Trend Analysis of Sulphur Dioxide in Bangalore & Effectiveness of Control Measures

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Abstract. Bangalore is a city in the Indian state of Karnataka. Many public sector businesses and R&D organisations, such as Hindustan Aeronautics Limited, Indian Space Research Organisation, Airbus, Boeing, General Electric (GE), Nokia, Toyota, and others, are housed here. Bangalore is known as India’s ‘Silicon Valley’, as it is home to many information technology (IT) enterprises. It is classified as a ‘non-attainment city’, meaning that pollution levels do not match the Central Pollution Control Board’s (CPCB) criteria. A high-level computer language called PYTHON was used to draw the trends of the air quality data collected over a 15-year period (2004-2019). PYTHON was used to clean, group, sort and aggregate the collected data to obtain the exceedance factor and draw the trend graphs. The policies of the Central Pollution Control Board (CPCB) and the Karnataka State Pollution Control Board (KSPCB) were examined to better understand the pattern. Over the years, the CPCB and the KSPCB have established a number of policies and guidelines, and the success or failure of these policies was examined in order to gain a better knowledge of the control measures. This report lays the groundwork for future policy implementation in other cities.

1. Introduction
At an elevation of 920 metres above sea level, Bangalore is located in the heart of the Precambrian Deccan Plateau (MSL). The coordinates are 12.54°N 77.22°E, and the area is 741 km² [1]. India is one of the world's developing countries, and it is facing a major air pollution challenge, which is a negative consequence of the growth process [2]. According to this report deaths linked with air pollution are due to the effects on lungs, damage to brain, throat issues and various forms of cancers. This shows a clear sign of the decreasing life-expectancy. A total of 2 billion individuals in India are exposed to excessive levels of air pollution [3]. During the year 2004 Bangalore saw a major change in the number of manufacturing industries. The industries include Engineering, wood, textiles, chemicals, plastics and metals. The air-quality became a cause of concern as there were no proper system in place to monitor pollution at the source. Hence, the CPCB and KSPCB started making action plans to step by step curb the pollution. Which will increase the air-quality. Only during the year 2014 National Air Quality Index was launched which included 8 pollutants. SO$_2$ is one among them. There is an increased need to understand the trends of SO$_2$ pollution in Bangalore. Understanding of the trends help the policy makers to identify the trouble areas and make policies to reduce the pollution levels. For the last two decades Karnataka government and the central government has tried to implement various pollution control methods to curb the rapidly increasing pollution levels in Bangalore. This paper tries to consolidate all the pollution control methods implemented from the year 2004-2019. It discusses the success and failure of the measures implemented in Bangalore. The
understanding can be used to implement the same measures in other highly polluted cities in India like Delhi, Mumbai etc.

2. Study Region
Karnataka state’s capital is Bangalore city. It houses major industrial areas and IT hubs [4]. The study area has been divided into three zones namely industrial, residential and sensitive areas. Air quality monitors are located in Victoria Hospital & Bangalore University (Sensitive areas), KHB, Graphite India & Peenya (Industrial areas) and Yeshwanthpur & AMCO Batteries (Residential Areas). These areas are represented in figure 1 taken from the map of Karnataka [5].

3. Methodology
Data was collected, grouped and aggregated using PYTHON and trends and impacts of the control measures were analysed individually for every region.

3.1. Data Collection
Data from 2004-2019 was collected from CPCB and Ministry of Environment, forests and climate change (MOEF & CC) with an accuracy of 98%. Field equipment adhering to NAMP guidelines were used for this purpose. The data was cleaned & sorted before using the PYTHON programming language.

3.2. Trend Analysis Using PYTHON
Python was made by Guido van Rossum in the year 1991. PYTHON serves as a high level general purpose programming language [6]. Application of this language is seen in most fields like Scientific & Numeric computing, software development, business applications, education and web development. In the recent years its potential has been tapped by civil engineers in urban planning for population forecasting, predicting traffic trends etc. This software was used in this study to sort, group and aggregate data to get simplified graphs for the analysis.
3.3. Data Analysis
Pollution data collected is presented as concentration levels in µg/m³. For every pollutant CPCB has established annual standards [7]. Every pollutant's Exceedance Factor can be determined using the following formula[8], and the criteria for comprehension have been tabulated in table 1.

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\text{Exceedance Factor (E.F)} = \frac{\text{Observed Annual Mean Concentration of a Criterion Pollutant}}{\text{Annual Standard for the Respective Pollutant}}
\] (1)

Using Eqn 1 the factors for the pollutants were found and the results are tabulated in table numbers 2, 3 & 4. The criteria for EF [8] has been shown in table 1.

| EF Range | Abbreviation used | Air Quality Levels          |
|----------|-------------------|-----------------------------|
| <0.5     | L                 | Low Pollution               |
| 0.5 – 1.0| M                 | Moderate Pollution          |
| 1.0 – 1.5| H                 | High Pollution              |
| >1.5     | C                 | Critical Pollution          |

4. SO₂ Levels
Sulphur dioxide (SO₂) is a poisonous gas that is colourless and has a pungent odour. It is produced when fossil fuels such as coal, petroleum, diesel, and other oils are burned. Sulphur dioxide is released even when other compounds containing sulphur are burned. Power stations, metal processing and smelting factories, and automobiles that run on fossil fuels are among the sources [9]. Sulphur dioxide emissions from diesel cars and equipment have long been a big problem.

4.1. Health Impact
In general air pollution is the cause of many premature deaths as it affects human health in various ways [10]. Sulphur dioxide can aggravate respiratory sickness by making breathing more difficult, particularly in youngsters, the elderly, and people with pre-existing disorders. When exposed to it, it also irritates the eyes. Longer exposures can aggravate a variety of lung problems, including coughing, asthma, chronic bronchitis, and respiratory tract infections, as well as cause cardiovascular effects [11].

4.2. Industrial Regions
Levels of SO2 in industrial regions Table 2 and figure 2 demonstrate the performance of Graphite India, KHB, and Peenya from 2004 to 2019. Graphite India's levels have been considerably below industry standards for the whole 15-year period studied. The highest SO2 level at KHB was 19.06 g/m³ in 2006. From the year 2017 until 2019, it has decreased by 89 percent, reaching 2 g/m³ and remaining steady. SO2 levels in the Peenya region have been fluctuating.
Table 2 Industrial Areas: SO₂ Levels (Annual Average), EF and Air Quality Levels.

| Year | Graphite India Levels | EF | Air quality | KHB Levels | EF | Air quality | Peenya Levels | EF | Air quality |
|------|-----------------------|----|-------------|------------|----|-------------|---------------|----|-------------|
| 2004 | 8.75                  | 0.18 | L           | 10.00      | 0.20 | L           | 9.28          | 0.19 | L           |
| 2005 | 8.63                  | 0.17 | L           | 8.81       | 0.18 | L           | 8.81          | 0.18 | L           |
| 2006 | 22.52                 | 0.45 | L           | 19.06      | 0.38 | L           | 17.78         | 0.36 | L           |
| 2007 | 17.41                 | 0.35 | L           | 16.41      | 0.33 | L           | 17.24         | 0.34 | L           |
| 2008 | 15.48                 | 0.31 | L           | 14.71      | 0.29 | L           | 14.92         | 0.30 | L           |
| 2009 | 16.57                 | 0.33 | L           | 14.83      | 0.30 | L           | 15.93         | 0.32 | L           |
| 2010 | 16.50                 | 0.33 | L           | 14.60      | 0.29 | L           | 15.43         | 0.31 | L           |
| 2011 | 19.65                 | 0.39 | L           | 18.29      | 0.37 | L           | 15.79         | 0.32 | L           |
| 2012 | 16.21                 | 0.32 | L           | 15.55      | 0.31 | L           | 15.61         | 0.31 | L           |
| 2013 | 15.04                 | 0.30 | L           | 14.00      | 0.28 | L           | 14.83         | 0.30 | L           |
| 2014 | 14.57                 | 0.29 | L           | 12.85      | 0.26 | L           | 14.24         | 0.28 | L           |
| 2015 | 4.95                  | 0.10 | L           | 4.69       | 0.09 | L           | 5.05          | 0.10 | L           |
| 2016 | 3.80                  | 0.08 | L           | 3.60       | 0.07 | L           | 2.00          | 0.04 | L           |
| 2017 | 3.8                   | 0.076| L            | 2          | 0.04 | L           | 2             | 0.04 | L           |
| 2018 | 2                     | 0.04 | L            | 2          | 0.04 | L           | 2             | 0.04 | L           |
| 2019 | 2                     | 0.04 | L            | 2          | 0.04 | L           | 2             | 0.04 | L           |

Standards: 50 µg/m³

Figure 2 Industrial Areas: SO₂ Levels, EF and Air Quality Levels

Residential Areas
SO₂ levels in the residential areas, AMCO Batteries and Yeshwantrup are shown in the table 3 and figure 3. In AMCO Batteries, SO₂ levels in the year 2004 was 7.40µg/m³. It increased till the year 2006 by 139.8%. Later it started decreasing till the year 2010 by 20%. It increased in the year 2011 again by 12.88%. Later on it started decreasing again and reached 2µg/m³ in the year 2017 i.e. 87.5%. It remained constant since then till 2019. Yeshwantrup’s SO₂ levels in the year 2006 was found to be 17.93µg/m³ and decreased for the
following two years by 15.4%. It started increasing in the year 2009 and continued till 2011 when it reached 18.68 µg/m³ i.e. by 23.13%. The highest level in the assumed period was in the year 2011. Since then the levels started decreasing and reached 2 µg/m³ i.e. reduced by 89.29% in the year 2017. Since then the levels were constant till 2019.

**Table 3** Residential Areas: SO₂ Levels (Annual Average), EF and Air Quality.

| Year | AMCO batteries | Yeshwanthpur |
|------|----------------|--------------|
|      | Levels | EF | Air quality | Levels | EF | Air quality |
| 2004 | 7.40   | 0.15 | L           | No Data | - | -           |
| 2005 | 8.75   | 0.17 | L           | No Data | - | -           |
| 2006 | 17.75  | 0.36 | L           | 17.93   | 0.36 | L           |
| 2007 | 16.85  | 0.34 | L           | 16.64   | 0.33 | L           |
| 2008 | 14.77  | 0.30 | L           | 15.17   | 0.30 | L           |
| 2009 | 14.88  | 0.30 | L           | 16.08   | 0.32 | L           |
| 2010 | 14.20  | 0.28 | L           | 16.30   | 0.33 | L           |
| 2011 | 16.03  | 0.32 | L           | 18.68   | 0.37 | L           |
| 2012 | 14.86  | 0.30 | L           | 16.17   | 0.32 | L           |
| 2013 | 14.50  | 0.29 | L           | 14.32   | 0.29 | L           |
| 2014 | 14.09  | 0.28 | L           | 13.09   | 0.26 | L           |
| 2015 | 5.09   | 0.10 | L           | 4.81    | 0.10 | L           |
| 2016 | 4.00   | 0.08 | L           | 3.60    | 0.07 | L           |
| 2017 | 2.00   | 0.04 | L           | 2.00    | 0.04 | L           |
| 2018 | 2.00   | 0.04 | L           | 2.00    | 0.04 | L           |
| 2019 | 2.00   | 0.04 | L           | 2.00    | 0.04 | L           |

Standards: 50 µg/m³
Figure 3 Residential Areas: SO\textsubscript{2} Levels, EF and Air Quality Levels.

**Sensitive Areas**

SO\textsubscript{2} levels in sensitive areas, Bangalore University and Victoria hospital are shown in the table 4. The SO\textsubscript{2} levels in the areas of Bangalore University was constant from the year 2011-2015 at 8.05μg/m\textsuperscript{3}, no monitoring stations were available in the area to record data before 2011. This was the highest level recorded in this area. Later on it decreased by 52.79% as it touched 3.80μg/m\textsuperscript{3} in the year 2016. In the years 2017-2019 the area recorded the lowest value at 2μg/m\textsuperscript{3}. The SO\textsubscript{2} level in Victoria hospital in the year 2004 was 7.52μg/m\textsuperscript{3} and it increased till the year 2006 by 138.16%. Later the trend decreased till the year 2011 by 30.48% and there was a slight increase in the year 2012 by 5.22%. From 2012-2017 it decreased drastically by 83.93% and has remained constant till 2019. The trend showed that the values fell below the prescribed levels of 20μg/m\textsuperscript{3}.

**Table 4** Sensitive Areas: SO\textsubscript{2} Levels (Annual Average), EF and Air Quality Levels.

| Year | Bangalore university | Victoria hospital |
|------|----------------------|-------------------|
|      | Levels | EF | Air quality | Levels | EF | Air quality |
| 2004 | No Data | - | - | 7.52 | 0.38 | L |
| 2005 | No Data | - | - | 9.04 | 0.45 | L |
| 2006 | No Data | - | - | 17.91 | 0.90 | M |
| 2007 | No Data | - | - | 16.77 | 0.84 | M |
| 2008 | No Data | - | - | 15.09 | 0.75 | M |
| 2009 | No Data | - | - | 14.39 | 0.72 | M |
| 2010 | No Data | - | - | 13.30 | 0.67 | M |
| 2011 | 8.05 | 0.40 | L | 12.45 | 0.62 | M |
| 2012 | 8.05 | 0.40 | L | 13.10 | 0.66 | M |
| Year | SO₂ Level (µg/m³) | EF (µg/m³) | Air Quality Level |
|------|------------------|-----------|------------------|
| 2013 | 8.05             | 0.40      | L                |
| 2014 | 8.05             | 0.40      | L                |
| 2015 | 8.05             | 0.40      | L                |
| 2016 | 3.80             | 0.19      | L                |
| 2017 | 2.00             | 0.10      | L                |
| 2018 | 2.00             | 0.10      | L                |
| 2019 | 2.00             | 0.10      | L                |

Standards: 20 µg/m³

Figure 4 Sensitive Areas: SO₂ Levels, EF and Air Quality Levels.

5. Analysis of the Effectiveness of the Control Measures on SO₂ Levels

Trend of SO₂ pollutant in all the 3 areas have been gradually increasing from 2004 and has reached the peak in 2006. Four meetings were held in New Delhi by the CPCB in the year 2004 to make decisions on the ways to reduce the amount of pollutants in some of the most populated cities of India that included Bangalore. The following decisions were approved in those meetings,

Firstly approval for National Emission Standards for Pesticide manufacturing industry. Secondly approval for the Emission Standards for sulphuric acid plants. One such plant Srinivasa Industrial chemicals is located in Peenya was established in 1990. Lastly, Approval for effluent and emission standards for petroleum oil refineries. One such refinery is Bhuruka Gases Ltd, established in 1974 and located in Doddanekkundi Industrial area. After all the regulations were made, the amount of pollutants decreased in small amounts.

In the following year 2005, the sales of vehicles were increased by 14% as per Annual report KSPCB and there was an increase of SO₂ level in the residential and sensitive areas [12]. The amount of SO₂ was recorded the highest in 2006. This was mainly due to traffic congestion in Bangalore and the Bangalore Metropolitan Region Development Authority made a decision to spend 6000 crores on development of Arterial ring roads, radial roads and 30000 crores on townships coming up at Hosakote, Ramanagar, Magadi and Kanakapura.
In the year 2006, few decisions were made by the central board to reduce pollution in major polluted Indian cities as stated, the board had approved the Environmental Standards and Code of Practice for Pollution Prevention for Sponge Iron Plants. There’s one such plant Prakash Sponge Iron Pvt Ltd located in Jayanagar. Also the board approved the proposal of National Emission Standards for Common Hazardous Waste Incinerator. To help Small Scale Industry units which have Diesel Generator Sets as the only source of power, the board had submitted proposal to Government to fix consent fee based on Kilo Volt Ampere rating rather than capital investment.

In the year 2007 the Control Board started funding to create awareness on pollution control. The board approved an expenditure of Rs. 1, 75, 000/- towards advertisements on televisions. Two such programs were aired on Doordarshan and India Today on how to control pollution in the environment.

The CPCB held another meeting on April 12, 2008, at which the following measures were announced: charging sampling and analysis fees for air quality analysis, limiting the storage duration for incinerable hazardous wastes by the Hazardous Waste Treatment, Storage, and Disposal Facility for Incineration Operators. These measures can be attributed to the decrease in pollution in the next years. Also a few months before the Deepavali festival which was celebrated on 17th October 2009 the KSPCB has displayed hoardings in all the districts in the State depicting the ill effect of bursting of crackers on environment and health of people. In spite of all these awareness measures on 21st October 2009 KSPCB reported an increase in air pollution by 7% from 15.48 μg/m³ of the previous year to 16.57μg/m³ [13] during this festive season as compared to the previous year.

A major problem started when the amounts of pollutants started increasing again in the residential areas in following year 2010. The main reason was due to the pollutants released by the vehicles were increasing and in the year 2010 Bharat Stage III was introduced nationwide and soon the amount produced started decreasing in sensitive area in the year 2011, whereas in the industrial and residential areas the SO₂ levels increased lightly. Hence, the government made a decision to scrap vehicles that are more than 10 years old due to the increase in pollutants. Namma metro was introduced in the year 2011, which considerably reduced the amount of pollutants from vehicles [14].

In the year 2012, for the small scale industries installation of the Latest Pollution Control Systems was made mandatory [14]. Some types of air pollution control equipment used in the industrial applications are, air filters, electrostatic precipitators, scrubbers, cyclones, bio filters, mist collectors, incinerators and catalytic reactors. About 65, 00, 00 saplings were planted in the State to help greening of industrial areas and open spaces to create a green belt which acts as a Carbon sink, this success encouraged. The board, in the year 2011, had also encouraged Small Scale industries to adopt latest Pollution Control Systems by helping them to speed up the process of giving permissions and low interest loans.

In the same year Industrial sectors have been targeted for creating awareness and promoting Clean Development Mechanisms in order to better comply with pollution control legislation and to upgrade pollution control technologies. Plastics, dairy, hazardous waste recyclers, sponge iron and desiccated coconut industries were among the businesses covered. It also motivated Schools and NGO’s to take up Greening initiatives. As the board achieved a success in the sapling plantation in the year 2011 one encouraged KSPCB to mandate a condition to provide 33% of the entire project area of the industry to be utilised for green belt and therefore about 13, 47,583 saplings were planted in the year 2013- 2014 [15].

In 2013, the CPCB updated the list of Red, Orange, and Green category activities with the purpose of introducing uniformity in classification across the country and for the issuing of approval, and other approvals [15]. This was done in order to cut the pollution levels even more, and the results can be seen in figures 2, 3, and 4. Approval of the Development of Uniform National Air Quality Index and approval to revise the Environmental Standards for Brick Kilns were among the approvals made for the major polluted cities at a meeting held on June 26, 2014 by the Central Pollution Control Board to discuss strategies to
further reduce pollutants. A few similar kilns may be found in Bangalore, such as the Basant Brick Kiln in Sathyarayanagar located in Sarjapur road, Keerthi Brick Works located in Bannerghatta Road.

In the year 2016 there was a decrease in the SO\textsubscript{2} trend. The Board has taken steps to outlaw individual incinerators within the city limits, as directed by the KSPCB, and has announced a fine of Rs. 25,000/- for each case of burning. [16]. The meeting of the Central Pollution control Board on 08-07-2016 paved way for the following initiatives, awareness programmes were conducted in Schools and public places like Malls, initiated by the Central Board with the help of the State Government across India, introduction and awareness creation on Eco-friendly Ganesha Festival and Deepavali.

In the year 2017, BS IV norms were enforced in the country which helped in decrease of SO\textsubscript{2} levels. SO\textsubscript{2} pollution drastically reduced in the year 2017. Another meeting was held on 06-05-2017 by CPCB to even more minimize the pollution and the following approvals were made: Approval of ‘Pet Coke’ as Approved Fuel under Section 2(d) of the Air (Prevention and Control of Pollution) Act, 1981. Pet cokes are used in electrical power plants and cement kilns. They are typically high in heating values and they don't produce ash when burnt. They are used an alternative for coal because coal ash will be produced during the combustion of coal which is harmful when they settle in water bodies and also burning of coal leads to SO\textsubscript{2} pollution [17]. It can be concluded that due to control measures implemented by CPCB and KSPCB the levels of SO\textsubscript{2} pollutant for all the three areas in the period 2004-2019 were within the permissible limits of 50 µg/m\textsuperscript{3}.

6. Conclusions
The data was grouped and sorted to get meaningful graphs and the trends were analysed. The following conclusions can be drawn from the analysis. Awareness creation has been the key to initiate the success of control measures. Making latest pollution control systems mandatory for small scale industries proved beneficial and it should be implemented on a wider scale. The plantation of sapling to act as a carbon sink was also beneficial. Research work on using alternative fuel to the conventional diesel, coal and petrol must be funded by KSPCB and CPCB which will prove beneficial on the longer run.

References
[1] Narendra Reddy, N and Kusuma Rao G (2018), ‘Contrasting variations in the surface layer structure between the convective and non-convective periods in the summer monsoon season for Bangalore location during PRWONAM’, Journal of Atmospheric and Solar-Terrestrial Physics, vol. 167, pp. 156-168, https://doi.org/10.1016/j.jastp.2017.11.017
[2] World Health Organisation, 2008, "Air Quality and Health," World Health Organisation, Geneva
[3] Pawankar, R (2019), ‘Climate change, air pollution, and biodiversity in Asia Pacific: impact on allergic diseases’, Asia Pacific Allergy, vol. 09, no. 02, pp. 1-4, https://doi.org/10.5415/apallergy.2019.9.e11
[4] Sudhira, H, S, Ramachandra, T, V, Bala Subrahmanya, M, H (2007), Bangalore, Cities, vil. 24, no. 05, 379- 390, https://doi.org/10.1016/j.cities.2007.04.003
[5] Karnataka 2016: Districts, Cities, Towns and Outgrowth Wards – Population Statistics in Maps and Charts, February 2016
[6] Sousa Miranda, Diego de, ‘Python: a Programming Language for Software Integration and Development.’ J Mol Graph Model, 1999
[7] Central Pollution Control Board, 2005-2006, Annual Report
[8] Subham Roy and Nimai Singha (2020), ‘Analysis of Ambient Air Quality Based on Exceedance Factor and Air Quality Index for Siliguri City, West Bengal’, Current World Environment, vol. 15, no. 02, pp. 235-245

[9] Qian Zhang, Jun Nakatani, Yuli Shan, Yuichi Moriguchi 2019, ‘Inter-regional spillover of China's sulfur dioxide (SO2) pollution across the supply chains’, Journal of Cleaner Production, Volume 207, 418-431, https://doi.org/10.1016/j.jclepro.2018.09.259

[10] Balakrishnan, K, Dey, S, Gupta, T, Dhaliwal, R. S, Brauer, M, Cohen, A. J, et al. (2019), ‘The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017’, The Lancet Planetary Health, vol. 03, no.01, pp. e26–e39

[11] Tunnicliffe, W, S, Hilton, M, F, Harrison, R, M and Ayres J, G, (2001), ‘The effect of Sulphur dioxide Exposure on Indices of heart rate variability in normal and asthmatic adults’, European Respiratory journal, vol. 17, no. 04, pp. 604-608

[12] Karnataka State Pollution Control Board, 2005-2006, Annual report

[13] Karnataka State Pollution Control Board, 2008-2009, Annual report

[14] Karnataka State Pollution Control Board, 2011-2012, Annual report

[15] Karnataka State Pollution Control Board, 2013-2014, Annual report

[16] PTI, ‘NGT bans open waste burning’, The Hindu, Dec 23, 2016

[17] Central Pollution Control Board, 2017, Annual Report