japan	26.2	Tokyo, Japan	34.4	Tokyo, Japan	35.2	Tokyo, Japan	38.1
2	Tokyo, Japan	11.3	New York-Newark	15.9	Ciudad de Mexico, Mexico	18.1	Ciudad de Mexico, Mexico	19.4	Delhi, India	26.5
3			Ciudad de Mexico, Mexico	10.7	New York-Newark	17.8	New York-Newark	18.7	Shanghai, China	28.5
4					Sao Paulo, Brazil	17.1	Sao Paulo, Brazil	18.3	Mumbai (Bombay), India	21.4
5					Mumbai (Bombay), India	16.1	Mumbai (Bombay), India	18.2	Sao Paulo, Brazil	21.3
6					Shanghai, China	13.2	Delhi, India	15	Beijing, China	21.2
7					Kolkata (Calcutta), India	13.1	Shanghai, China	14.5	Ciudad de Mexico, Mexico	21.2
8					Delhi, India	12.4	Kolkata (Calcutta), India	14.3	Kinki M.M.A, Japan	20.3
9					Buenos Aires, Argentina	11.8	Jakarta, Indonesia	13.2	Al-Qahirah (Cairo), Egypt	19.1
10					Los Angeles, USA	11.8	Buenos Aires, Argentina	12.6	New York, USA	18.6
11					Osaka-Kobe	11.2	Dhaka, Bangladesh	12.4	Dhaka, Bangladesh	18.2
12					Jakarta, Indonesia	11.1	Los Angeles, USA	12.3	Karachi, Pakistan	17.1
13					Rio de Janeiro, Brazil	10.8	Karachi, Pakistan	11.6	Buenos Aires, Argentina	15.3
14					Al-Qahirah (Cairo), Egypt	10.4	Rio de Janeiro, Brazil	11.5	Kolkata (Calcutta), India	15.0
15					Dhaka, Bangladesh	10.2	Osaka-Kobe	11.3	Istanbul, Turkey	14.4
16					Moscow, Russian Federation	10.1	Al-Qahirah (Cairo), Egypt	11.1	Chongqing, China	13.7
17					Karachi, Pakistan	10.0	Lagos, Nigeria	10.9	Lagos, Nigeria	13.7
18					Manila, Philippines	10.0	Beijing, China	10.7	Manila, Philippines	13.1
19							Manila, Philippines	10.7	Guangzhou, Guangdong, China	13.1
20							Moskva (Moscow), Russian Federation	10.7	Rio de Janeiro, Brazil	13.0
21									Los Angeles, USA	12.3
22									Moskva (Moscow), Russian Federation	12.3
23									Kinshasa, Democratic Republic of the Congo	12.1
24									Tianjin, China	11.6
25									Paris, France	10.9
26									Shenzhen, China	10.8
27									Jakarta, Indonesia	10.5
28									Bangalore, India	10.5
29									London, United Kingdom	10.4
30									Chennai (Madras), India	10.2
31									Lima, Peru	10.1

Table 2: Population of Cities With 10 Million Inhabitants or More During 1950, 1975, 2000, 2005 and 2016. (Source: World Urbanization Prospects 2005 & 2016) [47]

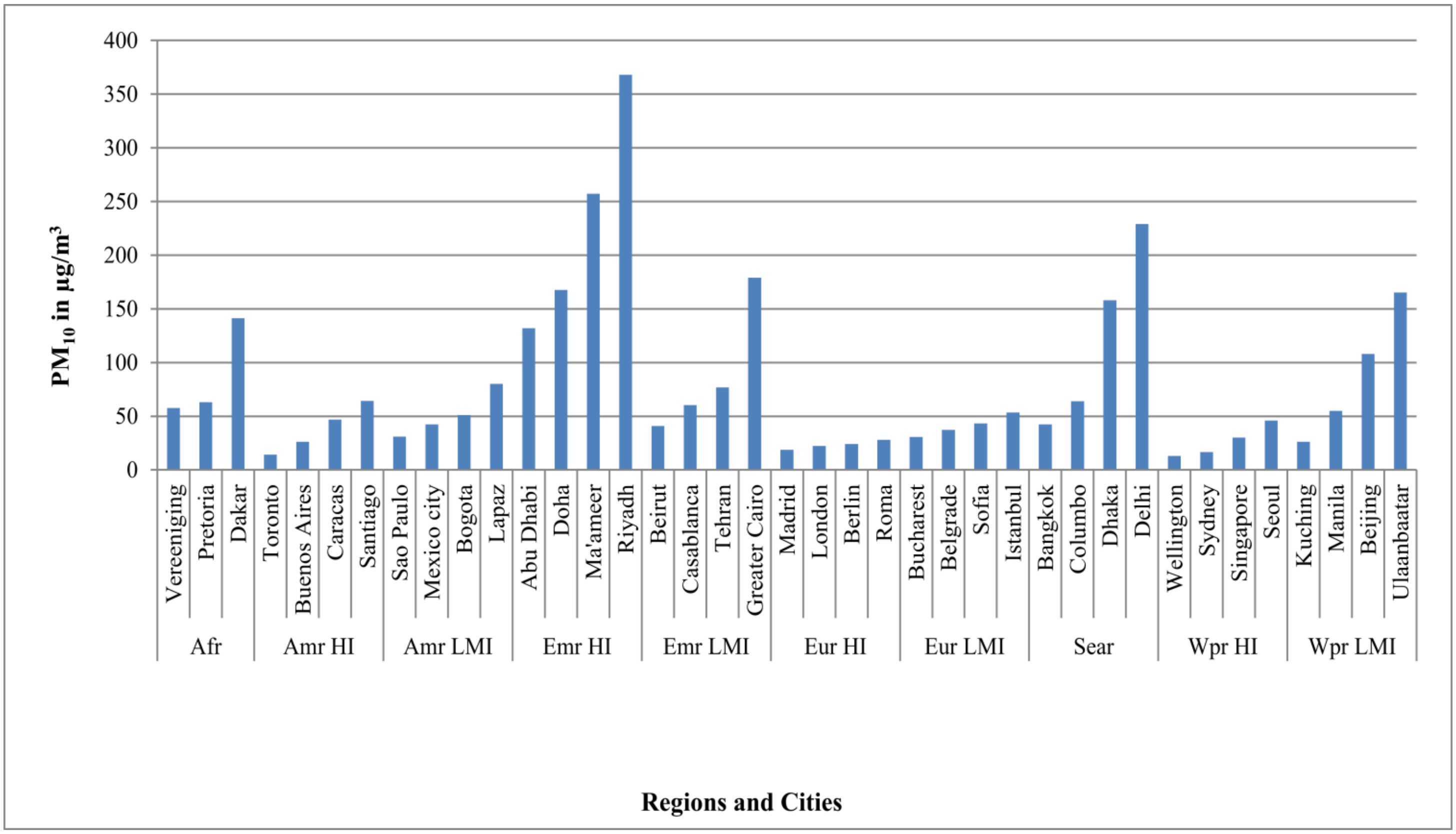


Fig. 3. PM_{10} Concentration of Various Regions of the World (Source WHO 2016)[46]

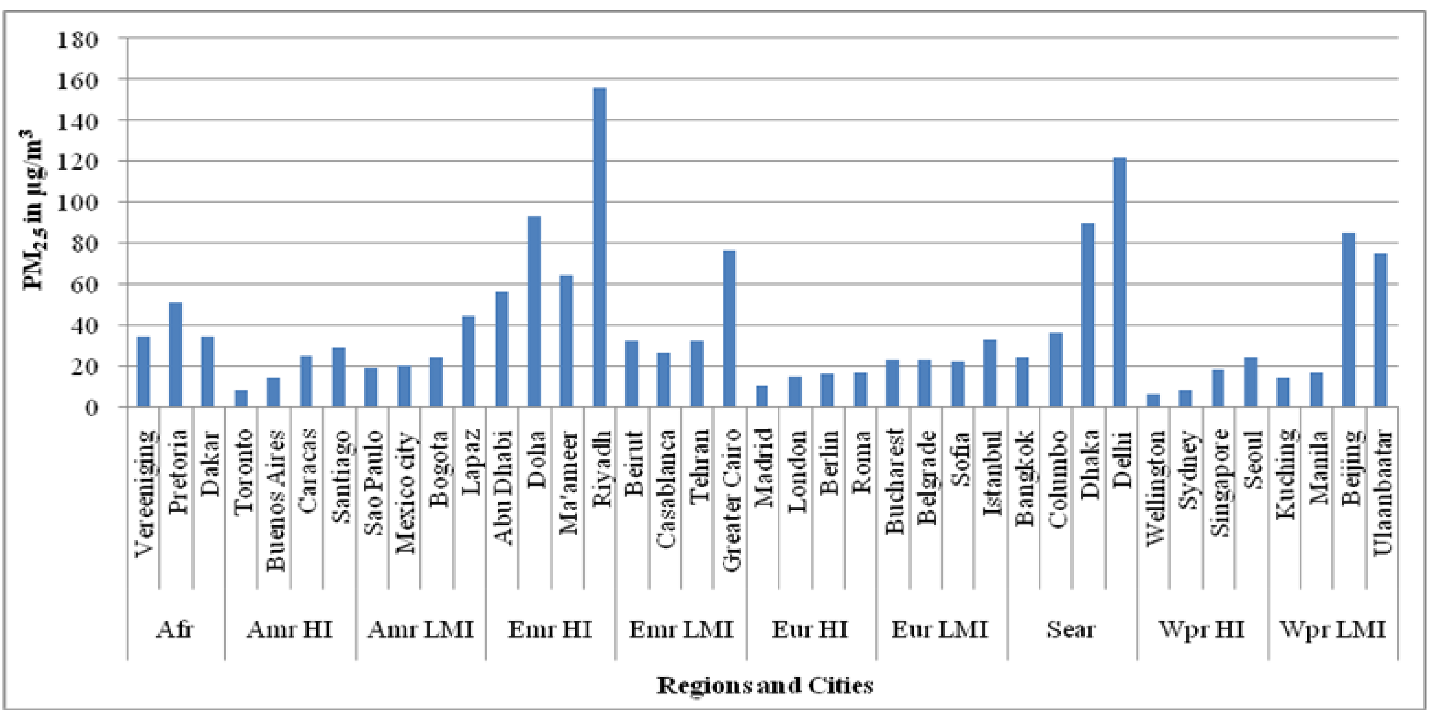


Fig. 4. $PM_{2.5}$ Concentration of Various Regions of the World (Source WHO 2016)[46]

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-concentration of PM_{10} compared to other regions of the world. The top three cities with highest concentration of $PM_{2.5}$ are reported in Riyadh, Delhi and Dhaka as shown in Fig. 4. The PM concentration of Riyadh was approximately 3 times higher than the Country's ambient air quality standards respectively [5]. Metals and ions contributed to about 21.5% and 16.2% of the PM concentrations respectively. Summer vs. winter comparison showed that PM concentrations were approximately 84% higher in summer and the crustal matter species such as Fe, Mn, Ti, Ca^{+2}, Mg^{+2} increased several folds in summer, primarily attributed to dust storms. Sources identified were crustol mineral aerosols, vehicular emissions and anthropogenic sources [5]. The various sources of PM_{10} and $PM_{2.5}$ in the city of Jeddah are (1) heavy oil combustion characterized by high Ni and V; (2) resuspended soil characterized by high concentrations of Ca, Fe, Al, and Si; and (3) a mixed industrial source. The two other sources in PM $_{2.5}$ were (4) traffic source identified by presence of Pb, Br, and Se; (5) other industrial source mixture; while in PM_{10} it was marine aerosol [23]. Biomass burning at the neighboring states, occurrence of cyclone during the winter season and the anthropogenic emissions in the city is one of the reason for 2012 Delhi smog [15]. The air quality of Delhi reported that PM_{10} decreases during monsoon by ~25–80 μg/m^3 and PM_1 and $PM_{2.5}$ by ~10–15 μg/m^3 from their pre-monsoon levels. Emissions from fireworks during festivals in the post-monsoon season increases PM_1, $PM_{2.5}$ and PM_{10} levels by 300, 350 and 400 μg/m^3. Seasonal variation of mixing heights, temperatures, winds and rainfall, accounts for the inter-annual variability of PM_1, $PM_{2.5}$, and PM_{10}. Accordingly, wintertime PM_1, $PM_{2.5}$ and PM_{10} components contribute by ~30–33% to annual levels [41]. The PM_{10} samples at three residential sites in Delhi, India during December 2008-November 2009 and identified 8 major and trace metals (Fe, Mn, Cd, Cu, Ni, Pb, Zn and Cr). Mean annual 24-h PM_{10} levels varied from 166.5-192.3 μg m^{-3} at the sites (8-10 times of the WHO limit) [22]. Source apportionment by principal component analysis-multiple linear regression (PCA-MLR) identified three major sources: crustal (49-65%), vehicular (27-31%) and industrial (4-21%) [22]. Air pollution in Delhi has increased the mortality and morbidity rate due to the air pollution [2]. The air quality of the Dhaka reported that 30–50% of the PM_{10}

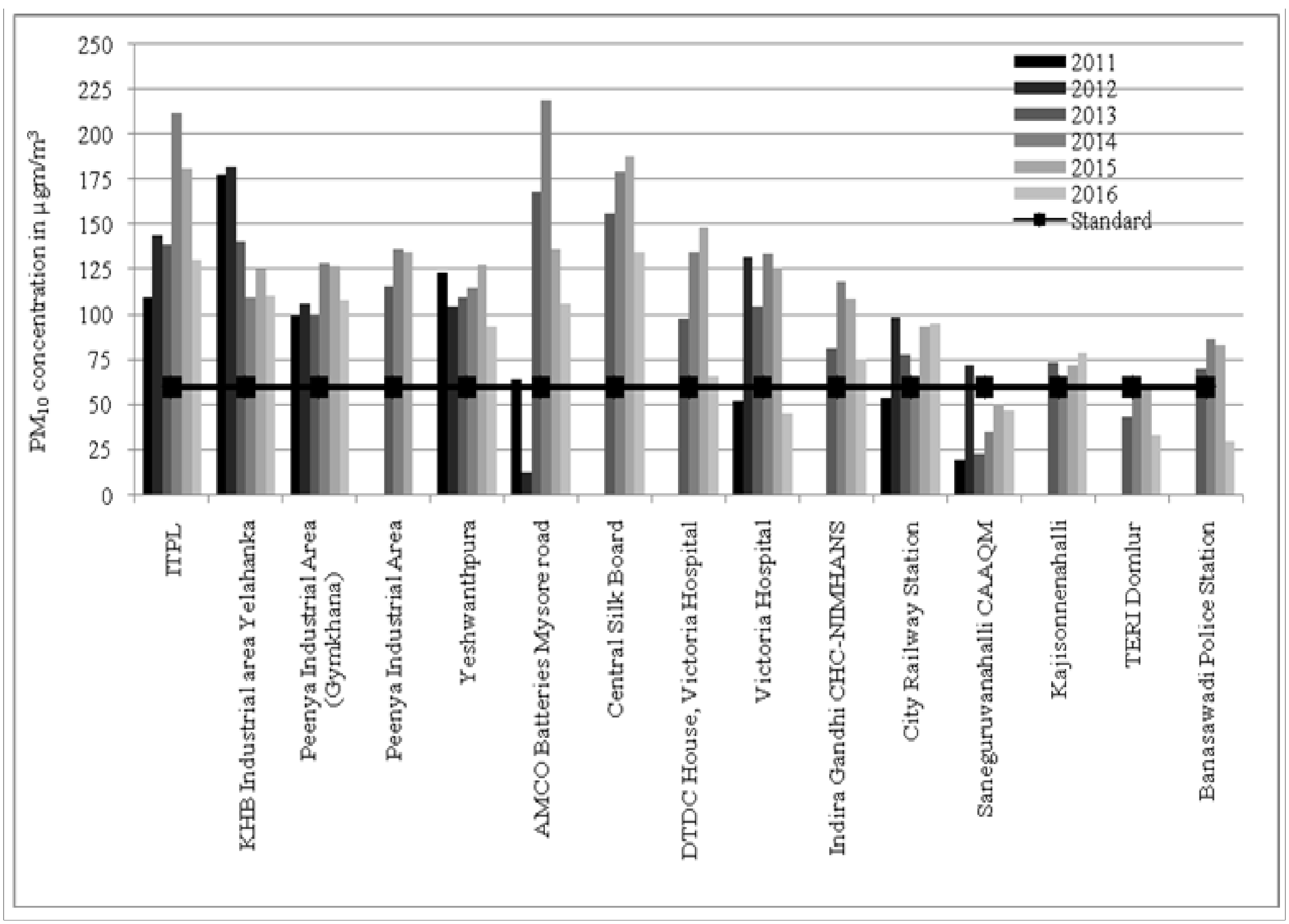

Fig. 5. PM_{10} Concentration of Study Area

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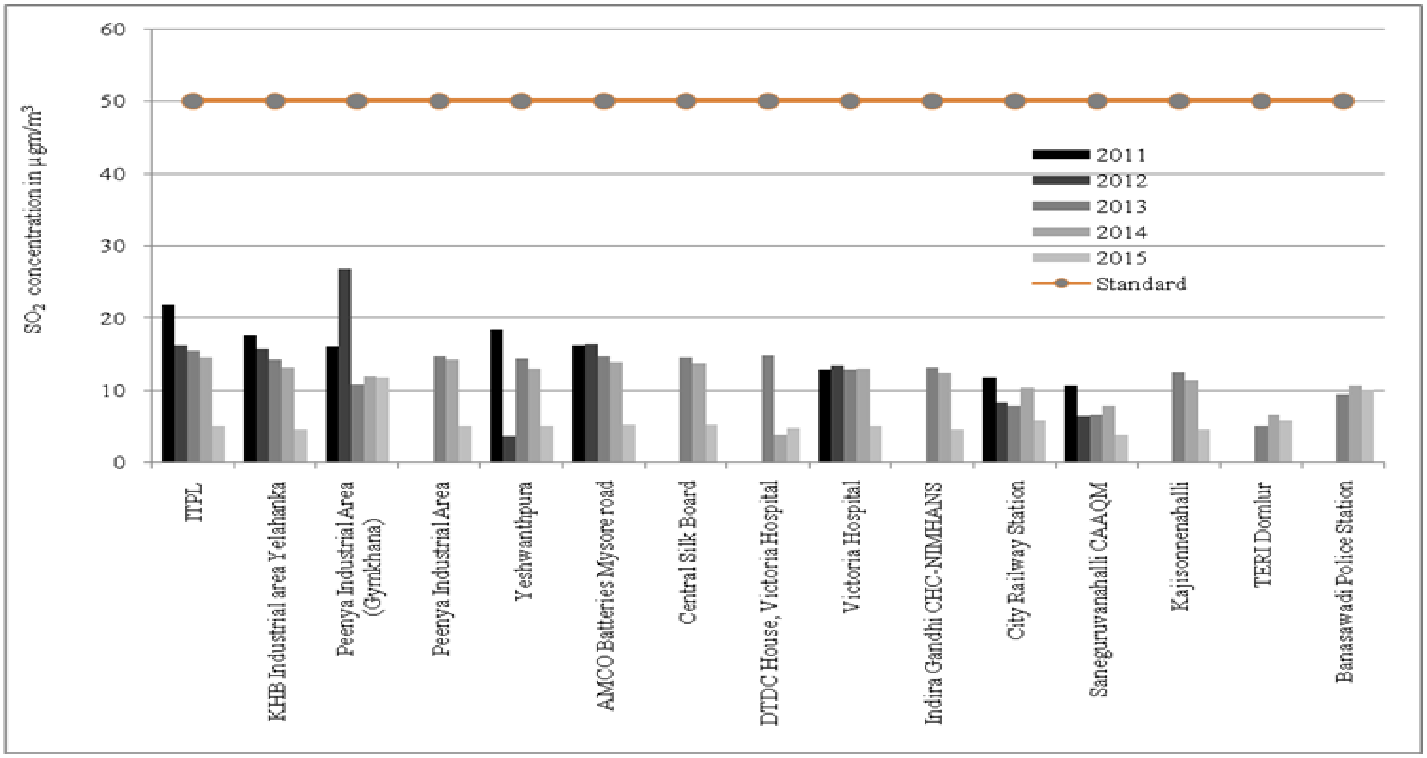

Fig. 6. SO_2 Concentration of the Study Area

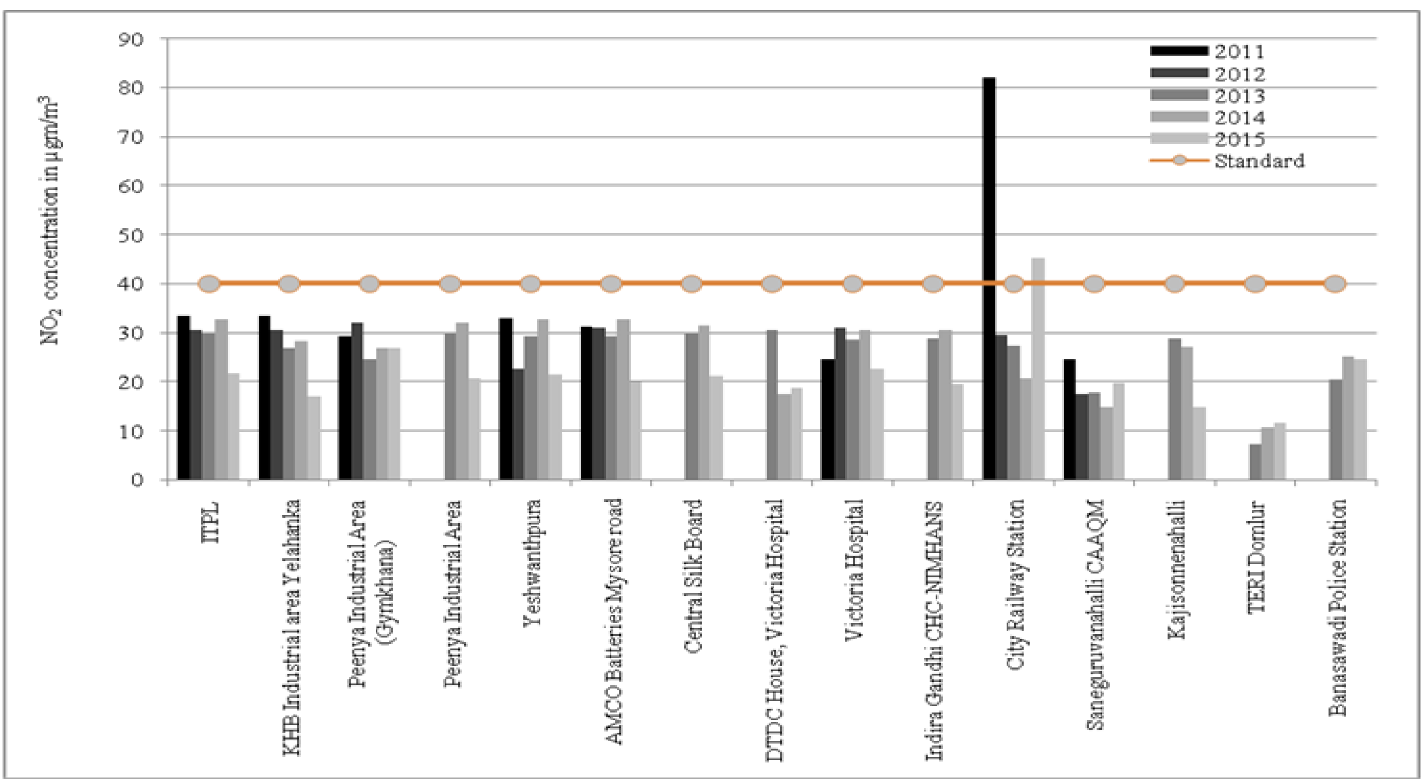

Fig. 7. NO_2 Concentration of the Study Area

mass in Dhaka (depending on location) is in fine particles with aerodynamic diameter less than 2.2 μm. These particles are mainly of anthropogenic origin and predominately from transport–related sources. However, the combination of meteorological conditions, long–range transport during the winter and local sources results in PM concentrations remaining much higher than the Bangladesh National Ambient Air Quality Standard (BNAAQS) [7]. Black carbon accounted for about 50% of the total fine PM mass before the adoption of control policies and its main source was "Brick Kiln" [7]. PM2.5 measurements can directly be linked to estimates of health risks [46] (WHO 2016), and are therefore of particular interest. PM10 measurements first need to be converted to PM2.5 in order to do so. In high-income countries, PM2.5 measurements are already being widely performed. In low and middle-income countries, while PM2.5 measures still aren't available in many countries but there has been a large improvement since the last 3 years: annual mean $PM_{2.5}$ measurements could be accessed in 339 cities, so almost 5 times more than in the 2014 version of the database. Annual mean PM_{10} measurements could be accessed in as many as 586 cities in low and middle income countries. In high income countries, 1241 cities and towns with $PM_{2.5}$ measures could be accessed, against 1639 cities and towns with PM_{10} measurements. Globally, according to the currently available data, 16% of the assessed populations are exposed to PM_{10} or $PM_{2.5}$ annual mean levels complying with Air Quality Guideline levels. Globally, annual PM levels are estimated to have increased by 8% during the recent five year period in the assessed cities. Urbanization in China from 2004 to 2012 led to increase $PM_{2.5}$ related mortality [25].

A. Particulate Matter 10 (PM_{10})

The PM_{10} concentrations in all the study areas have crossed the National Ambient Air Quality Standard limits (Fig. 5). In 6 locations, they are Peenya Industrial Area (PIA), PIA Gymkhana, DTDC Victoria hospital, Victoria hospital, Yeshwanthpura and Indira Gandhi CHC-Nimhans the concentration has exceeded the standard by two times (Fig. 5). PIA consists of 3000 nos. small, medium and large scale industries (Karnataka State Pollution Control Board) [19]. Yeshwanthpura is also an Industrial area at the neighbourhood of PIA located next to the National Highway. Victoria hospital is located near the City Market, which is almost the core area of the city with densely populated with people and vehicles commutation throughout the day. Indira Gandhi CHC-Nimhans is located next to a major road junction with three grade intersection that addresses traffic congestion regularly. Industrial and traffic emissions can be attributed for the high concentration of PM_{10} in these areas [19]. In 4 locations, they are ITPL, Yelahanka, AMCO Batteries, Mysore road and Central Silk Board, the concentration has exceeded the standard by three times (Fig. 5). ITPL (International Technology Park Ltd.) is located in white field, which is an industrial area known as EPIP (Export Promotion Industrial Park) Zone that houses a large number of companies, Business centers, residential colonies, commercial establishments and Hospitals. Yelahanka houses industries (KSPCB) and residential areas and is located at the neighborhood of State highway. The PM_{10} concentrations of industrial areas are less than the other sampling areas in its downstream that can be attributed towards the dispersion of pollutants at the downstream area due to the influence of meteorology [41]. But at the same time, a gradual reducing trend in the concentration can be observed at 11 study areas during the subsequent years (Fig. 5). All these study areas has a common source of pollution, i.e. vehicular emission and construction activities as identified by the state pollution monitoring agency, Karnataka State Pollution Control Board (KSPCB) [19]. Vehicle emissions are the major contribution for the pollution in Bengaluru towards PM_{10} [3]. The PM_{10} concentration at the construction site has been analysed via the study [4] in Bengaluru and identified that the particulates having varying aerodynamic diameters-fine particles 2.5 μm($PM_{2.5}$) has exceeded the coarse particles 10 μm (PM_{10}) by 4-5 times more than the permissible limits prescribed by Central Pollution Control Board (CPCB). A study carried out in Delhi and its satellite cities has identified vehicle exhaust, industries, waste burning, and construction activities account for the bulk of the particulate (PM) pollution, which between 2008 - 2011, averaged 123 +/- 87 $\mu g/m^3$ for $PM_{2.5}$ and 208 +/- 137 $\mu g/m^3$ for PM_{10}. The modeling of sector contributions to ambient $PM_{2.5}$ ranged between 16–34% for vehicle exhaust, 20–27% for diffused sources,14–21% for industries, 3–16% diesel generator sets, and 4–17% brick kilns.

B. Sulphur di oxide (SO_2)

The concentrations of SO_2 in all the study areas are within the prescribed air quality standard [31] (Fig. 6). Maximum concentration of SO_2 among all the study area is at ITPL, Yelhanka and Mysore road (Fig. 6). The three locations are connected with state highways and express way corridor having daily transportations of heavy vehicles like Trunks during night time, Buses along with Light Moving Vehicles in and out of Bengaluru during day time. A reducing trend in the concentration can be observed at most of the study areas during the successive years in Fig. 6. The control measures amended by the central and state government authorities can be attributed towards the reduction [10]. This is supported by other studies [39] and helped to identify that air pollution change in Beijing city is heavily policy driven. A significant reduction in the concentration of SO_2 at three site locations of Beijing by 13%, 26% and 36% was identified after implementing the pollution control measures [45]. A study [18] reported the national goals established by Chinese central government to reduce sulphur emission by 10% in both 10th and 11th Five-year plan. Emission increased by 28% during the 10th Five-year plan. But during the 11th Five-year plan number of policies such as 1. Instrument choice, 2. Political accountability, 3. Emission verification, 4. Political support, 5. Streamlined targets, and 6. Political and Financial incentives. Thus a 14% reduction in the SO_2 concentration was achieved during 11th Five-year plan. A high concentration can be observed at the core areas and locations with industries and high vehicular movements. The SO_2 concentration of various Asian megacities during 2000 including cities of India - New Delhi 23.6 µg/m^3, Kolkata 11.3 µg/m^3, Mumbai 12.9 µg/m^3 and Chennai 22.2 µg/m^3, Tokyo 7.7 µg/m^3, Cities of China ranged between 21.8 - 167.3 µg/m^3, and Seoul 27.4 µg/m^3 [38]. The same concentrations we can see at present in various sampling sites of Bengaluru city.

During the nationwide strike, 22%-41% of reduction in the concentration of SO_2 was observed by KSPCB [19]. Industrial emissions, vehicular emissions and construction activities are identified as the major source of air pollution [19] and [4].

C. Nitrogen di oxide (NO_2)

The concentrations of NO_2 in all the study areas are within the air quality standard [31] (Fig. 7) except city railway station twice. City railway station is located next to the City bus stand and Express bus stand. This is the core area with regular vehicle transportations during day and night. An increase in the pollution further can result in exceeding the prescribed standards. A slight and gradual reducing trend in the concentration can be observed at all the study areas. This can be attributed towards the usage of refined fuels in the automobiles as in the case of SO_2 [10]. A study [26] reported the control measures taken in San Francisco Bay area in the early 1960s and progressed from stationary source controls to new motor vehicle emission reductions to transportation control measures to limit emissions from vehicles in use. Air quality measurements demonstrate the success that these approaches have had in bringing days over the standard from 70 in the late 1960s to 2 or 3 in the most recent years. During the nationwide strike, 38%-77% of reduction in the concentration NO_2 was observed by KSPCB [19]. Industrial emissions, vehicular emissions and construction activities are identified as the major sources of air pollution [19] and [4].

D. Air quality Index (AQI)

Air Quality Index (AQI) is also known as Air Pollution Index (API) and Pollution Standard Index (PSI). Government uses this number to characterize the air quality at a particular location. AQI, 0-50 represents Minimal impact, 51-100 represents Satisfactory, 101-200 represent Moderate, 201-300 Poor, 301 - 400 Very poor and >401 as severe. As shown in Fig. 8, in all the site locations, the AQI index is within the satisfactory range. In most of the location, the trend seems to be varying every year. Hence, this needs to be studied further for the coming years to have a clear conclusion. A high values can be observed at the core areas and at locations with industries and high vehicular movements.

The reducing trend in the concentration of pollutants such as PM_{10}, SO_2, NO_2 etc. can be attributed towards the major initiatives such as improvement in the number of air quality monitoring stations, data accessibility, usage of clean fuels (Liquid Petroleum Gas – LPG fuel vehicles, reducing the usage of unleaded fuel etc.,), introduction of electric transportation system and increasing the LPG filling stations for vehicles. Central Pollution Control Board – CPCB 2010 has reported that Ministry of Road Transport had amended the fuel quality specifications such as Auto-Fuels commensurate to Euro III (whole country) and Euro IV (for 11 cities) specifications is proposed to be made available in the respective cities from 01.04.2010. The Research Octane Number (RON) for premium petrol available in 11 mega cities has been boosted to 95 with lead content being reduced to 0.005 g/l and benzene content of maximum 1%. From 01.04.2010, the content of sulphur in gasoline was proposed to be reduced to 0.005% (50 mg/kg) from existing 0.015% (150 mg/kg). However, all over the country, content of sulphur in gasoline was proposed to 0.015% (150 mg/kg) from 01.04.2010 [10].

Sl.	Sampling Stations	$PM_{2.5}$	Lead Pb	CO
		µg/m^3	µg/m^3	mg/m^3
1	ITPL	55	0.1	-
2	KHB Industrial area Yelahanka	54	0.1	-
3	Peenya Industrial Area RO	52	0.1	-
4	Swan silk Peenya Indl Area	50	0.1	-
5	Yeshwanthpura	46	0.1	-
6	AMCO Batteries Mysore road	51	0.2	-
7	Central Silk Board, Hosur road	58	0.1	-
8	DTDC House, Victoria Hospital	-	0.1	-
9	Banasawadi Police Station	41.2	0.3	-
10	CAAQM City Railway Station	-	-	0.9
11	CAAQM Saneguruvanahalli	-	-	0.5
12	Kajisonnenahalli	40	0.1	-
13	TERI Domlur	55	0.2	-
14	Victoria Hospital	40	0.1	-
15	Indira Gandhi CHC-NIMHANS	36	0.1	-

*CO: Carbon monoxide
*CAAQM: Continuous Ambient Air Quality Monitoring

Table 3: Ambient Air Quality Details for March 2017 (Source Kspcb)

For diesel the Cetane Number was enhanced to 51 with Sulphur content proposed to reduce further to 0.005 % (50 mg/kg) in the 11 mega cities by 01.04.2010.The amount of sulphur in diesel was proposed to 0.035% (350 mg/kg) all over the country. Amendment of mass emission standards such as Bharat Stage IV, Bharat Stage III and (Bharat (Trem) Stage III) for different types of vehicles during 2010 throughout the country and 11 mega cities. Mass emission standards are the primary technical policy for controlling emissions from vehicles.

Table 3 provides the Ambient Air Quality details for March 2017. The concentration of Lead (Pb) varies between 0.1–0.3 $\mu g/m^3$ at 13 locations. Ammonia (NH_3), Lead (Pb) and Carbon monoxide (CO) concentrations in ambient air are within the limits of national ambient air quality standards (100 $\mu g/m^3$, 0.5 $\mu g/m^3$ and 2 mg/m^3).

A reducing trend in the pH of Bengaluru wet precipitation has been reported, which is below the threshold of neutrality 5.6 [29], [30], [40] and [1]. The air pollutants such as sulphates and nitrates have been identified as the primary sources of pollutants for the cause of acid rain [29], [30] and [40]. Trace metals such as Fe, Mn, Zn, Al, Cr, Ni, Cd, Pb and Cu have been reported in the wet precipitation and particulate matter has been identified as the source of metals [1], [9], [12], [40], [43] and [48]. Metals present in the particulate matter get dissolved in wet precipitation due to its acidic nature. Similarly, particulate matter deposited on the building roof catchment combines with the harvested rainwater consisting of metals [9], [12], [40], [43] and [48]. The concentration of iron in few samples of wet precipitation was around 0.27mg/l and 0.01-0.41mg/l in harvested rainwater samples collected by the author from building roof catchment in his research work. The maximum range has crossed the drinking water standard limit of 0.3mg/l in few samples. Particulate matter has been identified as the source of iron [1], [9], [48] and [12] in wet precipitation and harvested rainwater samples.

V. CONCLUSION

- Particulate matter $PM_{2.5}$ & PM_{10} concentration has exceeded the air quality standards in most of the sampling locations. Emission from vehicles, construction activities and industries are the main sources of particulate matter in urban areas. Meteorology plays a prominent role towards the transportation and distribution of atmospheric pollutants from one place to another place in urban areas and gets deposited in the downstream or surrounding areas.

- Air pollution in urban areas has a direct impact on the quality of the harvested rainwater. The particulate matter falling on the roof surface consists of metals. Acid rain falling on the roof surface dissolves the metals in the particulate matter and combines with harvested rainwater. Hence, a close monitoring of air quality needs to be done before implementing the rainwater harvesting policy.

- Exponential growth, Land use plan, Air pollution, Meteorology, Transportation planning are among the key parameters that need a close attention during urban planning.

- Urban areas are engines of growth and leads to prosperity only, if it is planned with eco friendly reforms and policies.

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