



Air quality status in fast developing city of Western Himalayan State of India

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General Note



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ABSTRACT

A study was carried out to assess the status of air pollutants in Solan city and to find out the air quality index (AQI). The concentration of PM₁₀, SO₂, NO₂ and VOCs was found highest at commercial area while the minimum concentration was found at

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state highway except VOCs which was lowest at industrial area. The air quality index during post monsoon and pre monsoon seasons was "Moderately polluted" at three locations while at other two locations it was found to be "Fairly clean". The investigation found that the maximum concentration of Fe was observed in the city followed by Mn while the concentrations of As, Pb, Ni and Cu was found in less concentration.

Keywords: Hills, pollutants, quality, index, heavy metals.

1. INTRODUCTION

Air pollution has become a matter of serious concern in many parts of the world particularly in urban cities of India, where majority of the population is exposed to poor air quality. India ranked 141 out of 180 countries as per Environmental Performance Index (2016). In India, over the past two decades there has been a rapid increase in urbanization and industrialization, increase in technological, industrial and agricultural advancement, coupled with increases in population growth, has triggered the deterioration of environmental quality in many cities. Rapidly growing cities, more traffic on roads, growing energy consumption and waste production, and lack of strict implementation of environmental regulation are increasing the discharge of pollutants into air, water, and soil (Agrawal, 2005).

Burning of fossil fuels producing nitrogen oxides, sulfur oxides, dust, soot, smoke, and other suspended particulate matter, is also the major source of carbon dioxide, fine particles <100 mm which include carbon particles, metallic dust, resins, aerosols, solid oxides, nitrates and sulphate and coarse particles >200 mm largely carbon particles and heavy dust, sulphur compounds, nitrogen compounds, oxygen compounds and halogen compounds takes place.

Motor vehicles emit particulate matter, nitric oxide and NO₂, carbon monoxide, organic compounds and lead, account for 60-70% of the pollution in the air in urban environment (Dwivedi *et al.*, 2008). In India, the number of motor vehicles has grown from 72.7 million in 2004 to approximately 141.8 million in 2011. Globally, the number of motor vehicles is growing faster than global population, about 5 per cent per year compared with 2 per cent for population (Sharma *et al.*, 2008). The air quality index (AQI) that transforms weighted values of individual air pollutants (e.g. SO₂, CO, visibility, etc.) into a single number is widely used for air quality communication and decision making in many countries (Ganesh Chandra Kisku and Markandeya, 2015).

Ambient air pollution has a number of impacts on human health, starting from modest transient changes in the respiratory tract, impaired pulmonary function and cardiovascular system. Due to air pollution, more than two million premature deaths per year can be attributed to the effects of urban (outdoor and indoor) air pollution that is mainly caused by burning of solid fuels (WHO, 2000, 2002, 2005) more than half of it in developing countries (WHO, 2005).

The hilly areas of developing countries are lesser polluted as compared to urban areas. With the economical development and urbanization the air quality of hilly areas needs to be monitored. Solan city is among the rapidly growing cities of Himachal Pradesh which is situated on the Kalka - Shimla National Highway - 22 and spread over an area of 33.43 km² with a residential population of 1, 02,078 as per 2011 census. The average ambient temperature of the city ranges from a minimum of 5°C to a maximum of 32-35°C. The average annual rainfall is 1150-1200 mm and most of the rainfall is received during July and August. Relative humidity ranges from a minimum of 36% to a maximum of 92%. There is tremendous increase in vehicular traffic, urbanization, residential and

industrial activities in the Solan city. As such, an attempt has been made to investigate air quality status of the Solan city of Himachal Pradesh.

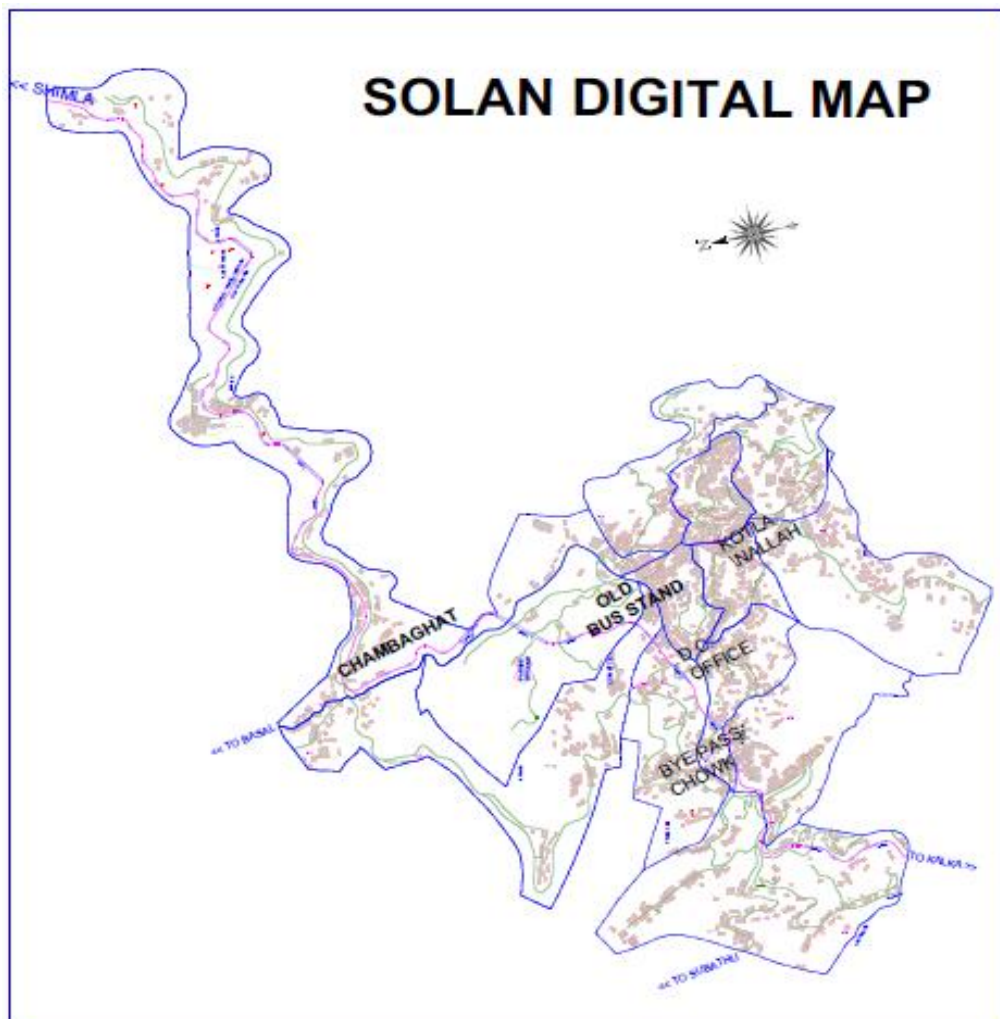


Figure 1 The sketch of Solan city

2. METHODOLOGY

The five locations were identified on the basis of state highway, national highway, commercial and industrial areas (Fig 1). The data were recorded for eight hours at each location during day time and repeated for three times during pre-monsoon (April-May) and post-monsoon (December-January) using Respirable dust sampler (Cat. No MBLRDS-002) and Environmental Perimeter Air Station (EPAS). The parameters recorded were SO_2 , NO_2 , Respirable Suspended Particulate Matter, Near Respirable Suspended Particulate Matter, Total Suspended Particulate and Volatile Organic Compounds.

The air quality index had been calculated from the observed PM_{10} , NO_x , SO_2 and VOCs values using the formula (Rao M. et al, 2003).

$$\text{AQI} = 1/4 \times (\text{I}_{\text{PM}_{10}} / \text{S}_{\text{PM}_{10}} + \text{I}_{\text{SO}_2} / \text{S}_{\text{SO}_2} + \text{I}_{\text{NO}_x} / \text{S}_{\text{NO}_x} + \text{I}_{\text{VOC}} / \text{S}_{\text{VOC}}) \times 100$$

Where:

I_{RSPM} , I_{SO_2} , I_{NOX} and I_{VOC} are individual values of respirable particulate matter, sulphur dioxide, oxides of nitrogen and volatile organic compounds, respectively. $S_{PM_{10}}$, S_{SO_2} , S_{NOX} and S_{VOC} are standards of ambient air quality.

3. RESULTS AND DISCUSSION

3.1. Concentration of Particulate Matter

The effect of location was found statistically significant with a maximum concentration ($114.8\mu\text{g}/\text{m}^3$) of PM_{10} at commercial area during pre monsoon and $129.67\mu\text{g}/\text{m}^3$ during post monsoon while the minimum concentration ($80.06\mu\text{g}/\text{m}^3$) of PM_{10} was found at state highway during pre monsoon and $70.3\mu\text{g}/\text{m}^3$ during post monsoon at state highway (table 1).

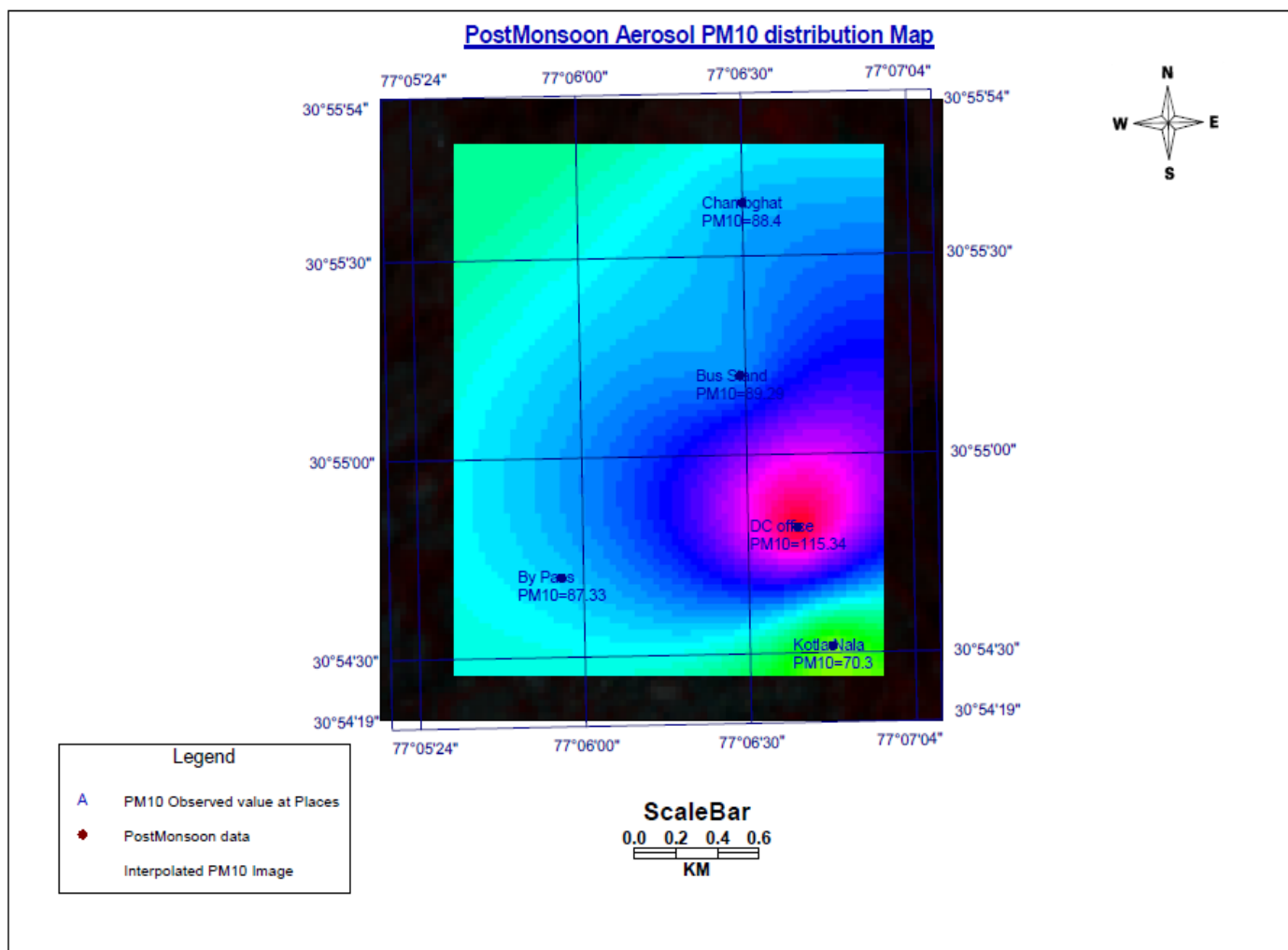


Figure 2 Variation of PM_{10} at different locations in Solan city during post-monsoon

Table 1 Concentration of air pollutants ($\mu\text{g}/\text{m}^3$) at different locations in Solan city

Locations	Pre monsoon				Post monsoon			
	PM ₁₀	NO ₂	SO ₂	VOCs	PM ₁₀	NO ₂	SO ₂	VOCs
State Highway	80.06	17.90	2.51	2.31	70.30	18.47	4.34	6.62
Commercial area	114.81	28.27	8.65	2.52	129.67	30.68	7.86	7.32
National Highway	85.16	28.65	6.63	1.05	87.33	22.34	5.65	6.79
Old bus stand	87.19	29.86	4.71	1.72	99.29	21.72	4.22	7.12
Industrial area	88.40	26.35	8.13	1.48	88.40	22.51	6.03	4.47
Mean	91.12	26.21	6.12	1.81	94.99	23.14	5.62	6.46

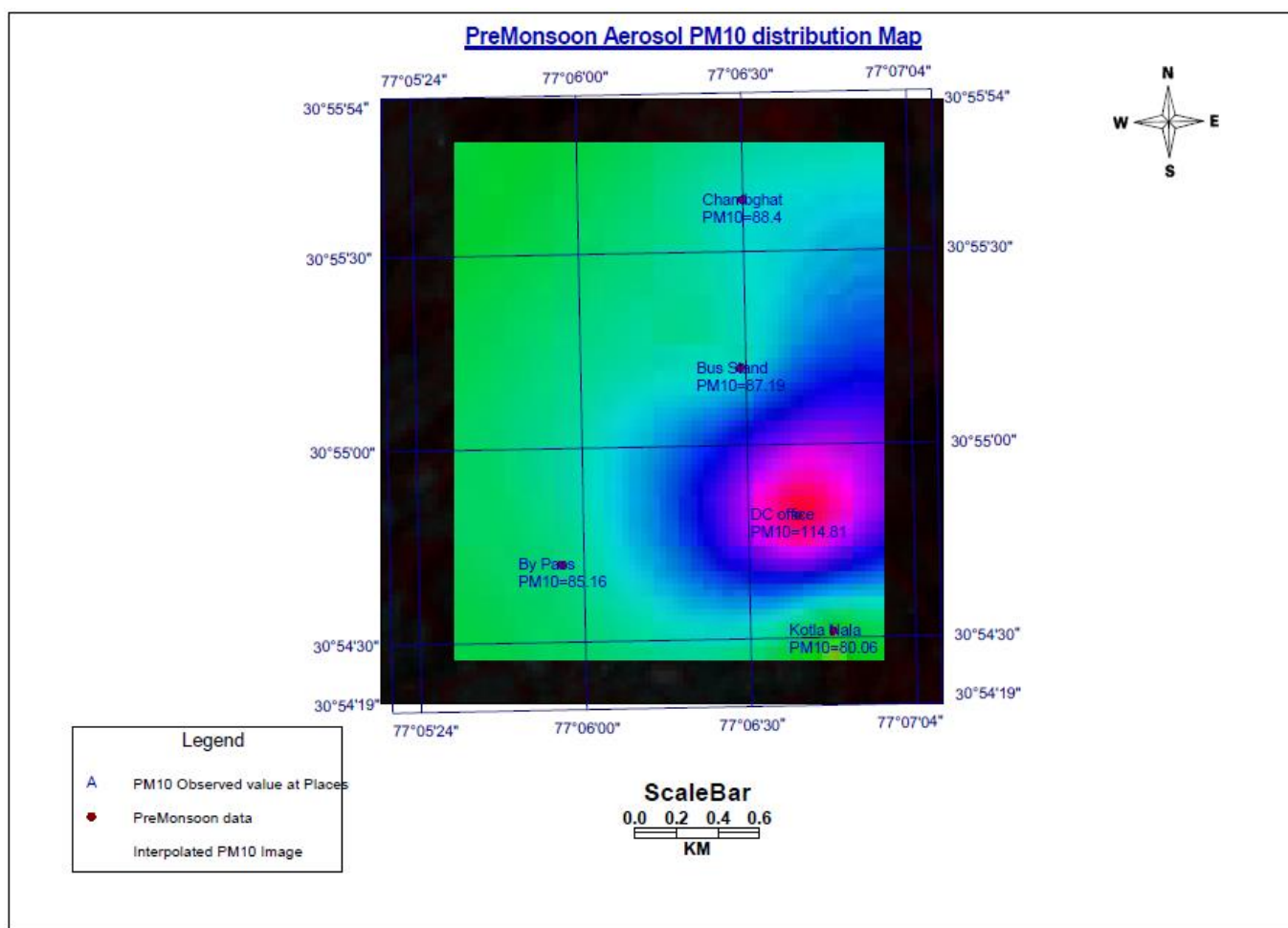


Figure 3 Variation of PM₁₀ at different locations in Solan city during pre-monsoon

Fig. 2 and Fig. 3 show the concentration of PM₁₀ at different locations in Solan city by interpolating the data using Erdas, GIS software during post-monsoon and pre-monsoon seasons, respectively.

It predicts that as we move away from commercial area the concentration of PM₁₀ starts decreasing and minimum at state highway during pre monsoon and post monsoon. The concentration of particulate matter ($\mu\text{g}/\text{m}^3$) was found to be highest at commercial area during post monsoon and lowest in pre monsoon at state highway (Fig.4).

3.2. Concentration of Nitrogen dioxide (NO₂) in Solan city

The effect of location on the concentration of nitrogen dioxides (NO₂) in the Solan city was statistically significant. The maximum concentration ($29.86\mu\text{g}/\text{m}^3$) of NO₂ was found at old bus stand during pre monsoon and $30.68\mu\text{g}/\text{m}^3$ at commercial area during post monsoon while minimum concentration ($17.9\mu\text{g}/\text{m}^3$) of NO₂ was found at state highway during pre monsoon and $18.47\mu\text{g}/\text{m}^3$ during post monsoon at the same location (table 1). The seasons exhibited statistically significant effect on the concentration of NO₂ measured during both the seasons.

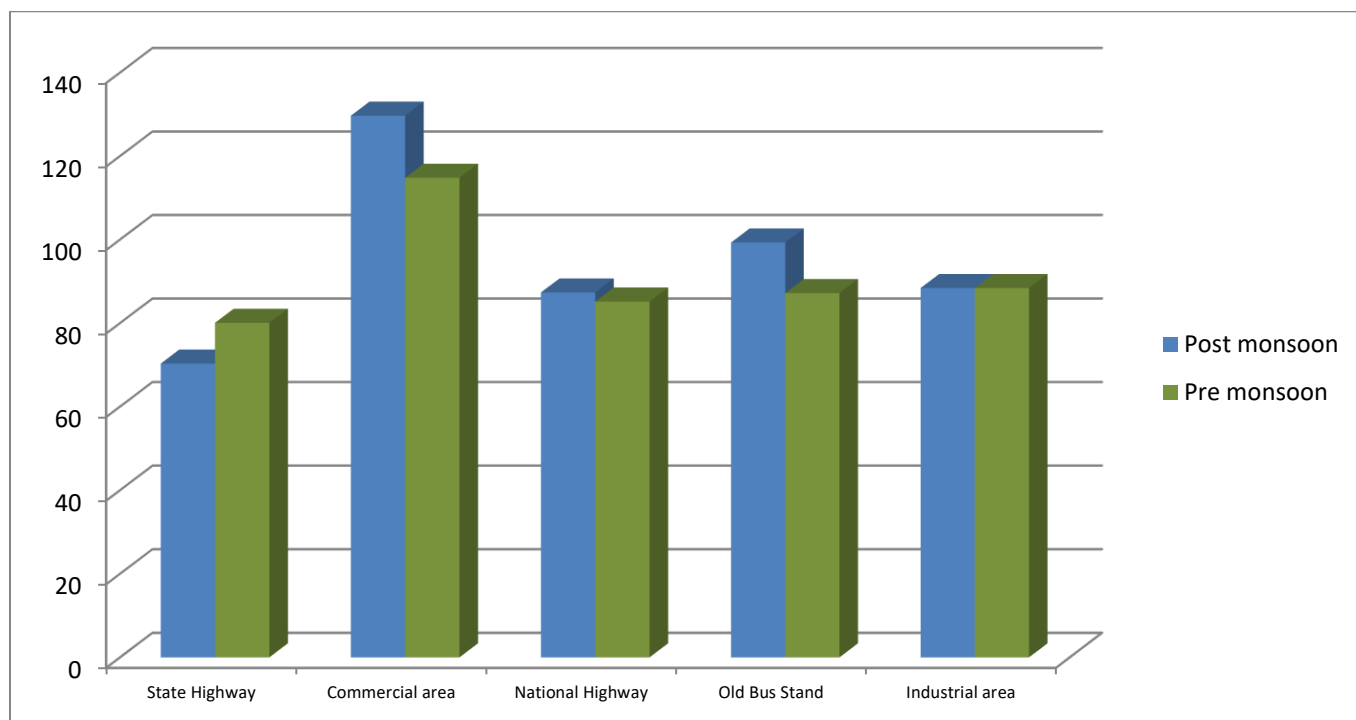


Figure 4 Seasonal variation in concentration of Particulate Matter ($\mu\text{g per m}^3$) at different locations in Solan city

The interaction between locations and seasons also showed statistically significant effects during both the seasons. The concentration of NO₂ was highest at commercial area during post monsoon and lowest at state highway during pre monsoon (Fig. 5).

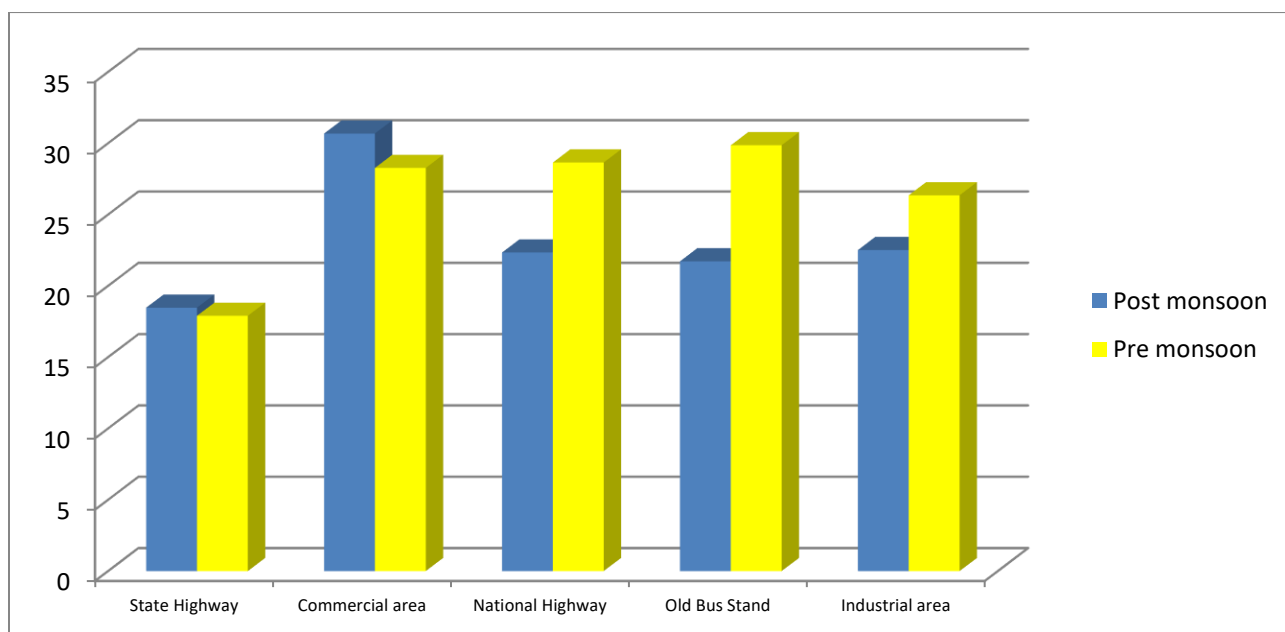


Figure 5 Seasonal variation of concentration of Nitrogen dioxide ($\mu\text{g per m}^3$) at different locations in Solan city

3.3. Concentration of Sulphur dioxide (SO_2) in Solan city

The effect of locations on the concentrations of Sulphur dioxides (SO_2) was statistically significant in the Solan city. The maximum concentration ($8.65\mu\text{g/m}^3$) of SO_2 was found at commercial area during pre monsoon and $7.86\mu\text{g/m}^3$ during post monsoon at the same location while minimum concentration ($2.51\mu\text{g/m}^3$) of SO_2 was found at state highway during pre monsoon and $4.22\mu\text{g/m}^3$ during post monsoon at old bus stand. The seasons exhibited non-significant effect on the concentration of SO_2 measured during both the seasons. The interaction between locations and seasons showed statistically significant effects during both the seasons. The concentration of SO_2 was highest at commercial area during pre monsoon and lowest at state highway during same season (Fig. 6).

3.4. Concentration of Volatile organic compounds (VOCs) in Solan city

The effect of locations on the concentrations of volatile organic compounds (VOCs) in the Solan city was non-significant. The maximum concentration ($2.25\mu\text{g/m}^3$) of volatile organic compounds was found at commercial area during pre monsoon and $7.86\mu\text{g/m}^3$ during post monsoon at the same location while minimum concentration ($1.05\mu\text{g/m}^3$) of volatile organic compounds was found at national highway during pre monsoon and $4.47\mu\text{g/m}^3$ during post monsoon at industrial area (table 1). The seasons exhibited significant effect on the concentration of volatile organic compounds measured during both the seasons. The interaction between locations and seasons showed non-significant effects during both the seasons. The concentration of volatile organic compounds was highest at commercial area during pre monsoon and lowest at national highway during post monsoon (Fig. 7).

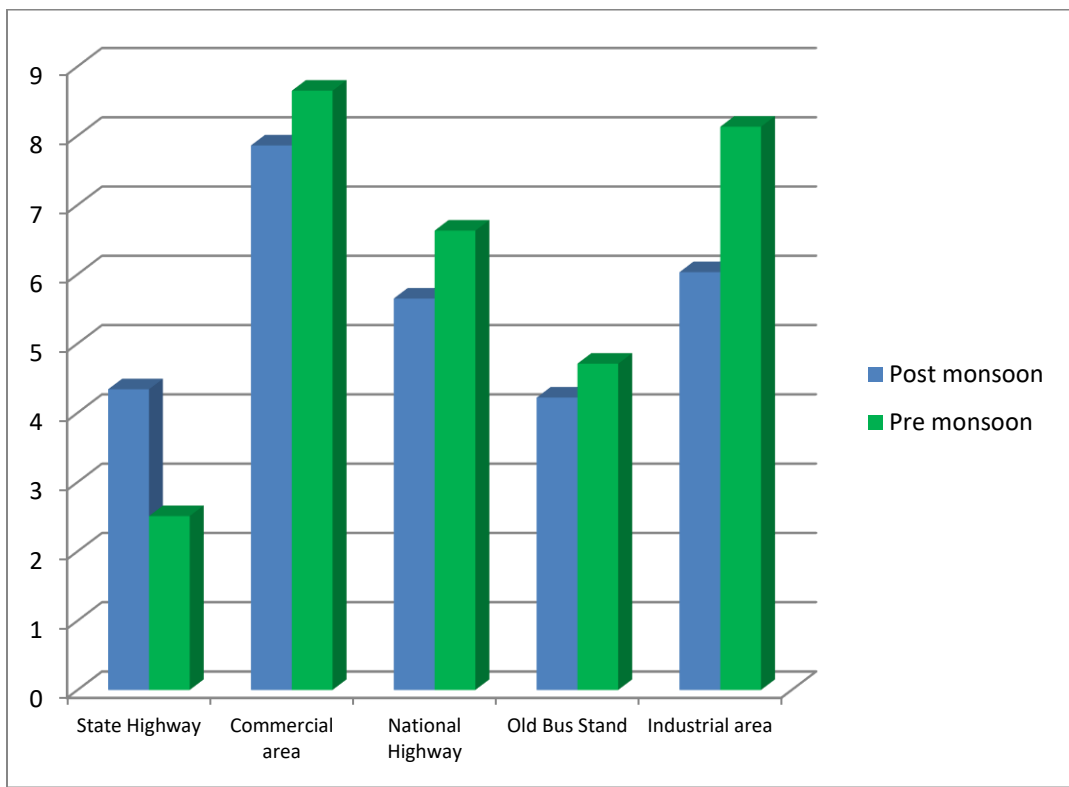


Figure 6 Seasonal variation in concentration of Sulphur dioxide ($\mu\text{g per m}^3$) at different locations in Solan city

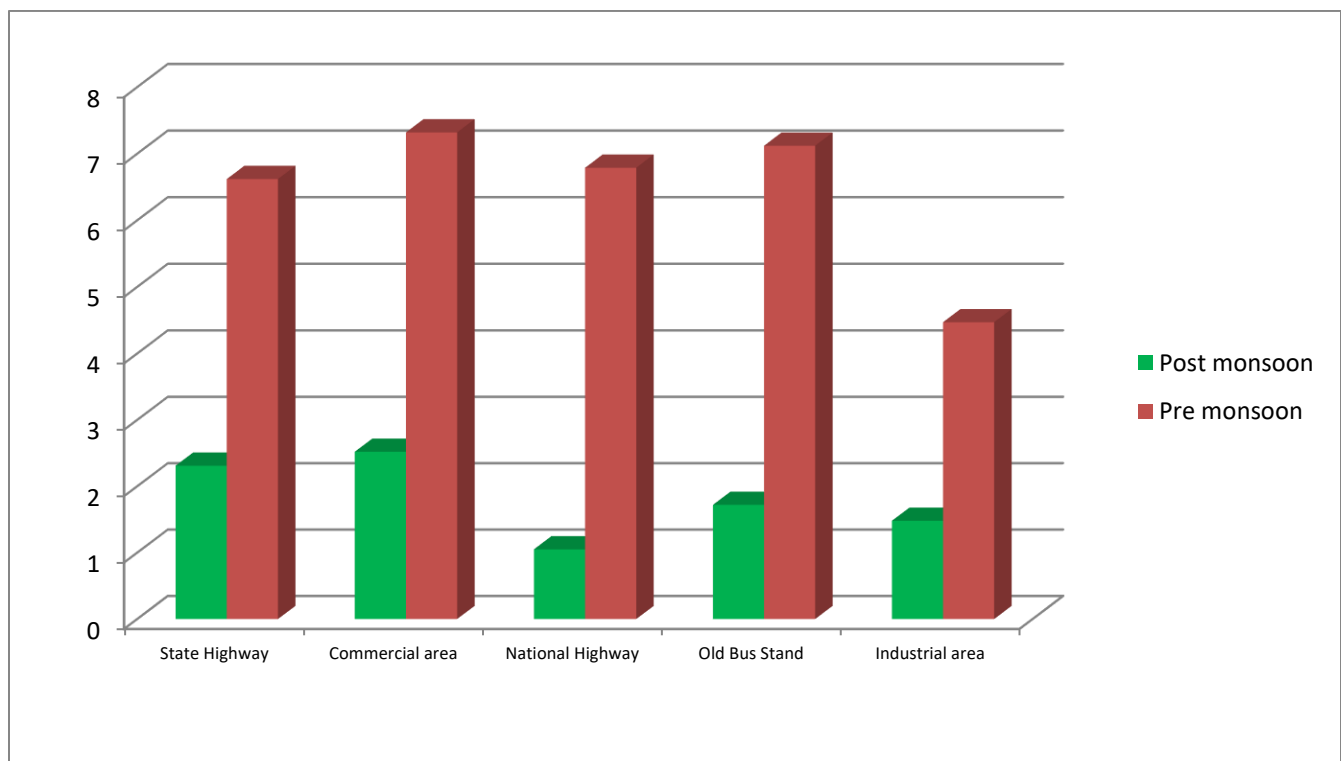


Figure 7 Seasonal variation in concentration of Volatile Organic Compounds($\mu\text{g per m}^3$) at different locations in Solan city

The occurrence of maximum pollutants at commercial site may be because of number of restaurants, bakery shops, food vendor outlets, prominent shopping complexes for tourists as well as for local community and continuous lines of street level shops are present around this site. Use of diesel-powered generator sets during power breakdown is also very common at this site. Moreover, this site repeatedly suffered from prolonged episodes of traffic congestion and stoppage throughout the day as the roads are narrow and congested. In addition, lack of sufficient parking space leads to parking of vehicles at this location by tourists as well as shopkeepers that reduced the actual street width and obstruct traffic flow therein. Mathew (2012) pointed out that the emissions of gases and particulates steadily increase with decrease in speed of vehicles. The problem is further aggravated by the presence of high buildings on both the sides of the road which prevent wind speed from being sufficiently strong for the dispersion of air pollutants. Higher concentrations of NO₂ in winter may also result from photochemical oxidation of NO to NO₂ (Gurtu et al, 2001; Khaled SM Essa *et al.* 2015; Akinnubi *et al.* 2016; Khaled SM Essa *et al.* 2016).

The minimum concentration of pollutants was found at location state highway which is an open area and the dispersion of air pollutants is more at this site in comparison to other locations. The construction activities are comparatively less, the number of vehicles is less and road condition is good at this location. Moreover, sufficient vegetation is present at this location which helps in absorbing the pollutants. Although, the traffic flow is high other three locations but due to wide and open area and smooth traffic flow, the air pollutants get dispersed into air easily and also the vegetation present on both sides of road in these locations absorbed the air pollutants. The concentration of PM₁₀ found at Industrial area was found to be less because there was no source of direct emission of any pollutants from this area.

The data recorded for the gaseous pollutants in all the locations revealed that the concentration of gaseous pollutants (NO₂, SO₂ and VOCs) is well within the NAAQS (National Ambient Air Quality Standards) limits as stipulated by Central Pollution Control Board, Government of India whereas, the concentration of suspended particulate matter is higher than the prescribed limits of National Ambient Air Quality Standards.

3.5. Air Quality Index in Solan city

Table 2 represented the air quality index for Solan city during post monsoon and pre monsoon seasons and had been found that the air quality at commercial area, old bus stand and national highway was "Moderately polluted" while at locations state highway and industrial area it was found to be "Fairly clean" as per standards fixed by Central Pollution Control Board.

Table 2 Location wise Air Quality Index in Solan city during post-monsoon and pre-monsoon seasons

Location	Post-monsoon		Pre-monsoon	
	AQI	Ambient air quality	AQI	Ambient air quality
State Highway	38.05	Fairly clean	44.34	Fairly clean
Commercial area	67.83	Moderately polluted	64.46	Moderately polluted

National Highway	51.22	Moderately polluted	51.22	Moderately polluted
Old bus stand	58.07	Moderately polluted	52.07	Moderately polluted
Industrial area	25.39	Fairly clean	28.70	Fairly clean

3.6. Correlation of meteorological parameters with studied pollutants

The statistically significant negative correlation between temperature and air pollutants in the selected areas during post-monsoon season in the Solan city has been observed (table 3). Negative correlation of NO₂ with temperature in post-monsoon may be due to ineffective fuel burning in vehicle engines during cold winter season (Steinberga et al, 2013). Ilten and Selici (2008) have also reported higher SO₂ and NO₂ concentrations in the atmosphere during low temperature periods.

A non-significant correlation between all the studied pollutants with relative humidity had been observed in the selected areas during post-monsoon season. The absence of possible impact of humidity on the concentration of pollutants during post monsoon season has also been reported by Jayamurugan et al (2013).

Table 3 Correlation of meteorological parameters with studied pollutants during post-monsoon season

Pollutants Meteorological parameters	PM ₁₀	NRSPM	TSP	NO ₂	SO ₂	VOCs
	Temperature	-0.187*	-0.068*	-0.070*	-0.403*	-0.440*
Relative Humidity	0.268 ^{NS}	-0.124 ^{NS}	0.085 ^{NS}	0.527 ^{NS}	0.590 ^{NS}	-0.131 ^{NS}
Wind speed	-0.794**	-0.271*	-0.622*	-0.576 ^{NS}	-0.500 ^{NS}	0.229 ^{NS}
Rain fall	-0.309 ^{NS}	-0.523 ^{NS}	-0.483 ^{NS}	0.138 ^{NS}	-0.068 ^{NS}	-0.294 ^{NS}

* 5 percent lever of significance, **1 percent level of significance.

The correlation between wind speed and pollutants viz., NO₂, SO₂ and volatile organic compounds was non-significant and negative, while a significant negative correlation with particulate matter (PM₁₀), non-respirable suspended particulate matter (NRSPM) and total suspended particulate (TSP) was found in the study area during post-monsoon season. It was due to the fact that as wind speed decreases the particulate matter increases. The wind speed is not the only factor that affects the concentration of pollutants in air as topographic features can also play their role (Giri *et al*, 2008). Celik and Kadi (2007) have also reported lesser influence of wind speed on pollutants in mountainous regions. Non significant negative correlation of pollutants with rainfall has been recorded in post-monsoon season except NO₂ which showed positive correlation with rainfall. Absence of rain leads to accumulation of pollutants in the atmosphere which has been supported by Yaseen (2003).

The correlation of meteorological parameters with the studied air pollutants in Solan city during pre-monsoon season has been presented in table 7. It revealed non-significant correlation between temperature and studied pollutants except NO₂ during pre-monsoon season in the Solan city. Elminir (2007) has also pointed out that temperature did not significantly influence particulates, SO₂ and NO₂ concentrations during pre-monsoon season.

Table 4 Correlation of meteorological parameters with studied pollutants during pre-monsoon season

Meteorological Parameters \ Pollutants	Pollutants					
	PM ₁₀	NRSM	TSP	NO ₂	SO ₂	VOCs
Temperature	-0.182 ^{NS}	-0.014 ^{NS}	-0.119 ^{NS}	0.167 ^{NS}	-0.083 ^{NS}	0.214 ^{NS}
Relative Humidity	0.420 ^{NS}	0.110 ^{NS}	0.334 ^{NS}	0.411 ^{NS}	0.550 ^{NS}	0.176 ^{NS}
Wind speed	-0.345 ^{NS}	-0.033 ^{NS}	-0.231 ^{NS}	-0.115 ^{NS}	-0.358 ^{NS}	-0.165 ^{NS}
Rain fall	-0.387 ^{NS}	-0.020 ^{NS}	-0.246 ^{NS}	-0.431 ^{NS}	-0.372 ^{NS}	-0.015 ^{NS}

The correlation between relative humidity and studied pollutants revealed non-significant positive correlation during pre-monsoon season (table 4). Local factors such as increased vehicular traffic due to increased flow of tourists in summer vacations played the major role in influencing the pollutant concentration rather than meteorological parameters. The fact that local factors are responsible for low or no correlation has also been pointed out by Vanadeep and Krishnaiah (2011).

The correlation between studied pollutants and wind speed revealed non-significant negative correlation during pre-monsoon season. The non significant negative correlation of rainfall with pollutants during pre-monsoon season indicated that during rains the concentration of pollutants decreases. Non significant correlation has been observed between wind speed and studied pollutants in the study area during pre monsoon season. Non significant correlation with wind speed indicated that dust particles have come from the lower level of sources i.e. vehicles and domestic sources and not from industries. Yassen (2003) also pointed out that the effect of wind speed operate to be far more effectively on high level emissions than on lower emissions.

3.7. Concentration of heavy metals in respirable dust in Solan city

The Concentration of heavy metals in respirable dust in Solan city has been presented in table 5. It showed the statistically significant effect of location on the concentrations of Arsenic (As) recorded in the Solan city. The maximum concentration of As was found at old bus stand and industrial area with a mean value of 0.03 ppm while minimum concentration of As was found at location National highway with a mean value of 0.01 ppm. The seasons exhibited statistically significant effect on the concentration of As measured during both the seasons. The interaction between locations and seasons also showed statistically significant effects during both the seasons.

Table 5 Seasonal variation in the concentrations of heavy metals at different locations in Solan city

Locations	Pre monsoon						Post monsoon					
	Cu	Fe	Mn	Ni	Pb	As	Cu	Fe	Mn	Ni	Pb	As
State Highway	0.17	43.95	1.67	0.17	0.07	0.04	0.16	28.01	0.92	0.09	0.04	0.01
Commercial area	0.18	42.61	1.37	0.10	0.05	0.03	0.17	32.29	0.63	0.11	0.07	0.02
National Highway	0.16	8.71	1.41	0.18	0.05	0.01	0.12	13.15	1.16	0.09	0.02	0.01
Old bus stand	0.30	37.87	1.75	0.16	0.02	0.04	0.26	28.52	0.69	0.13	0.02	0.02
Industrial area	0.26	51.89	1.58	0.13	0.04	0.04	0.15	27.32	1.08	0.04	0.03	0.02
Mean	0.22	37.01	1.56	0.15	0.05	0.03	0.17	25.86	0.90	0.09	0.04	0.02

There was a statistically significant effect of location on the concentrations of Lead (Pb) recorded in the Solan city. The maximum concentration of Pb was found at commercial site with a mean value of 0.06 ppm while minimum concentration of Pb was found at old bus stand with a mean value of 0.024 ppm. The seasons exhibited statistically significant effect on the concentration of Pb measured during both the seasons. The interaction between locations and seasons also showed statistically significant effects during both the seasons. Higher concentration of Pb had been observed at commercial area. It could be due to the continuous use of leaded petrol in the past few decades resulting emission of Pb into atmosphere which has led to a considerable concentration of Pb in soil along the road side. The movement of vehicles renders the dust containing Pb, resuspended in air.

The statistically significant effect of location on the concentrations of Nickel (Ni) was found in the Solan city. The maximum concentration of Ni was found at old bus stand with a mean value of 0.14 ppm while minimum concentration of Ni was found at industrial area with a mean value of 0.08 ppm. The seasons exhibited statistically significant effect on the concentration of Ni measured during both the seasons. The interaction between locations and seasons also showed statistically significant effects during both the seasons.

The statistically significant effect of location on the concentrations of Manganese (Mn) was revealed under the study in the Solan city. The maximum concentration of Mn was found at industrial area with a mean value of 0.13 ppm while minimum concentration of Mn was found at commercial area with a mean value of 1.0 ppm. The seasons exhibited statistically significant effect on the concentration of Mn measured during both the seasons. The interaction between locations and seasons also showed statistically significant effects during both the seasons. Higher concentration of Mn had been observed at industrial area. It may be attributed to

the windblown soil borne particles in the vicinity of area (Roy et al., 2012). Previous studies reported the earth crust or wind-blown soil as a contributor of Mn, in PM₁₀ (Shah et al., 2006; Dubey et al., 2012).

The statistically significant effect of location on the concentrations of Iron (Fe) was found in the Solan city. The maximum concentration of Fe was found at industrial area with a mean value of 39.6 ppm, while minimum concentration of Fe was found at national highway with a mean value of 10.9 ppm. The seasons exhibited statistically significant effect on the concentration of Fe measured during both the seasons. The interaction between locations and seasons also showed statistically significant effects during both the seasons. The higher concentration of Fe at industrial area may be due to the particulates originate from weathering of a unique form of local geological material due to wind erosion, construction work, traffic related and residential activities in the vicinity of industrial area which is an industrial area.

The statistically significant effect of locations on the concentrations of Copper (Cu) was indicated in the study in the Solan city. The maximum concentration of Cu was found at old bus stand with a mean value of 0.28 parts per million (ppm) while minimum concentration of Cu was found at national highway with a mean value of 0.14 ppm. The seasons exhibited statistically significant effect on the concentration of Cu measured during both the seasons. The interaction between locations and seasons also showed statistically significant effects during both the seasons. Higher concentration of Cu at old bus stand may be due to more vehicular activities and re-suspension of road dust due to the movement of vehicles along the road.

The results related to heavy metals revealed that the concentrations of Fe and Mn were higher as compared to other heavy metals found in the study area. Further, the concentrations of all the heavy metals were higher in pre-monsoon season as compared to post-monsoon season. The most common sources of these two heavy metals are emissions from vehicular, industrial and construction (geological) related activities. Nickel in the atmosphere originates from the smelting and combustion of fossil fuel, particularly oil (Sub- Committee on Nickel, 1975; Salmon, Atkins, Fisher, Healy and Law, 1978; Pacyna, 1984). The Zn might be from abrasion of vehicles because Zn is a part of the materials for brass alloy. Therefore, vehicles are the major sources of emissions of these heavy metals supported by the data presented in the table 6. It indicates that the number of vehicles have been increasing continuously in the Solan city during last three years. However, the concentrations of heavy metals were within the permissible limit prescribed by the Central Pollution Control Board.

Table 6 Number of vehicles registered in Solan city

Vehicle	2013-14	2014-15	2015-16
Two-wheeler	1274	1582	1809
Three-wheelers	89	55	58
Four-wheelers	1165	1377	1464
Buses	29	54	33
Goods vehicles	637	760	797
Others	17	29	38

Total

3211

3857

4199

Source: Deputy Commissioner Office, Solan and Regional Transport Office, Solan

4. CONCLUSIONS

Based on the present investigation it can be concluded that the concentrations of gaseous pollutants i.e. SO₂, NO₂ and volatile organic compounds in the air are within the National Ambient Air Quality Standards at all the sites in Solan city. However, the concentrations of particulates matter have been found higher (122.24 µg/m³) at commercial area than the prescribed limits. Thus, particulate pollutants have been observed to be the major pollutants in the present study area. The air quality index during post monsoon and pre monsoon seasons at commercial area, old bus stand and national highway was "Moderately polluted" while at state highway and industrial area it was found to be "Fairly clean". The concentration of heavy metals has been found to be present in the air in Solan city which can be dangerous in near future. To tackle the problem of air pollution in the city, the roads should be maintained properly in order to reduce congestion and traffic jams, solar based battery vehicles should be used for local transportation and air quality should be monitored regularly.

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