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Statistical Analysis of SO_2 and NO_2 with Respect to Meteorological Parameters (Gwalior, India)

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Abstract

The present study is carried out in Gwalior to know the level of pollutants viz sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). In this study, both NO_2 and SO_2 were collected during different seasons, and estimation was done using chemical methods. The methods used for the determination of SO_2 and NO_2 in the ambient air of Gwalior was (Modified West and Geake method) and (Modified Jacob and Hochheisier). The SO_2 from the air stream was absorbed in a sodium tetramer curate solution. NO_2 was collected by bubbling air through a sodium hydroxide solution to form a stable solution of sodium nitrate. Meteorological parameters like temperature, relative humidity were recorded by thermometers and hygrometry during the sampling. Rainfall data was taken from Indian Meteorological Department, New Delhi, for four sampling years. The statistical analysis was carried out between the level of pollutants SO_2 and NO_2 measured and meteorological parameters recorded during the sampling. This study observed that pollutants were very high in winter and summer compared to monsoon and post-monsoon periods due to the heavy transport movement and favourable meteorological conditions like temperature, humidity, rainfall, and wind speed and directions.

***Keywords**:* SO_2, NO_2, Meteorological parameters, Gwalior, India

Introduction

Air pollution is considered a serious environmental concern throughout the world. The activities of industrialization, urbanization along with fast growing population, pollute the environment. As a result of these activities, the most dangerous pollutants like NO_2, SO_2, SPM, and RSPM enter the atmosphere, resulting in air pollution. Particulate and gaseous pollutants from vehicles and industrialization are responsible for polluting the environment, which in turn is causing many health problems. The gases pollutants SO_2 and NO_2 emitted are very reactive, short-lived are emitted from both anthropogenic and natural activities. Various sources that led to the increase in the concentration of NOx ($NOx=NO+NO_2$) include activities like the burning of fossil fuels, agricultural residues, vehicular emission, besides natural activities like volcanic emissions and lightning and thundering [1]. The NO_2 is also used in the nitrogen cascade of air, water, and soil [2, 3], which undergoes various oxidation processes in the atmosphere of air [4], and results in the formation of ozone [5, 6]. The main sources that led to the emission of SO_2 are natural activities like volcanic and anthropogenic activities. SO_2 is also emitted by vehicles and combustion of fossil fuels, and by the refinement process of sulfide ores. During the volcanic eruption, the SO_2 gas is emitted into

the atmosphere at high altitudes above the planetary boundary layer (PBL), while anthropogenic activities which led to the emission of SO_2 occur slightly above the PBL. The chemical reactions that occur in the PBL involving both gases SO_2 and NO_2 result in the production of sulfate and nitrate aerosols and tropospheric ozone [6]. In the presence of sunlight NO_X and sunlight react with volatile organic compounds (VOCs) undergo oxidation results in the formation of ozone (O_3) which is a major pollutant in the troposphere and greenhouse gas (EPA, 2013). The nitrate aerosols are formed by the oxidation of NO and nitric acid (HNO_3) with ammonia (NH_3). The sulphate aerosols are formed by oxidization of SO_2 with the hydroxyl radical (OH) in gas phase reaction or in aqueous-phase when it undergo reaction with O_3 or hydrogen peroxide (H_2O_2). Both sulfate and nitrate aerosols pose in the form of fine particulate matter pollution poses serious health concerns [7, 8]. These aerosols are observed to degrade visibility, and are causing various problems by affecting both plants and soil, and brings climatic changes which are found to promote radioactive and result in the medication of cloud formation and optical properties [9, 10]. The gaseous pollutants emitted into the atmosphere SO_2, NO_2, along with their oxidative products like O_3 and PM2.5, are known as "criteria pollutants" [11, 12].

Study Area

Gwalior is one among the four major and smart cities of Madhya Pradesh, India and has historical importance (Fig. 1). It is located 319 km south of Delhi. The area of Gwalior is 780 km^2. The population of Gwalior district, according to the 2011 census is 2,030,543 with a population density of 5,478 per km. The vehicular registration is MP 07. The city has its historical importance and consists of a fortress that has been ruled by several historic northern Indian kingdoms. Among the major kingdoms that ruled Gwalior City included Kachchapaghatas in the 10^{th} century, Tomars in the 13^{th} century, after Tomars it was passed on to the Mughal Empire, then to the Maratha in 1754, followed by the Scindia in the 18^{th} century. A study of urban pollution globally in 2016 found that the city Gwalior in 2016 had the highest level of air pollution in India with respect to particulate pollution. The metropolitan area includes sub-cities, Lashkar, Thatipur Morar, and the City centre.

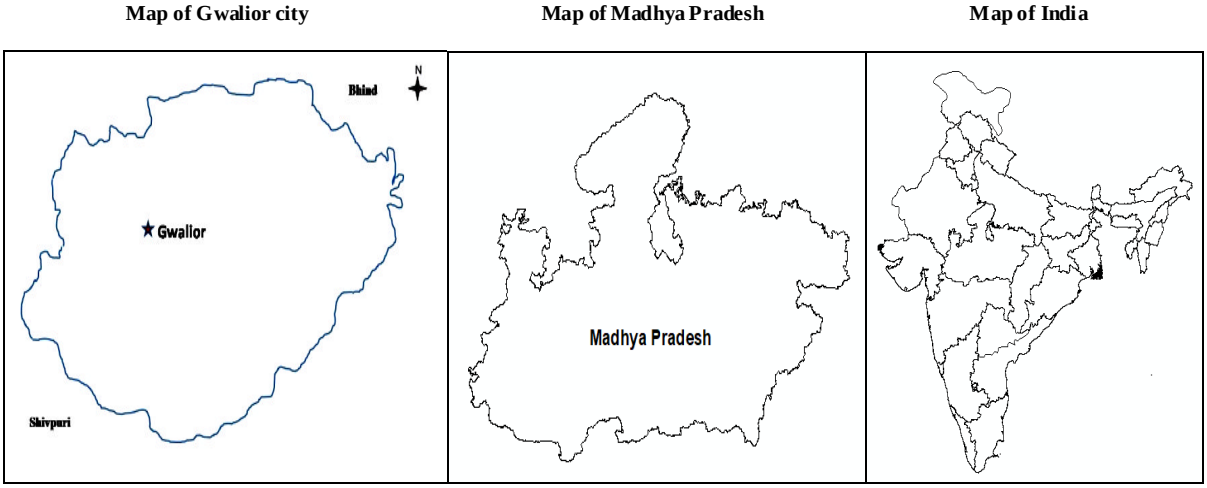

Figure 1. **Map of study area**

The city Gwalior has been selected as one of the hundred Indian cities that can be developed into a smart city under PM Narendra Modi's flagship Smart Cities Mission. The Gwalior is the attraction of millions of people throughout the country. The present study analyses the recent reports of both local/ global agencies experimentally and critically that put Gwalior at the top among the most air polluted cities in India.

Material and Methods

Measurement Method

In this study, the pollutants like NO_2 and SO_2 were collected in Gwalior using the KIMOTO HANDY air simpler model (HS-7A). The method used for the determination of SO_2 in the ambient air of Gwalior was Modified West and Geake method [13]. In contrast, NO_2 was determined by Modified Jacob and Hochheisier method [14]. The estimation of pollutants SO_2 and NO_2 was done by a UV-Visible spectrophotometer. In this study, SO_2 and NO_2 samples were collected at an interval of 8 h. For 8 h sampling, 10 mL of absorbing solution (stock solution) was taken in impingers, and the flow rate was maintained at 0.5 to 1 L/min. NO_2 was collected by bubbling air through a sodium hydroxide solution to form a stable solution of sodium nitrate. The nitrate ions produced during sampling were determined calorimetrically by reacting the exposed absorbing reagent with phosphoric acid, sulfanilamide, and an N (1-Napthyl) ethylenediamine dihydrochloride [13]. The interference of SO_2 is eliminated by converting it to H_2SO_4 before analysis. The SO_2 from the air stream was absorbed in sodium tetramer curate solution. It forms a stable dichloro sulphito mercurate. The amount of SO_2 was then estimated by the colour produced when p-rosaniline hydrochloride was added to the solution. The colour was estimated than reading from the spectrophotometer. The meteorological parameters like temperature and humidity were measured during the sampling by thermometers and hygrometry, and rainfall has been taken from Indian Meteorological Department, New Delhi.

Pearson Correlation Analysis

The Pearson correlation is applied to know the degree of association among the variables. The Pearson correlation among all the monitored parameters is calculated by using the following formula

$$r = \sum_{i=1}^{x} \frac{(xi - x)(y = \bar{y})}{(n-1)SxSy}$$

Where X and Y are two variables, with means X and Y, respectively with standard deviations SX and SY

Results and Discussion

The purpose of this study was to determine the concentration of gaseous pollutants SO_2 and NO_2 in the ambient air of Gwalior. These pollutants were found to play an important part in the contribution of environmental pollution. The monthly average concentrations of gaseous pollutants were taken thrice a week for four respective years.

Temporal Variation of Air Pollutants NO_2 and SO_2 at different Stations of Gwalior

The ambient air quality of Residential (Thatipur), Commercial (Maharaja Bada), and Industrial (D.D Nagar near industrial area Malnapur) has been monitored during different seasons from 2014 to 2017.

Winter (January to March 2014-2017)

The mean concentration of NO_2 and SO_2 during winter was found higher at residential area (Thatipur) i.e., 22.61 $\mu g/cm^3$ followed by commercial area (Maharaja Bada)

21 µg/cm^3 and Industrial zone (D.D Nagar near industrial area Malanpur) as 20.96 µg/cm^3 (Table 1). The maximum peak of NO_2 was observed at 14-22 h in all studied areas. It was possibly due to the heavy transport movement and favourable meteorological conditions like temperature, humidity, rainfall, and wind speed and directions. It was observed that the high concentration of NO_2 was observed maximum as per Fig. 2a at Maharaja Bada (26.7 µg/cm^3) and SO_2 as per Fig. 2e as 25.7 µg/cm^3. It may be due to the commercial activities and congestion with damaged roads at Maharaja Bada and along with heavy traffic because of National highway passing through the D.D Nagar area, and it is found in the vicinity of Industrial area Malanpur and favourable meteorological conditions like temperature, humidity, rainfall, and wind speed and direction. The minimum peaks were observed in the morning at 14 to 6 i.e., 2 to 6 am as per the Fig 2a and 2e for both NO_2 and SO_2 for all the study centres as Thatipur (19.85 µg/cm^3 and 16.16 µg/cm^3), Maharaja Bada (16.1 µg/cm^3 and 18.5 µg/cm^3), and D. D. Nagar (19.4 µg/cm^3 and 19.82 µg/cm^3). This may be due to less or no traffic movements and off hours for commercial and other activities and favourable meteorological conditions like temperature, humidity, rainfall, and wind speed and direction.

Summer (April to May 2014-2017)

During summer NO_2 and SO_2 concentrations were found relatively higher (Table 1) in Industrial (D.D Nagar near industrial area Malanpur) as 24.6 µg/cm^3 followed by residential area (Thatipur) as 22.76 µg/cm^3 and commercial area (Maharaja Bada) as 21.46 µg/cm^3. The maximum peak of NO_2 and SO_2 was observed at 14-22 h, i.e., 2 to 10 pm for all the Study Centers in winter, while the minimum peaks were observed in the morning at 14 to 6, i.e., 2 to 6 am as per the (Fig. 2b and 2f) for both NO_2 and SO_2 for all the study centres.This may be due to the traffic movements and working/off hours for commercial and other activities and the favourable meteorological conditions like temperature, humidity, rainfall, and wind speed and direction.

Monsoon (July to August 2014-2017)

It was observed from Table 1 that the NO_2 and SO_2 during Monsoon was found at a lower concentration at residential area (Thatipur) as 14.2±4.64 and 17.6±2.65, followed by commercial area (Maharaja Bada) as 17.2±4.06 and 17.2±2, and at industrial (D. D. Nagar near industrial area Malanpur) as 19.16±5.0 and 17.33±4.66. As per other weathers like summer and winter, the maximum peak of NO_2 and SO_2 in monsoon per the Fig.2 c & g was observed at 14-22, i.e., 2 to 10 pm for all the Study Centres, Thatipur (19.3 µg/cm^3 and 20.2 µg/cm^3), Maharaja Bada (21.7µg/cm^3 and 19.2 µg/cm^3), and D. D. Nagar (24.2µg/cm^3 and 21.8µg/cm^3) for similar reasons of the heavy transport movement, commercial activities, and favourable meteorological conditions. It may be due to the and heavy traffic.

Post monsoon (October to Dececember 2014-17)

As evident from Table 1, that the mean concentration of NO_2 post monsoon was found higher in Industrial (D.D Nagar near industrial area Malanpur) as 21.1 µg/cm^3 as compared to commercial area, Maharaja Bada (20.16 µg/cm^3), and residential area Thatipur (17.47 µg/cm^3). While SO_2 content in post monsoon was higher in the commercial area, Maharaja Bada (19.6 µg/cm^3). The maximum peak of NO_2 and SO_2 was observed as per Fig 2 d & h at 14-22, i.e., 2 to 10 pm for all the study centres due to the heavy transport movement and favourable meteorological conditions like temperature, humidity, rainfall, and wind speed and directions.

Table 1. **Temporal variation of NO_2 (µg/cm^3) and SO_2 (µg/cm^3) in different seasons at three sampling sites of Gwalior city.**

Sampling Stations	Time Interval H/D/M	Winter		Summer		Monsoon		Post Monsoon	
		NO_2	SO_2	NO_2	SO_2	NO_2	SO_2	NO_2	SO_2
TP	6-14	22.7	19.2	22.6	19.3	13.1	17.7	16.3	18.9
	14-22	25.3	21.7	26.1	23.2	19.3	20.2	21.2	21.1
	22-6	19.85	16.16	19.6	18.8	10.2	14.9	14.91	13.7
	Mean±sdv.	**22.61±2.72**	**19.02±2.72**	**22.76±3.25**	**20.43±2.40**	**14.2±4.64**	**17.6±2.65**	**17.47±3.30**	**17.9±3.8**
MRBD	6-14	20.2	19.7	19.8	20.9	16.1	17.2	18.7	15.9
	14-22	26.7	23.9	25.2	23.7	21.7	19.2	23.9	25.7
	22-6	16.1	18.5	19.4	20.02	13.8	15.2	17.88	17.2
	Mean±Sdv.	**21±5.34**	**20.7±2.83**	**21.46±3.23**	**21.54±1.92**	**17.2±4.06**	**17.2±2**	**20.16±3.24**	**19.6±5.32**
D.D.N	6-14	19.7	21.2	23.9	21.67	19.1	17.7	21.9	19.3
	14-22	23.8	25.7	26.2	24.9	24.2	21.8	26.2	21.1
	22-6	19.4	19.82	23.7	19.15	14.2	12.49	15.2	11.6
	Mean±sdv.	**20.96±2.45**	**22.24±3.07**	**24.6±1.34**	**21.90±2.88**	**19.16±5.0**	**17.33±4.66**	**21.1±5.54**	**17.33±5.04**

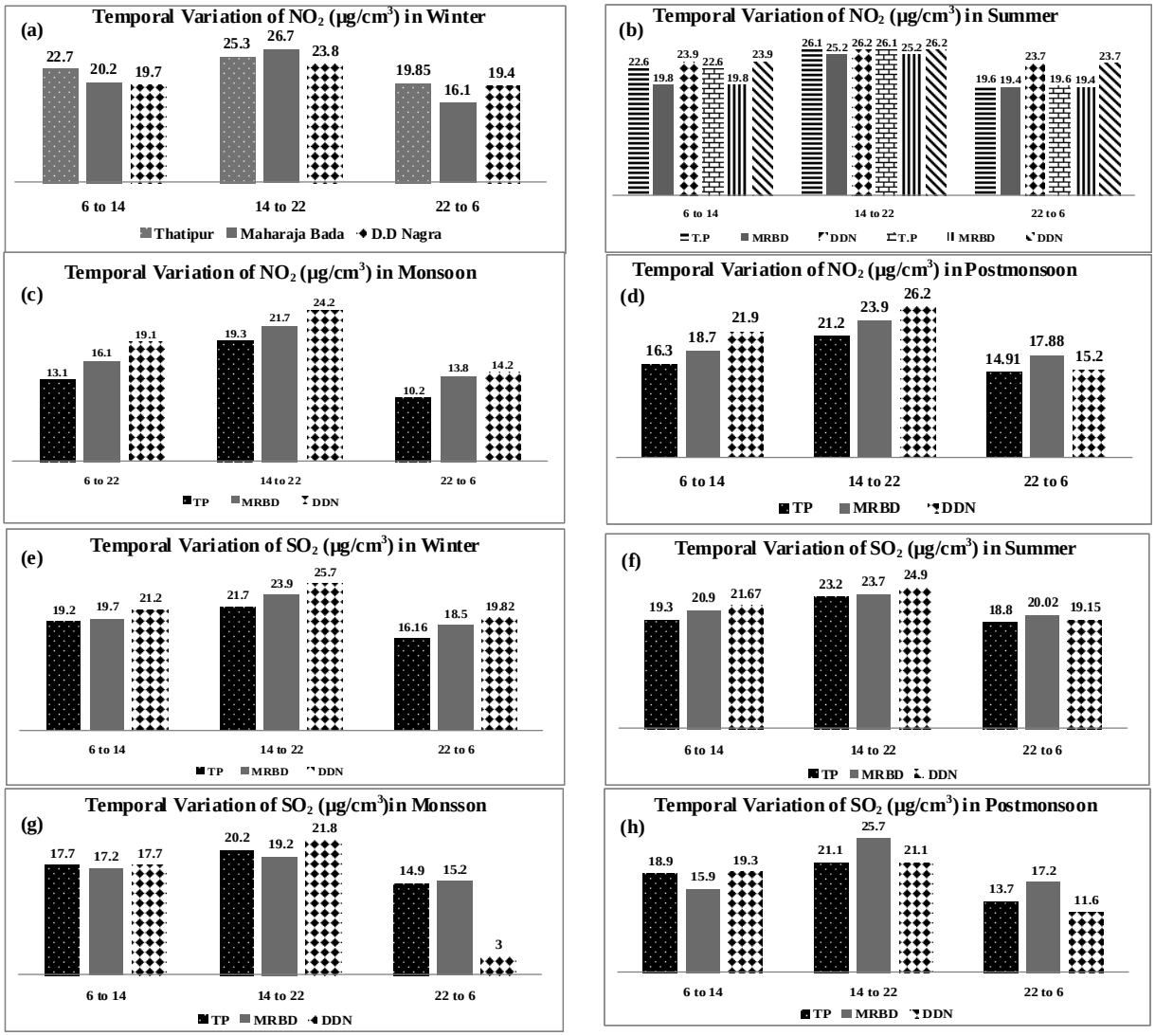

Figure 2. **Variation in NO_2 (µg/cm^3) and SO_2 (µg/cm^3) in different seasons at three sampling sites of Gwalior city**

Seasonal Distribution of Air Pollutants and Meteorological Parameters

The concentration level of SO_2 and NO_2 in winter was observed as 23.75 µg/cm^3 and 23.55µg/cm^3. In summer, the value of SO_2 and NO_2 was observed as 24.39 µg/cm^3 and 26.43 µg/cm^3. In monsoon, the value of SO_2 and NO_2 was observed as 23.98 µg/cm^3 and 20.91 µg/cm^3. In Post-monsoon, the value of SO_2 and NO_2 was observed as 24.61 µg/cm^3 and 23.91 µg/cm^3. The variation in (±) of SO_2 and NO_2 during all seasons was 0.360 and 2.910, respectively, as shown in Fig. 3.

Metrological Parameters

The average value of temperature, rainfall, and humidity in winter was observed as 21.5°C, 2.7 mm, and 57.43. In summer, the average temperature, rainfall, and humidity were 32°C, 31.36 mm, and 52.16, respectively. In monsoon, the average temperature, rainfall, and humidity were 31.16°C, 165.73 mm, and 70.33. In post-monsoon, the average temperature, rainfall, and humidity were observed as 21.83°C, 1.83 mm, and 60.16 (Fig. 3).

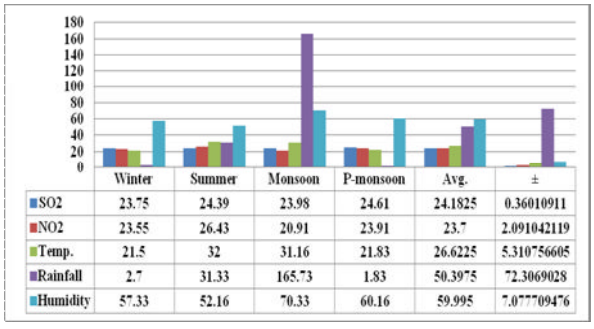

Figure 3. **Concentration level of various parameters**

Statistical analysis

It was observed that SO_2 and NO_2 showed a positive correlation with each other (r-value is 0.487). Both SO_2 and NO_2 showed positive correlation with temperature (r = 0.054, and r = 0.046). Both SO_2 and NO_2 showed negative correlation with rainfall (r = -0.301), and (r=-0.712). The SO_2 and NO_2 also negatively correlated with relative humidity (r=-0.279 and r=-096) Table 2. The air pollutants SO_2 and NO_2 are assessed and correlated with meteorological parameters to find out the relation between deteriorating air quality and meteorological parameters. It has been observed from the study that there was a negative co-relation between the rainfall and the level of pollutants as the rain washes down the pollutants and the concentration level of pollutants decreased during heavy rains. The level of air pollutants SO_2, NO_2 is significantly and negatively correlated with humidity. Still, it shows a positive correlation with temperature due to the temperature inversions, leading to increased pollution. The level of pollutants was observed high during winter and summer than monsoon and post-monsoon periods. This was due to the favourable meteorological parameters.

Table 2. **Correlation analysis of various parameters during the sampling.**

Parameters	SO_2	NO_2	Temperature	Rainfall	Humidity
SO_2	1				
NO_2	0.487	1			
Temperature	0.0543	0.0458	1		
Rainfall	-0.301	-0.712	0.668	1	
Humidity	-0.279	-0.961	0.133	0.815	1

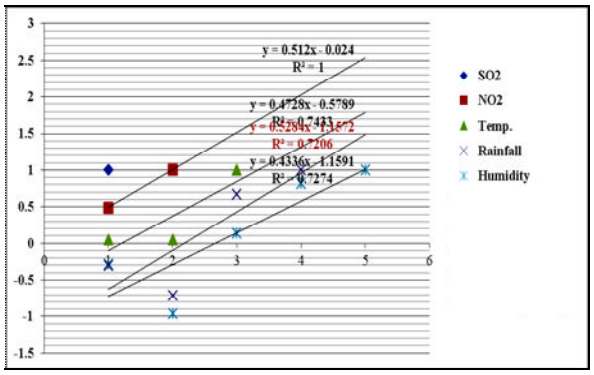

Figure 4. **Correlation graph of various parameters**

In this study, it was found that higher concentrations were observed during winter and summer, and lower concentrations were observed during monsoon. This may be due to the temperature inversions during summer and heavy rainfall that effect washes out the level of pollutants during monsoon. The regression analysis of gaseous pollutants showed a good correlation with meteorological parameters and led to various health problems during respective seasons (Fig. 4). The interesting fact regarding the observations found to make similar values of the regression coefficients indicating the effect of the meteorological parameters in the distribution of gaseous pollutants. The maximum concentration of gaseous pollutants was observed in the summer and winter months, and the minimum concentration was observed in the Monsoon season. This may be due to the wash down of pollutants in the monsoon and temperature inversion during summer and winter, leading to higher concentrations.

Conclusion

The air pollutants SO_2 and NO_2 were observed and analysed with meteorological parameters to determine the relationship between deteriorating air quality and meteorological parameters. It was observed from the study that there is a negative co-relation between the rainfall and the level of pollutants as the rain washes down the pollutants and the concentration level of pollutants is decreased during heavy rains. The level of air pollutants SO_2, NO_2 is significantly and negatively correlated with humidity but shows a positive correlation with temperature. The level of the pollutants was found to be increased due to the temperature inversions. The level of pollutants is observed high during winter and summer than monsoon and post-monsoon periods. This is due to the favourable meteorological parameters. The increase in the level of both SO_2 and NO_2 observed during the study may be due to emissions from vehicles like tempos, auto rickshaws, minibuses, two wheelers, private cars, trucks, and industrial activities in these areas. The effects were observed among the people day and night because these activities are going on through the clock. It has also been observed that the auto rickshaws, tempos along with road are the damage which are the cause of concern and major precaution should be taken in this regard.

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Conflict of Interest

The authors declare no conflict of interest.

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