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# AIR QUALITY AS AFFECTED BY INDUSTRIAL AND COMMERCIAL ACTIVITIES: A CASE STUDY OF BENGALURU CITY

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**ABSTRACT**

Air pollution is one of the most serious forms of environmental pollutions posing huge threat to human life. Air pollution is increasingly becoming a global concern and is believed to be one of the causes of death in the world today. Developing countries, like India are struggling between the focus on economic development and curbing air pollution emissions. Bengaluru is one of India's fastest growing metropolises although benefiting economically due to its rapid development has along with rapidly deteriorating air quality. Several epidemiological studies and clinical evidence have linked both the short and long-term exposures of air pollution on various health issues such as respiratory disorders, lung cancer, heart disease and even damage the brain and nerves. In the present study an attempt has been made to present the air quality status and its prediction at the four selected locations of Bengaluru using multiple linear regression modeling. These predictions of the pollutant concentration are able to improve decision making and also provide appropriate solutions. This study examines the performance of multiple-linear regression in order to achieve an efficient model to estimate the concentration of oxides of sulphur and nitrogen and respirable suspended Particulate Matter (PM10) contents in the ambient air and represent air pollution trend at various industrial, residential, commercial and sensitive locations of Bengaluru over the period 2011-2019. From the model it was observed that the concentration of sulfur dioxide was lower than the other air contaminants whereas the concentration of nitrogen dioxide predominant than the other pollutants.

## INTRODUCTION

Air pollution is a growing problem in the world today and the World Health Organization (WHO) ranks air pollution as the 13th leading cause of world mortality (promoting health life, 2015). Air pollution leads to environmental instability and has harmful and undesirable effects on the environment (Akbari, et al., 2015). Air pollution is defined as the presence of one or more substances in the atmospheric air at concentrations and duration above the natural limits (Seinfeld, et al., 2015). Such pollutants majorly include Ozone ($O_3$), Lead (Pb), Carbon Monoxide (CO), Sulphur Oxides ($SO_x$) and Nitrogen Oxides ($NO_x$) (Nemmar, et al., 2013).

Urbanization, population growth, industrial expansion, increased consumption of fossil fuels along with the low quality of fuels, lack of efficient transport systems, heating and high dust levels due to local construction, smoking and traffic congestion have led to a daily discharge of large amounts of pollutants, which are incompatible with the natural mechanisms, into the air (Antanasijevic, et al., 2013). In 2014, the WHO estimated that 92% of the world population was living in places with less than optimum outdoor air quality. Furthermore, WHO reported that in 2012, outdoor air pollution caused around 3 million deaths worldwide and 6.5 million deaths (11.6% of all global deaths) were associated with indoor and outdoor air pollution together (Khreis, et al., 2017).

Air pollution was linked to cancer, respiratory diseases, negative pregnancy outcomes, infertility, cardiovascular diseases, stroke, cognitive decline and other adverse medical conditions (Bloemsma, et al., 2016). Most of the Indian cities are also experiencing rapid urbanization and the majority of the country's population is residing in cities. This has also resulted in tremendous increase in the number of motor vehicles. The vehicle fleets have even doubled in cities over the past decade. Vehicles are now becoming the main source of air pollution in urban India (Vizcaino, et al., 2016).

Bengaluru is one of India's fastest growing metropolitan cities although benefiting economically due to its rapid development, has along with rapidly deteriorating air quality. Bengaluru has the largest concentration of number of IT, electronic and bio-tech industries and is popularly known as the 'silicon valley of India' (Zanoli, et al., 2017). In the last two decades, Bengaluru has seen unprecedented growth in the field of industrial, commercial and institutional sectors. This phenomenal growth has resulted in unplanned urban activities surrounding Bengaluru and increase in population and construction activities. Bengaluru has an estimated population of 12.34 million in its urban area in 2017, up from 8.5 million in 2011 (Power, et al., 2016).

It is now the 24$^{th}$ most populous city in the world and the fastest growing Indian metropolis next to New Delhi. This fast growth in population is posing tremendous pressure on infrastructure and vehicle population. Around 1,750 new vehicles are registered in the city every day and the vehicle population in Bengaluru has crossed 80.45 lakh vehicles, five times more than what Bengaluru roads can officially handle. The city has overtaken Mumbai, Hyderabad and Chennai (Siddika, et al., 2016). As a result, traffic speeds have slowed down to around 10 kilometres per hour. Experts say the poor condition of public services and high fares, bad last mile connectivity, exuberant parking fee at metro station and lack of suburban trains are pushing people to opt for private vehicles. This increase in rising number of vehicles is in turn leading to congestion on roads, bringing down average speed and causing pollution level to rise. The average speed on city roads has dropped over the past few years due to rising number of vehicle population (Orellano, et al., 2017).

National ambient air quality standards are set by the Central Pollution Control Board (CPCB) that is applicable nationwide. The CPCB has been conferred this power by the air (Prevention and control of pollution) act, 1981 (Jacobs, et al., 2017). The current national ambient air quality standards as notified on 18$^{th}$ November 2009 is given in the Table 1 below (Shrivastava, et al., 2017).

**Tab. 1.** The standards in (μg/m$^3$) prescribed by CPCB (Central Pollution Control Board).

| **Area type** | **RSPM** | **$SO_2$** | **$NO_2$** |
|---|---|---|---|
| Industrial, residential,commercial and sensitive areas | 60 | 50 | 40 |

## Study Area

For the present study Bengaluru, the state head quarter of Karnataka is assessed for the air quality for the parameters mentioned in Table 1. Bengaluru is nicknamed the Garden city and was once called a Pensioner's Paradise. It is located on the Deccan Plateau in the south-eastern part of Karnataka at a height of over 900 m (3,000 ft) above the sea level and the city is blessed with pleasant climate throughout the year. The Bengaluru City limit is enclosed within 12°58' North latitude and 77°35' East longitudes. The city has dry tropical savannah type of climate. The rains are very frequent and the summers are warm, winters are cold, but no weather goes to its extreme. One can visit the city any time of the year and enjoy the pleasant climate (Shrivastava, et al., 2013).

Today as a large city and growing metropolis, Bengaluru is home to many of the most well-recognized colleges and research institutions in India. Numerous public sector heavy industries, software companies, aerospace, telecommunications and defense organizations are located in the city. Bengaluru is known as the Silicon Valley of India (Hugar, 2017) because of its position as the nation's leading IT exporter. A demographically diverse city, Bengaluru is a major economic and cultural hub and the fastest growing major metropolis in India.

The advance of economic development in the city has led to a rise in population and number of vehicles. Bengaluru is growing faster than ever, the urban region has grown three times faster than the state as a whole.

Vehicles contribute hugely to air pollution in Bengaluru. This has exerted a tremendous pressure on the infrastructure of the city which is now witnessing a significant increase in air pollutants and a deterioration of environmental quality and health. Air pollution is a growing problem in the city and according to a report by TERI (CPCB, 2010), it is said to be high, severe or critical in most of its areas. The main sources of pollution in the city are the exponential growth in the number of vehicles, that contribute to almost 50% of the pollution then come construction activities, paved and unpaved road dust, domestic pollution and the increased use of diesel generator sets.

The major pollutants emitted into the ambient air are $SO_2$, $NO_2$ and RSPM. Hence in the present study an attempt has been made to study the concentration of the above pollutants in the selected locations. The study area is shown in the Fig. 1 below.

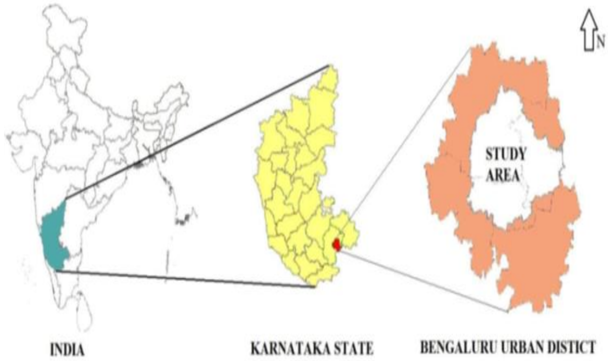


**Fig. 1 Study area map.**

### Sampling Stations

Four sampling stations have been selected for establishing the trend of air pollution. The areas are representative of various kinds of growths viz., commercial, residential, sensitive and industrial areas. Out of these four sampling stations one is residential/commercial, next is sensitive area, other is traffic and the last is industrial area.

High vehicular emissions, large amount of fumes coming out from industrial activities, constructional activities, solid waste burning, road dust are leading sources of high pollution in these areas. The Table 2 below shows the details of sampling stations selected for study.

**Tab. 2.** Details of sampling stations.

| Sl. no | Location name | Lattitude (N) | Longitude (E) | Zone type |
|---|---|---|---|---|
| 1 | Peenya industrial area | 13°01’23.2” | 77°31’22.4” | Industrial |
| 2 | Amco batteries, Mysore road | 12°57’08.44” | 77°32’26.0” | Residential/Commercial |
| 3 | Central silk board | 12°55’00.7” | 77°37’19.2” | Traffic |
| 4 | Indira Gandhi Child Care Center (IGCC) | 12°56’12.1” | 77°35’32.7” | Sensitive |

### Parameters Selected for Statistical Modeling

The parameters hampering air quality are many, however, three air quality parameters *viz.,* $SO_2$, $NO_2$ and RSPM are found to be critical as per the records obtained and are playing important role in deteriorating the urban air quality hence a detailed analysis of the same is made here. Ambient air quality reports of selected sampling stations were collected from Karnataka State Pollution Control Board (KSPCB) Bengaluru for the span from 2011 to 2019.

## CASE PRESENTATION

KSPCB is monitoring ambient air quality of Bengaluru city at 14 locations as per guidelines of the CPCB covering industrial, residential, commercial and other areas under National Ambient Air Quality Programme (NAMP). Continuous monitoring of air quality parameters is carried out round the clock using continuous Ambient Air Quality Monitoring Stations (CAAQMS).

Using high volume sampler three air pollutants as defined earlier were monitored at all the selected locations with a frequency of twice a week. As prescribed in National Ambient Air Quality Monitoring (NAAQM) standard methods of sampling and analysis. Atmospheric air was drawn for 8 hours’ time intervals for a period of 24 hours at a flow rate of 0.8 $m^3$/min to 1.2 $m^3$/min through glass fibre filter (Whatman GF/A).

Then the amount of particulate matter per unit volume of air passed was calculated on the basis of the difference between initial and final weights of the filter paper and the total volume of the air drawn during sampling. For gaseous sampling, the impenger was exposed for 24 hours at an impingement rate of 1 l/min to get one sample in a day. $NO_2$ was analysed by employing the Jacob-Hocheiser method on a spectrophoto meter at a wave length of 540 nm on the other hand $SO_2$ was analysed on a spectrophotometer at wave length of 560 nm by employing west-Greak method.

### Statistical Analysis

The mathematical model and evaluation of the subsequent regression analyses were done using JMP_10.0. Service pack software (version 6.0.6, Stat-Ease, Inc., Minneapolis, USA) [17]. The regression method consists of determining the exact mathematical form of relationship between the different pollutant variables and then using this relationship for prediction purposes. The regression model is fit to a set of sample data.

## RESULTS AND DISCUSSION

The minimum and maximum concentrations (μg/$m^3$) of various pollutants in the study area is given in the Table 3 given below.

**Tab. 3.** The minimum and maximum concentrations (μg/m³) of pollutants in the study area.

| Station name | $SO_2$ | | $NO_x$ | | RSPM | |
|---|---|---|---|---|---|---|
| | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** |
| Peenya industrial area | 2 | 30.3 | 11.3 | 54.1 | 49 | 255 |
| Amco batteries | 2 | 32 | 12.2 | 60.7 | 25 | 280 |
| Central silk board | 2 | 17.9 | 13.2 | 60.04 | 28 | 259 |
| IGCC | 2 | 16.3 | 10.5 | 98 | 24 | 285 |

The monthly concentration of pollutants *i.e.,* $SO_2$, $NO_2$ and RSPM are tabulated against months. The multiple linear regression analysis is carried out for each of the pollutant. Multiple linear regression analysis is carried for $SO_2$, $NO_2$ and RSPM concentrations as independent variables and year as dependent variable. Using the model the concentration of pollutants is predicted.

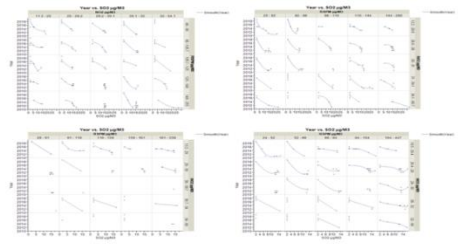

**Fig. 2 Monthly concentration of pollutants in the study area.**

It is represented in the form of tables and graphs. The graphical plot of the curve for Peenya industrial area is shown in the Fig. 2. This figure shows the relationship between Year in y axis and $SO_2$, $NO_2$ and RSPM along x axis for the period 2011 to 2019 for this study area.

It is clear from the Figure 2, that the pollutant concentration has an increase in trend for the study period. Multiple linear regression model is developed between the parameters of the study for Peenya industrial area, AMCO batteries, central silk board and IGCC areas. A first order regression model based on all predictors was fitted to the given dataset for to serve as a starting point.

The summary of fit and parametric estimates are presented in the Table 4 and their regression model are presented in equations (1-4) respectively for the areas listed above.

**Tab. 4.** The summary of fit and parametric estimates of the study area.

| Summary of fit | | Parameter estimates | | | | | |
|---|---|---|---|---|---|---|---|
| Rsquare | 0.813417 | Term | Estimate | Std error | t Ratio | Prob>(t) | |
| Rsquare adj | 0.810561 | Intercept | 2016.843 | 0.408411 | 4938.3 | <0.0001* | |
| Root mean square error | 1.08689 | $SO_2$ug/M³ | -0.33865 | 0.01283 | -26.4 | <0.0001* | |
| Mean of response | 2014.735 | $NO_2$ug/M³ | 0.042282 | 0.012023 | 3.52 | 0.0005* | **Peenya industrial area** |
| Observations (or sum wgts) | 200 | RSPM ug/M³ | -0.00336 | 0.002157 | -1.56 | 0.1213 | |
| Rsquare | 0.80137 | Term | Estimate | Std error | t Ratio | Prob>(t) | |
| Rsquare adj | 0.798491 | Intercept | 2016.643 | 0.426692 | 4726.2 | <0.0001* | |
| Root mean square error | 1.141575 | SO2ug/M³ | -0.34216 | 0.012222 | -28 | <0.0001* | **AMCO batteries** |
| Mean of response | 2014.905 | $NO_2$ug/M³ | 0.028738 | 0.012056 | 2.38 | 0.0180* | |
| Observations (or sum wgts) | 211 | RSPM ug/M³ | 0.0019 | 0.001692 | 1.12 | 0.2626 | |
| Rsquare | 0.824408 | Term | Estimate | Std error | t Ratio | Prob>(t) | |
| Rsquare adj | 0.81914 | Intercept | 2017.642 | 0.607468 | 3321.4 | <0.0001* | |
| Root mean square error | 1.091603 | $SO_2$ug/M³ | -0.3789 | 0.017731 | -21.37 | <0.0001* | **Central silk board** |
| Mean of response | 2014.885 | $NO_2$ug/M³ | 0.00708 | 0.016566 | 0.43 | 0.67 | |
| Observations (or sum wgts) | 104 | RSPM ug/M³ | -0.00089 | 0.001643 | 0.54 | 0.5912 | |
| Rsquare | 0.777439 | Term | Estimate | Std error | t Ratio | Prob>(t) | |
| Rsquare adj | 0.774198 | Intercept | 2017.265 | 0.346689 | 5818.7 | <0.0001* | **IGCC areas** |
| Root mean square error | 1.212563 | $SO_2$ug/M³ | -0.43098 | 0.016498 | -26.12 | <0.0001* | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mean of response | 2014.9 | $NO_2$ug/M$^3$ | 0.015643 | 0.009182 | 1.7 | 0.09 | |
| Observations (or sum wgts) | 210 | RSPM ug/M$^3$ | 0.003618 | 0.001757 | 1.86 | 0.0649 | |

The coefficient of determination ($R^2$) equals to 0.81, 0.80, 0.82 and 0.77 with their adjusted R squared values close to R squared indicate the summary of fit is significant respectively for Peenya industrial area, AMCO batteries, central silk board and IGCC areas as seen in Table 4.

The value of the parameters for prob>|t| falling in the vicinity of 0.05 have their major role in the regression model developed. The first order regression model for the above mentioned study areas are as below.

1. $Y=2016.84+0.04 \times NO_x+(-0.003) \times RSPM+(-0.34) \times SO_2$
2. $Y=2016.64+0.028 \times NO_x+0.002 \times RSPM+(-0.342) \times SO_2$
3. $Y=2017.64+0.071 \times NO_x+0.008 \times RSPM+(-0.379) \times SO_2$
4. $Y=2017.26+0.016 \times NO_x+0.003 \times RSPM+(0.431) \times SO_2$

The values of the coefficients are consistent with the physical effect of the respective variables. The coefficient of the oxides of nitrogen concentrations is expected to have the greater positive value in accordance with the fact that it is the highest correlated with increased level of ambient air pollution. On the contrary, the coefficient of the RSPM and sulphur dioxide has a negative sign and their p values are also greater than permissible limits state that their role is not directly influencing the pollution at all the places under study.

## CONCLUSION

The parameters studied though hardly have exceeded the limits, the yearly increase in the pollutant concentration trend is quite alarming. The vehicular emissions, incineration and constructional activities are also increasing year by year, a control measure has to be laid to avoid the possible damage in the near future. The stringent emission norms for vehicles have to be implemented for improving the quality of fuel and introducing alternate fuels (e.g., LPG), improving traffic management and promoting the use of green fuel by industries. The public transport system also has to be made more attractive and reachable so that it becomes the priority of mobility for the public, thus vehicular population can be kept under check. The statistical analyses gave a fair relation amongst the parameters studied and significantly developed the regression model for estimating the future pollution, which would facilitate to check the pollution inducers under a proper check.

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