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Spatial and Temporal Variation of Air Quality in Himachal Pradesh

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Abstract: Study was conducted to investigate the air quality status during national highway expansion by analyzing the relationship of air quality pollutants (PM_{10}, NO_2 and SO_2) with meteorological parameters at different locations. The elevated concentration of PM_{10}, NO_2 and SO_2 was observed around the road construction activities, which indicated vehicular emissions, dust generation and biomass burning for energy purpose to be the main sources of these pollutants. Since combustion of fuel generates these pollutants and are directly released in the atmosphere. PM_{10} have higher values (74.56 to 116.77 µg m^{-3}) and was above the permissible limit (100 µg m^{-3} of National Ambient Air Quality Standards (NAAQS). NO_2 ranged from 16.96 to 26.33 µg m^{-3} and SO_2 from 3.72 to 7.94 µg m^{-3}, respectively and were below the prescribed permissible limits. Seasons played significant role in catalyzing the air pollutants, especially higher values of PM_{10}, NO_2 and SO_2 in post monsoon season i.e. in winter months. Air Quality Index of study region was satisfactory to moderate.

Keywords: Highway expansion, Ambient air quality, PM_{10}, SO_2. NO_2, Impact assessment

Air pollution is a major challenge and concern in the present world causing serious health issues, loss of life and adversely affecting the economic productivity of a country like India say $5 trillion by 2024 (Pandey et al 2021). Air quality degradation has caused around 4.2 million deaths per year due to heart disease, bronchitis, lung cancer and respiratory diseases, since 9 out of 10 people breathe impure air that exceeds the permissible limits of air quality standards (WHO 2022). There have been numerous research studies, which significantly demonstrate that India is experiencing high rates of development and urbanization to strengthen the economic growth but on the verge of air quality and its adverse effects on different ecosystem services (Diaz et al 2020). The degradation of air quality subsequently is due to increased burden of anthropogenic activities like transportation, power generation, industries, agriculture and biomass burning since these activities have great potential to disturb the homeostasis of atmospheric system (Ganguly and Thapa 2016, Sharma et al 2020a). These human induced undertaking in context to road construction activities involving transportation material, equipment and other vehicular movements act as acts as source of gaseous pollutants such as carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO, NO_2, NO_x), ozone (O_3), particulate matter in different range (PM_{10}, $PM_{2.5}$) and heavy metals, catalyze the degradation of air quality (Sharma et al 2019, Sharma et al 2020, Sharma et al 2020b). According to Environment Protection Agency (EPA) there are six criteria air pollutants such as particulate matter (PM), oxides of nitrogen (NOx), carbon monoxide (CO), sulphur dioxide (SO_2), ozone (O_3) and lead (Pb); which are generally used to measure air quality status, based on the permissible limits of National Ambient Air Quality Standards (NAAQS) (Pattinson et al 2015). The air quality degradation is significantly affected by the meteorological conditions such as solar radiation, temperature, cloud cover, rainfall, wind speed, humidity and mixing height and further hampering the dispersion, accumulation and chemical transformation processes of air pollutants to extreme levels (Liu et al 2020). Increased vehicular activities and linked emissions has been contributing significant deterioration of air quality. Henceforth, there is need of assessment of ambient air quality of a particular region, by an index named Air Quality Index (AQI) based on eight pollutants *viz*., PM_{10}, $PM_{2.5}$, NO_2, SO_2, NH_3, CO, O_3 and Pb, which further compromises six categories, i.e., good, moderate, unhealthy for sensitive group, unhealthy, very unhealthy and hazardous (Pant et al 2020). Additionally, elaborates information on how much air quality has been degraded or polluted with a value ranging from 0 to 500. In this study we have investigated that how road expansion project in Himachal Pradesh have impacted ambient air quality.

MATERIAL AND METHODS

The present study deals with ambient air quality status in and around national highway expansion of NH-154 (Kiratpur-Nerchowk Expressway) which is being upgraded from its present two lane layout, to a four lane divided carriageway.

The present stretch of national highway falls in Himachal Pradesh at Garamoura in Bilaspur to Nerchowk in Mandi districts in the altitude ranging from 650-940 m amsl. Bilaspur district is located between 31°19'48'' North latitude and 76°45'0'' East longitude and Mandi district is located between 31°42'25'' North latitude and 76°55'54'' East longitude.

Ambient air quality was assessed at four locations around road expansion activities during the years 2016 and 2017. The parameters considered for this study were $PM_{10,}$ NO_2 andSO_2. The monitoring of these pollutants was carried out on a yearly basis at four locations namely Garamoura & Kainchi Mod in Bilaspur district and Jarol & Chaumukha in Mandi district (Fig. 1); during pre-monsoon (May-June) and post monsoon (October-November) seasons considered as treatments and at three periodic assessments (1^{st}, 15^{th} and 30^{th} day) of the selected month considered as replications. In total there were eight treatment combinations (4 x 2) which were replicated three times under randomized block design.

Respirable dust sampler (RDS) was used to assess PM_{10}based on the principle of gravimetric, which is operated at an average flow rate of 1.0-1.5 m^3 min^{-1}.The sampling was carried out for 8 hours and the sampler was installed at a height of 1.5 m above the ground level and flow rate was noticed after 5 minutes of starting of sampling. For this, Whatman filter paper (20.3×25.4 cm) was used for the collection of particulate matter.The gaseous pollutants such as NO_2 and SO_2 were monitored simultaneously in glass impinger attached internally with the RDS for 8 hours. Then the collected samples were brought to the laboratory and analyzed by following the Jacobs and Hochheiser (1958) method for NO_2 pollutant and West and Gaeke (1956) method for SO_2concentration, respectively. Ambient NO_2 was collected by bubbling air through a solution of sodium hydroxide. The concentration of nitrite ion produced during sampling was determined by reacting the nitrite ion with phosphoric acid and sulphanilamide and N-(1-napthyl)-ethylenediamine di-hydrochloride (NEDA). The absorbance

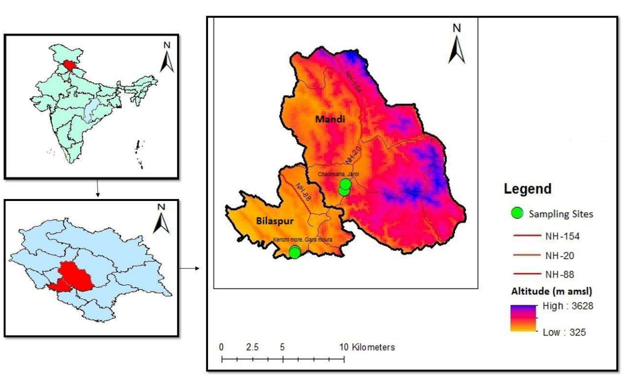

Fig. 1. Study area

of the solution was recorded on Spectrophotometer (Model-Spectronic-20) at 540 nm.

$$\mu g\,\frac{NO_2}{ml} = \frac{\mu g / NO_2 \times Vs(ml)}{Vt(ml) \times Va\,(m^3) \times 0.82}$$

Where

µg per NO_2 = NO_2 concentration from calibration curve,

Vs, Vt, Va = Volume of sample, aliquot taken for analysis and air sampled

Overall sampling efficiency = 0.82

Sulphur dioxide from air is absorbed in a solution of potassium tetrachloromercurate (TCM) and dichlorosulphitomercurate complex is formed. This complex is made to react with pararosaniline and formaldehyde to form the intensely coloured pararosaniline methyl sulphonic acid. The absorbance of the solution was recorded on Spectrophotometer (Model-Spectronic-20) at 560 nm.

$$SO_2\left(\frac{\mu g}{m^3}\right) = \frac{\frac{\mu g}{SO_2} \times Vs(ml)}{Vt(ml) \times Va\,(m^3)}$$

Where

µg per SO_2= SO_2concentration from calibration curve, Vs, Vt, Va = Volume of sample, aliquot taken for analysis and air sampled

Furthermore, the results obtained for PM_{10} concentration and gaseous pollutants, were compared with the air quality permissible limits given by National Ambient Air Quality Standards, to know whether the pollutant is above or below the permissible limit (Table 2).

Climate and weather condition: The climate of the study region is sub-tropical type and there is a considerable variation in the seasonal temperature. In general, May and June are the hottest months and December and January, are the coldest ones in the region. The average maximum and minimum temperature varies from 22.50 to 38.77°C and 2.40 to 20.40°C. The average annual rainfall in the region is 1200 mm, the bulk of which is received during monsoon months (June-September) with few pre monsoon showers during early June period (Fig. 2 and 3).

Air quality index (AQI): The quality of air in the study region has been estimated with help of air quality index. AQI had been calculated from open access internet source provided by Central Pollution Control Board (http://app.cpcbccr.com/AQI_India/).

To convert concentration to AQI, the equation used is:

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low}$$

Where;

I: The air quality index
C: The pollutant concentration
C_{low}, C_{high}: The concentration breakpoint that is ≤*C and* ≥*C*
I_{low}, I_{high}: The index breakpoint corresponding to C_{low} *and* C_{high}

RESULTS AND DISCUSSION

PM_{10} concentration: There was a slight change in PM_{10} during road expansion/construction activities in the study region. The highest concentration of PM_{10}(114.56 µg m^{-3}) was at Chaumukha, while lowest of 80.39 µg m^{-3} was in Garamoura during the highway expansion activities (Table 4). This indicated that PM_{10}during the observation was slight above the permissible limit of 100 µg m^{-3} given by National Ambient Air Quality Standards (Table 2). During post monsoon, the significantly higher concentration of PM_{10} was observed (97.85 µg m^{-3}) whereas lowest of 92.85 µg m^{-3} was in pre monsoon season. The interaction between locations and seasons was significant. Highest PM_{10} concentration of 116.46 µg m^{-3} was at Chaumukha in post monsoon season mainly in October and November while lowest of 74.77 µg m^{-3} was at Kainchi Mod during pre-monsoon (summer) season especially in May and June. Higher PM_{10} concentration recorded during winter season may be ascribed to low temperature, cool and dry period, strong atmospheric stability and less rainfalls which reduces vertical mixing of pollutants in the atmosphere leading to less dilution and further dispersion of particulate matter (Bodor et al 2020).

Table 1. Location, latitude, longitude and elevation of the study area

Location	Latitude	Longitude	Elevation (m asl)
Garamoura	31°12'52.6"N	76°39'08.4"E	663
Kainchi Mod	31°13'58.2"N	76°39'48.5"E	698
Jarol	31°27'35.2"N	76°51'40.2"E	705
Chaumukha	31°30'54.8"N	76°52'36.9"E	927

The local sources can be vehicular emissions and forest fires in the study region which comes under high risk zones of forest fires in Himachal Pradesh mainly caused by both man-made and natural sources (Kumar et al 2019).

Gaseous Pollutants

Nitrogen dioxide (NO_2): Highest NO_2concentration of 26.33 µg m^{-3} was at Chaumukha while lowest of 16.96 µg m^{-3} was at Garamoura (Table 4). Elevated NO_2levels in the atmosphere are usually ascribed to combustion of fuel (petrol and diesel), emissions from road traffic, construction activities and catalyzed by weather parameters as reported by Niepsch et al (2021).The effect of different seasons was significant. The highest NO_2 concentration of 23.90 µg m^{-3} was during post monsoon months whereas lowest of 19.56 µg m^{-3} was in the summer season. Higher NO_2 concentration during post monsoon may be attributed to combination of anthropogenic emissions and weather parameters. This include winter temperature inversion (i.e. low temperature conditions) and increased energy needs by biomass burning for domestic heating (Rowell et al 2021). The interaction between different locations and seasons was significant. Highest NO_2 concentration of 30.79 µg m^{-3} was at Jarol during winter season (i.e. October and November), while lowest of 16.58 µg m^{-3} was at Garamoura in the summer season (May and June), which was at par with Jarol and Garamoura in post monsoon at Kainchi Modduring pre-monsoon (summer months). The nitrogen dioxide is well within permissible limits prescribed by National Ambient Air Quality Standards (Table 2).

Sulphur dioxide (SO_2): Significant highest SO_2 concentration of 7.94 µg m^{-3} was at Chaumukha whereas lowest of 3.72 µg m^{-3} was at Kainchi Mod (Table 4). The main considered source of SO_2may be due to emissions released from transportation system i.e. vehicular movement and burning of fuel (Sudalma et al 2015).Seasonal effect on SO_2 was significant. Highest SO_2concentration of 6.09 µg $m^{-3}$was

Table 2. Permissible limit standards of ambient air quality parameters

Pollutant	Time weighted average	Concentration in ambient air		Methods of measurement
		Industrial area residential, rural & other areas	Ecologically sensitive area (Notified by Central Govt.)	
Particulate matter (size less than 10µm) or PM_{10}, µg/m^3	Annual*	60	60	-Gravimetric -TOEM -Beta attenuation
	24 hours**	100	100	
Sulphur dioxide (SO_2), µg/m^3	24 hours**	100	100	-Improved West and Gaeke method -Ultraviolet fluorescence
	24 hours**	80	80	
Nitrogen dioxide (NO_2), µg/m^3	Annual*	40	30	-Modified Jacob and Hochheiser -Chemiluminescence
	24 hours**	80	80	

Source: NAAQS (2020)
*Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform interval.
**24 hourly or 8 hourly or 1 hourly monitored values, as applicable shall be complied with 98 % of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

during post monsoon (winter season) while lowest of 5.63 µg m^{-3} was in the pre monsoon months. Higher SO_2 concentration in winter season can be attributed low temperature, lesser precipitation and dry conditions that limits the dispersion of SO_2 (Kuttippurath et al 2022). The interaction between locations and seasons was have significant effect on SO_2 concentration. The highest SO_2 concentration of 8.43 µg m^{-3} was at Chaumukha during post monsoon season while lowest of 3.37 µg m^{-3} was noticed at Kainchi Mod in the summer months. The Sulphur dioxidewas well within permissible limits prescribed by National Ambient Air Quality Standards (Table 2).

The higher values of NO_2, SO_2 and PM_{10} were estimated during post monsoon season i.e. (October and November months) in comparison to pre monsoon months (May and June) (Table 5). The year wise assessment showed slight differences in the pollutants. Moreover, the analysis identified higher PM_{10} in comparison to gaseous pollutants NO_2 and SO_2.

Table 3. Air quality index-category and range

AQI	Remark
0-50	Good
51-100	Satisfactory
101-150	Moderate
151-200	Poor
201-300	Very poor
301-500	Severe

Source: Pant et al (2020)

Air quality index (AQI): AQI during pre-monsoon and post monsoon seasons was moderate (101-150) at two locations i.e. Jarol and Chaumukha, whereas at Garamoura and Kainchi Mod it was satisfactory (51-100) (Table 6). The AQI is one of the most important tools for knowing overall air quality condition. Based on the overall conditions, ambient air quality of the study region was satisfactory to moderate (Table 3).

Local meteorology: The maximum monthly average temperature at Mandi and Bilaspur districts was observed to be 34.9ºC and 32.2ºC in 2016 which was followed by 35.1ºC and 32.3ºC in 2017 during observation period, minimum temperature for Mandi district was minus 0.6ºC in December 2016 and 0.3ºC in January, 2017. In Bilaspur, minimum temperature was minus 0.9ºC in January 2016 and minus 1.8ºC in January 2017. The monthly highest rainfall at Bilaspur district was 241.6 mm in June 2016 followed by 521.0 mm in August 2017. The monthly maximum rainfall at Mandi was 388.0 mm in August 2017

Table 4. Spatial and seasonal variations in ambient air pollutantconcentration (µg m^{-3}) around national highway

Locations	PM_{10} (µg/m3)			NO_2 (µg/m3)			SO_2 (µg/m3)		
	Pre-monsoon	Post-monsoon	Mean	Pre-monsoon	Post-monsoon	Mean	Pre-monsoon	Post-monsoon	Mean
Garamoura	78.35	82.42	80.39	16.58	17.35	16.96	3.64	4.14	3.89
Kainchi Mod	74.77	84.27	79.52	18.48	20.95	19.71	3.37	4.06	3.72
Jarol	105.61	108.26	106.94	17.00	30.79	23.90	8.06	7.73	7.89
Chaumukha	112.67	116.46	114.56	26.17	26.50	26.33	7.45	8.43	7.94
Mean	92.85	97.85		19.56	23.90		5.63	6.09	
C.D. (p=0.05)									
Seasons		0.46			1.70			0.17	
Locations		0.32			1.20			0.12	
Seasons x Locations		0.65			2.41			0.25	

Table 5. Concentration of PM_{10}, NO_2 and SO_2 (2016 and 2017)

Parameters	NO_2 (µg/m3)		SO_2 (µg/m3)		PM_{10} (µg/m3)	
	2016	2017	2016	2017	2016	2017
Pre monsoon	19.30	19.81	92.57	93.13	5.56	5.70
Post monsoon	23.61	24.18	97.52	98.19	5.97	6.20
Maximum	26.16	26.50	114.23	114.89	7.81	8.06
Minimum	16.86	17.07	79.18	79.85	3.67	3.76
SD*	5.09	5.41	16.94	17.04	2.18	2.28
SE*	2.54	2.71	8.47	8.52	1.09	1.14

Table 6. AQI in the selected sites during study period

Locations	Air quality index	
	Pre monsoon	Post monsoon
Garamoura	78	82
Kainchi Mod	75	84
Jarol	104	105
Chaumukha	109	111

followed by 317.2 mm in July 2017. These meteorological conditions play their role dominantly in affecting the PM_{10} and gaseous pollutant concentrations at experimental sites. The weather data was collected from India Meteorological Department, Meteorological Centre Shimla, Himachal Pradesh (Table 7).

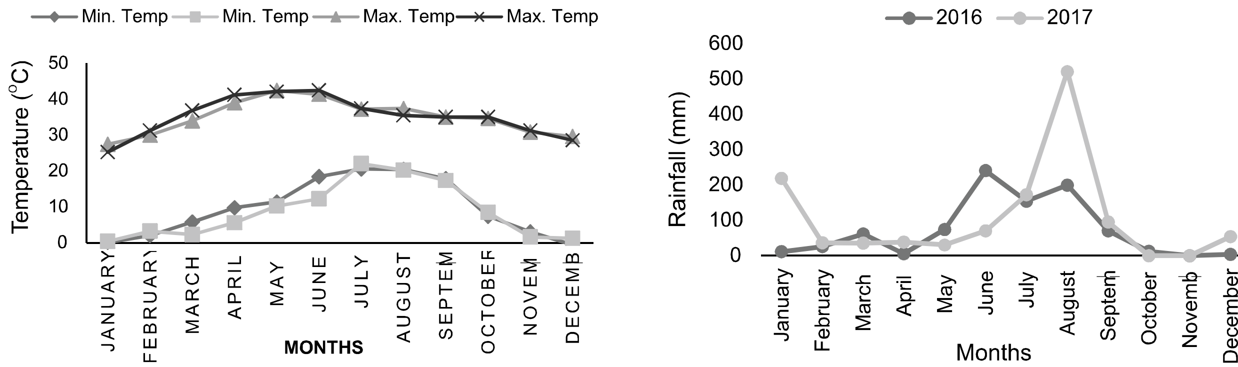

Fig. 2. Maximum and minimum temperature (°C) and rainfall (mm) conditions at Barthein, Bilaspur (2016 and 2017)

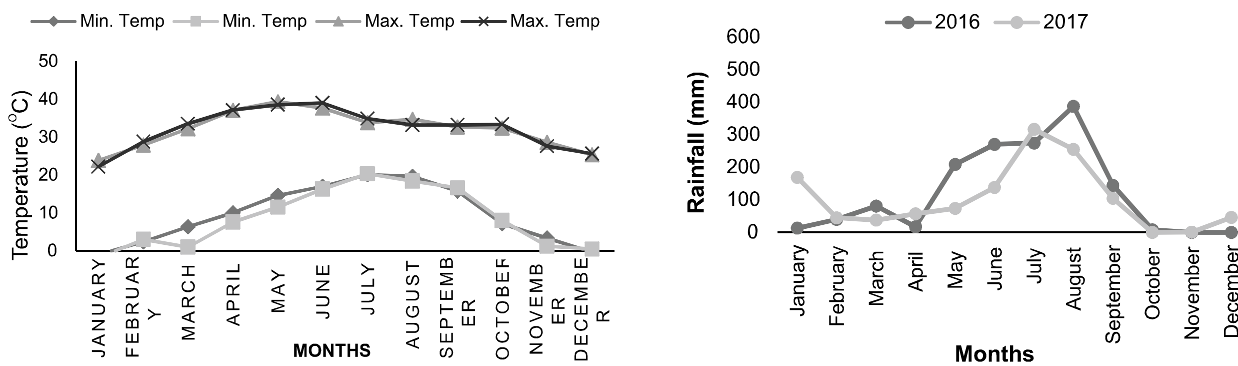

Fig. 3. Maximum and minimum temperature (°C) and rainfall (mm) conditions at Sundarnagar, Mandi (2016 and 2017)

Table 7. Average maximum and minimum temperature (°C) and monthly rainfall (mm) of the study sites during study period

Months	Bilaspur						Mandi					
	Minimum Temp		Maximum Temp		Rainfall (mm)		Minimum Temp		Maximum Temp		Rainfall (mm)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
January	0.1	0.3	27.4	25.2	11.6	219.2	-0.9	-1.8	23.9	22.2	13.8	169.1
February	2.0	3.2	30.0	31.2	26.4	36.8	2.4	3.0	27.9	28.8	40.2	45.5
March	5.8	2.2	34.0	36.8	61.6	36.0	6.4	1.0	32.2	33.6	81.1	37.8
April	9.8	5.6	39.0	41.2	6.0	38.4	10.1	7.6	37.1	37.2	17.6	57.4
May	11.4	10.2	42.4	42.2	74.0	30.4	14.6	11.6	39.4	38.6	209.4	74.4
June	18.4	12.2	41.4	42.4	241.6	70.2	17.0	16.3	37.7	39.0	270.8	138.8
July	20.6	22.0	37.2	37.4	154.9	172.3	20.1	20.4	33.8	34.9	274.7	317.2
August	20.4	20.2	37.4	35.5	200.4	521.0	19.7	18.4	34.7	33.2	388.0	255.1
September	17.8	17.4	35.0	35.0	70.8	95.8	15.8	16.7	32.7	33.2	144.9	105.0
October	7.4	8.4	34.6	35.0	12.8	0.0	7.2	8.0	32.4	33.4	8.3	0.0
November	3.0	1.6	30.8	31.2	0.0	0.0	3.4	1.3	28.6	27.7	0.0	1.7
December	-0.6	1.2	29.6	28.6	4.0	54.0	-0.3	0.5	25.4	25.6	0.4	46.2

Source: India Meteorological Department, Meteorological Centre Shimla, Himachal Pradesh

CONCLUSIONS

The concentrations of gaseous pollutants i.e. NO_2 and SO_2 in the air are within the National Ambient Air Quality Standards at all the sites in Bilaspur and Mandi district. However, the concentration of PM_{10} was slight higher in study sites than the prescribed limit i.e. 100 µg m^{-3}. Thus, particulate matter has been observed to be the major pollutant identified in the study sites. Moreover, meteorological parameters have played a significant role in catalyzing the air pollutants in the atmosphere, since higher values of the pollutants was observed post monsoon season i.e. winter season in comparison to pre monsoon months i.e. summer season both the years. Concluding values of Air Quality Index showed that the air quality index during post monsoon and pre monsoon seasons was satisfactory to moderate.

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