Assessment and prediction of PM10 concentration using ARIMA

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Abstract. Urban air pollution is rapidly becoming an environmental issue of global concern, affecting public health, regional weather, and climate. The air quality crisis in cities is mainly caused by vehicle emissions. A city's air quality is assessed using the Air Quality Index (AQI), which analyses concentrations of air pollutants such as PM10, sulphur dioxide SO2, and nitrogen dioxide NO2. The current study on air pollution was carried out in the SG Halli area of Bangaluru and required air pollutant data was collected from the Karnataka State Pollution Control Board (CPCB). With the exception of PM10, the pollutant concentration was within the permissible limits set by the Central Pollution Control Authority (CPCB). Pollutant concentrations were analyzed using meteorological variables such as relative humidity (RH), temperature (T), wind direction (WD), wind speed (WS), and solar radiation (SR). PM10 concentrations are predicted using an auto-regressive integrated moving average (ARIMA) model. PM10 concentrations were well predicted by ARIMA model. On the AQI scale, it can be seen that the atmospheric environment of SG Halli is moderately polluted.

Keywords: PM10, Pollutants, AQI and ARIMA

1. Introduction
Modernization and industrialization in developing countries have led to an increase in the use of fossil fuels and their derivatives [1]. Exaggerated transport associated with industrialization has polluted the atmosphere to the point where it is slowly losing its self-cleaning capacity. Anthropogenic emissions of pollutants in a geographical area will change the composition of the atmosphere, chemistry, and life cycles in downwind regions [2]. Air quality deterioration can be a significant environmental downside affecting several urban and industrial sites, and thus nearby regions. In fact, there is an exhaustive correlation between poor air quality and poor health, as air pollution leads to respiratory problems, affects hyperbolic manifestations of bronchial asthma, cancer, metastases, nervous and vascular systems in humans, impairs lung function, diseases and even death [3]. Episodes of poor air quality in cities, both in developed and developing countries, demonstrated the need for a local air quality management system to protect people and materials from the negative effects of air pollution [4, 5]. India, one of the fastest developing countries in the world, is experiencing a sharp increase in atmospheric pollution [6,7]. Many metropolitan cities in the country, especially Delhi, Calcutta, Mumbai, Bangalore, and Chennai suffer from poor air quality, mainly in their central business district, the CBD, and along major roads in adverse weather conditions [8]. AQI is one of the criteria that measures / categorizes the city on the basis of a pre-defined set of clearly recognized criteria, which should be universal and independent of the level of
pollution [9]. Fine dust refers to a combination of solid and liquid droplets found in the air. Particles such as mud, dirt, soot, or smoke are huge enough to be seen by the eye. Fine dust includes inhalable particles, usually ten micrometers or smaller in diameter. Fine dust impairs lung function, exacerbates respiratory symptoms, aggravates asthma, develops chronic bronchitis, and can even lead to premature death [10,11]. In general, fine dust causes a variety of diseases and its presence is considered more dangerous to human health than any other common air pollutant. The sources of SO2 associated with Bangalore City are mainly due to the combustion of fossil fuels and diesel exhaust gases, and the resulting health effects are inflammation of the respiratory tract, lung dysfunction and irritation of the eyes, mucous membranes and skin [12]. SO2 is known to be responsible for increased asthma attacks, worsening heart and lung diseases, and reduced resistance to respiratory diseases in adolescents [13]. NO and NO2 are man-made pollutants, the addition of which is stated as oxides of nitrogen and expressed as NOx [14]. Exposure to NOx is associated with adverse effects on the respiratory tract and inflammation in healthy individuals and increased respiratory symptoms in people with asthma. In general, PM causes a variety of diseases and its presence is said to be more dangerous to human health than any other common air pollutant, and the main pollution in Bangalore is due to the presence of fine dust in the ambient air. The aim of this study is to assess the air quality at SG Halli and to predict PM10 concentrations using the ARIMA model.

2. Materials ans methods
2.1. Site specifications
The sampling site in the current study was at Nisarga Bhavan, S.G.Halli, Basaveswara Nagar, Bangalore, India. Bangalore is the capital city of Karnataka. It has a population of over 13.9 million people, according to the 2019 census, making it the third-largest city and the fifth most populous urban agglomeration in India. Bangalore is located in southern India, on the Deccan Plateau at an altitude of over 900 m above sea level, the highest among India's major cities. Bangalore has a tropical savanna climate with pronounced wet and dry seasons. Due to its altitude, the city enjoys a temperate climate throughout the year compared to other cities in India. The coolest month is January, with an average low temperature of 15.1 °C. The hottest month is April, with an average extreme temperature of 35 °C. Bangalore receives rainfall from both the northeast and the southwest, and the wettest months are September, October, and August. The climate of Bangalore is divided into four seasons as per the classification given by Indian meteorological Department. The four seasons are winter months (January–February), pre monsoon or summer months (March - May), Monsoon months (June - September) and Post monsoon months (October -December). The criteria pollutants namely NO2, PM10, CO and SO2 are considered for determining the indexes for Bangalore.
2.2. Sampling and analytical procedure
The pollutant data were continuously recorded over a 24-hour period every day at an interval of one hour over the period from September 2019 to January 2020. Parameters taken into account for the study included fine dust PM10, sulfur dioxide SO2, and nitrogen oxides such as NO2 and NOx. Sampling at the station was carried out with high volume samplers, ensuring that the sampler was placed in a free atmosphere without disturbance from standing areas or large buildings and at a height of 2.0 m. As stipulated in the NAAQM standard methods for sampling and analysis, the sampling and analysis of the samples took place. A known quantity of air was drawn at a rate of 0.8 to 1.3 m3 / min on eight hourly bases for 24 hours using a pre-balanced glass fiber filter paper, and fine dust was determined using the gravimetric method. Gaseous pollutants, in particular SO2 and NO2, were collected with the absorption solution on four hourly bases for 24 hours by air suction at a rate of 1 LPM and analyzed using the West method or the Geaek and Jacob and Hochheiser method. Pollutant concentrations were expressed in ug/m3.

2.3. Statistical analysis of monitored data
Table 1 shows the descriptive statistics for meteorological data and air pollutants concentration for a period of August 2019 to January 2020 in Bangalore city. The statistics include minimum, mean, maximum, standard deviation, Skewness and Kurtosis. Overall, the concentration of PM10, SO2, NOx, and CO ranged from 10.4063 to 136.829 µg/m3, 0.007 to 11.885 µg/m3, 8.196 to 23.845 µg/m3, 0.05625 to 1.30411 ppm respectively. On the other hand, meteorological parameters i.e., wind direction (WD), wind speed (WS), relative humidity (RH). Temperature (T) and Solar radiation (SR) ranged from 17.57 to 294.04, 0.5506 to 2.7239, 24.07 to 93.06 %, 6.063 to 31.115 °C, 73.76 to 347.17 respectively. Meteorological data show low levels of skew and kurtosis, which

Figure 1. Locations of sampling station S G Halli, Bengaluru.
could indicate that their distribution is slightly different from the normal distribution, but PM10, SO2, have high levels of skew and kurtosis, which may indicate that their distribution is significantly different from the normal distribution.

2.4 ARIMA

ARIMA linear models have taken over many areas of time series forecasting. The linear function is based upon three linear components: auto regression (AR), integration (I), and moving average (MA) method. The autoregressive or ARIMA (p,0,0) method is represented as follows.

\[ Y_t = q_0 + f_1 Y_{t-1} + f_2 Y_{t-2} + \cdots + f_p Y_{t-p} + e_t \]  

(1)

where \( p \) is the number of autoregressive terms, \( Y_t \) is the forecasted output, \( Y_{t-p} \) is the observation at time \( t-p \), and \( f_1, f_2, \ldots, f_p \) is a finite set of parameters. The f terms are determined by linear regression. The \( q_0 \) term is the intercept, \( e_t \) is the error associated with regression. The time series depends only on \( p \) past values of itself and a random term \( e_t \). The moving average or ARIMA (0,0,q) is represented as

\[ Y_t = m - q_1 e_{t-1} - q_2 e_{t-2} - \cdots - q_q e_{t-n} + e_t \]  

(2)

where \( q \) is the number of the moving average terms, \( q_1, q_2, \ldots, q_q \) are the finite weights or parameters set, and \( m \) is the mean of the series. This time series depends only on \( q \) past random terms and a present random term \( e_t \). As a particular case, an ARIMA(p,0,q) or ARMA(p,q) is a model for a time series that depends on \( p \) past values of itself and on \( q \) past random terms et. This method has the form of equation (3).

\[ Y_t = q_0 + f_1 Y_{t-1} + f_2 Y_{t-2} + \cdots + f_p Y_{t-1} + m - q_1 e_{t-1} - q_2 e_{t-2} - \cdots - q_q e_{t-n} + e_t \]  

(3)

3. Results and discussion

3.1. Daily Variation of Pollutant Concentrations

The daily average variation of criteria pollutants of Bangalore city during the period August 2019 to January 2020 is shown in figure 2. From the graph it can be observed that the daily average concentration of PM10 was highest in the month of November (94.74µg/m³) and December (136.83µg/m³) whereas PM10 is lowest in the month of October (10.41 µg/m³) during the study period. The daily average concentration of PM10 is less than 40 µg/m3 in the entire month of August. This variation is mainly due to location of the monitoring stations and other local factors such as economic development and meteorological conditions. The high variation might be also due to resuspension of road dust, soil dust, and vehicular traffic and nearby industrial emission. The daily average concentration of NOx observed, were in the range of 8.2µg/m³ to 23.85µg/m³ during the study period as against the national standards.
of 40µg/m³ to 30µg/m³. This variation in concentration of NOx may be attributed to variation in traffic density, distance of monitoring site from roads and other meteorological parameters. The concentration of SO₂ remained in the range of 1µg/m³ to 4µg/m³ during the period respectively except for few days where the concentration of SO₂ exceeded more than 10 µg/m³ which is much below the national standards of 80 µg/m³. This may be due to various pollution control measures, adopted by different industrial sectors like use of low Sulphur content diesel in automobiles.

![Figure 2. Daily average concentration of pollutants](image)

3.2. Monthly variation of Pollutant Concentrations.

The monthly average variation of criteria pollutants of Bangalore city during the period August 2019 to January 2020 is shown in figure 3. From the graph it can be observed that the monthly average concentration of PM₁₀ was highest in the month of October (46.44 µg/m³) whereas PM₁₀ is lowest in the month of August (25.35 µg/m³) during the study period. The monthly average concentration of NOₓ was highest in the month of December (16.82 µg/m³) whereas NOₓ is lowest in the month of September (9.71 µg/m³). From the graph it is observed that the monthly average concentration of SO₂ is less than 5µg/m³ which is very small than the standards prescribed by NAAQS (80 µg/m³).
3.3. AQI

The figure 4 shows monthly average AQI values. The AQI increased gradually from August to December. The maximum AQI was observed in the month of December whereas lowest in the month of August. The AQI values are in the range of 20 to 50 therefore study area can be categorized as good in the view of health impacts.

![Figure 4. AQI of Bangalore](image)

3.4. Meteorological parameters and air pollutants

The Pearson correlation was calculated in Table 2 to see the relationship between different air pollutant concentrations and meteorological factors such as wind direction, wind speed, relative humidity, temperature, and solar radiation. It can be found that temperature has a negative correlation with wind direction, wind speed, and relative humidity. Solar radiation also has a negative correlation with wind direction and relative humidity. SO2 has a negative correlation between wind direction and wind speed. NO has a positive correlation with humidity and solar radiation and a negative correlation with temperature. CO has a negative relationship with wind direction, wind speed, humidity, and NO, and a positive relationship with temperature, SO2, and NOx. PM10 has a negative relationship with wind
speed, humidity, NO, NO₂, and a positive relationship with CO. Weather conditions play a crucial role in air pollution as they, directly and indirectly, influence emissions, transport, formation and deposition of air pollutants. Several research studies on the effects of weather and air pollution on humans have found links between environmental conditions and air pollutants. These studies have shown that meteorological factors such as wind speed and direction, temperature, and relative humidity will have a significant impact on air quality. Another study found that fine dust particles are mainly controlled by wind and temperature and that 60% to 74% of today's fluctuations in fine dust concentration can be explained by meteorological parameters and that any change in PM2.5 concentration is well correlated with pressure, relative humidity and wind speed [15, 16, 17].

Table 2. Person's Correlation matrix

| Variables | WD | WS | R  | T  | SR | SO₂ | NOX | NO  | NO₂ | CO  | PM10 |
|-----------|----|----|----|----|----|-----|-----|-----|-----|-----|------|
| WD        | 1  |    |    |    |    |     |     |     |     |     |      |
| WS        | 0.598 | 1  |    |    |    |     |     |     |     |     |      |
| R         | 0.534 | 0.648 | 1  |    |    |     |     |     |     |     |      |
| T         | -0.164 | -0.182 | -0.251 | 1  |    |     |     |     |     |     |      |
| SR        | -0.269 | 0.016 | -0.255 | -0.15 | 1  |     |     |     |     |     |      |
| SO₂       | -0.223 | -0.266 | -0.042 | 0.041 | 0.039 | 1  |     |     |     |     |      |
| NOX       | 0.004 | 0.009 | -0.115 | 0.45 | -0.041 | 0.006 | 1  |     |     |     |      |
| NO        | -0.093 | 0.244 | 0.213 | -0.196 | 0.235 | -0.045 | 0.094 | 1  |     |     |      |
| NO₂       | -0.16  | -0.234 | -0.314 | 0.372 | 0.003 | 0.135 | 0.705 | -0.003 | 1  |     |      |
| CO        | -0.566 | -0.784 | -0.67  | 0.312 | -0.09 | 0.18 | 0.173 | -0.276 | 0.156 | 1  |      |
| PM10      | 0.06  | -0.421 | -0.18  | 0.056 | -0.107 | 0.094 | -0.103 | -0.27 | -0.16 | 0.314 | 1    |

3.5. ARIMA

In order to construct effective models for PM10 concentration forecasting, we fit an ARMA/ARIMA model to original PM10 data. The daily average PM10 concentrations from July 2019 to January 2020 were selected as training samples performance by using the ARIMA model in forecast PM10. Generally, this ARIMA method is capable of monitoring the pollution situation. The simplest solution is to use statistic modelling and especially the ARIMA approach. If the info at time t is Xₜ and therefore the data at the period of time before t is named Xₜ₋₁, the difference is Xₜ₋₋₁. So as to work out the optimal lag for these variables, we used several plots including ACF and CCF plots. We consider the many lags as explanatory variables from the plots of ACF of PM10 and plots of CCF of PM10 and explanatory variables. The Observed values and predicted values statistic plot for Figure 5 indicate the performance of the ARMI model is sort of satisfactory. Moreover, supported statistic plot in Figure 5, it also demonstrates the potential of ARIMA model in analysis the seasonal data pattern occurred in air quality which is that the comparison between actual and predicted values ARIMA model was wont to find the foremost suitable model to predict the PM10 concentrations in Bangalore by using three error measures. The results show that ARIMA (2,1,3) × (1, 0, 0) is the best suited model to predict PM10 concentrations in Bangalore city.

Statistical significance of ARIMA model is shown in table 3. The P-value is used to check the significance of the model. The values of P are found to be zero, for AR(2), MA(1) and MA(3). The value of P is less than 0.005 i.e. (P<0.005) indicates the models significance. Higher values of T indicates that the parameter used for ARIMA model have significant difference.
Table 3. Estimated parameters

| Type  | Coefficient | SE Coefficient | T    | P    |
|-------|-------------|----------------|------|------|
| AR 2  | 0.4096      | 0.0902         | 4.54 | 0    |
| MA 1  | 0.7789      | 0.0318         | 24.49| 0    |
| MA 3  | 0.2096      | 0.0453         | 4.62 | 0    |
| Constant | 0.08851    | 0.07223        | 1.23 | 0.223|

Figure 5. Predicted versus observed PM10

4. Conclusion
The approach proposed in this paper enables environmental engineers to study and characterize concentration measurements of air pollutants over time, especially in areas with very high road traffic. In particular, such an approach allows us to provide a true estimate of the substances analyzed and to reconstruct the ultimately missing data within the time domain. By using ARIMA techniques, it is possible to count on endless and valid knowledge, with the further goal of reducing measurement uncertainty as PM10 concentrations increase in Bangalore. Accordingly, we have proposed a forecasting model for PM10 and examined some important characteristics that influence PM10 concentration. The statistical model used in forecasting is a crucial tool for monitoring and controlling air quality. It is useful to demand rapid action before the situation worsens during the day.

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