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Study of ambient air pollutants over Rishikesh at foothills of north-western Indian Himalaya

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Air quality parameters measured over Rishikesh city of Uttarakhand, where a large number of visitors and pilgrimage stay and pass by throughout the year are analyzed and studied. Such intensive human activities lead to the impacts and its manifestation on regional scale environment. Due to consistent infrastructure development and the increased vehicular emission due to transport, a large amount of particulate matters is added to the ambient environment and affects the air quality adversely. Here an attempt is made to understand the growth in level of ambient air pollutants through available measurement. In this study particulate matter (PM_{10}), suspended particulate matters (SPMs) and the concentration of gaseous pollutants (SO_2 and NO_2) from 2011 to 2014 are measured and analyzed. It is observed that concentrations of the pollutants increase during pre-monsoon season as compared to the winter and monsoon seasons. In addition, PM_{10} and SPM concentrations are found about two times higher than the prescribed national standard. SO_2 and NO_2 levels are found within the limits as proposed by the Central Pollution Control Board (CPCB) New Delhi, India. A detailed statistical analysis is carried out on the basis of monthly mean values of the observed pollutants. The PM_{10} exhibits a significant positive correlation with SO_2 and NO_2 concentrations. In addition, back trajectories show partly long-term transport from North Africa, Saudi Arabia and central Asian region in contributing over the region with local emission that is considered to be the main and direct cause of increasing trend of the pollutants.

Keywords: Air Quality status, Statistical Analysis, Meteorological parameters and Aerosols Optical Depth.

1 Introduction

In the recent decades, air pollution in the atmosphere is becoming a major problem for many developing cities in India. It affects natural activities, human health, modification of regional weather and climate, etc. These are mainly aerosols and particulate matters in solid and liquid form that remain suspended in the air consisting many types of impurities. There are mainly two types of sources, viz. primary, directly emitted from their sources, and secondary, pollutants which are formed from the combination of primary pollutants with any other compound. For the greater details on particulate matter and closely relate aspect with their impact on various environmental issue one can see[1]. The main sources of urban air pollution are anthropogenic as they are emitted from automobiles, industries, domestic fuel combustion and road construction etc [2-3]. Vehicular emissions are responsible for higher levels of air pollutants like SPM, RSPM, SO_2, NO_2 and other organic and inorganic pollutants including trace metals[4-8]. These investigations also revealed that, the gaseous pollutants in this expanse generally are always well within the Indian air quality standards while the concentration of particulate matter exceeds the criteria[4,9]. The Air Act (Prevention and Control of Pollution) Act was enacted in 1981 and amended in 1987 to provide for the prevention, control and abatement of air pollution in India[10]. Under this act, continuous national ambient air quality monitoring system has been initiated to collect the air pollution data with a wide network of monitoring stations throughout the country[11-13]. During past two decades, the problem of atmospheric pollution is one of the key environmental issues for all the developing countries. In-situ anthropogenic pollutants are measured at a number of sites across the world to define the impact of such impurities on the environment. As increasing levels of air pollutants have significant impact on

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global warming, they also have deleterious effect on human health, vegetation and other living organisms. They show significant spatial and temporal variability. Despite of all these effects, on-site measurements of air pollutants are limited in the developing countries including India.

A few attempts have been made to measure the air pollutants in some regions of our country. For example, the Indo-Gangetic plain (IGP) is an important region from various point of view and it depicts higher level of anthropogenic emissions. Ground based and space-born observations are made in this region by[14-15]. They have summarized the state of pollutants in this area. However, most recent activities in terms of natural calamities and increased transport system have changed the ambient environmental conditions over the study region. Hence it is needs to be assessed critically. In the present work, analysis based on the four years site measurements of air pollutants (SO_2, NO_2, RSPM, and SPM) is presented. The measurements were carried out under the umbrella of the Central Pollution Control Board (CPCB) during 2011-2014.

Ambient air quality parameters as mentioned above, of Rishikesh-city in Uttarakhand during this period along with prevailing meteorological condition during different season are discussed here.

2 Study Area

Rishikesh is one of the important towns of Uttarakhand, situated along the bank of the river Ganga in the foothills of Himalaya. Sampling station is a selected location as marked and shown in Fig 1. The study area is a specific partly in the sense that it is located in three different districts Dehradun, Tehri and Haridwar in Uttarakhand. Study area includes observations from three districts, Dehradun, Tehri, and partly Haridwar district. The study area consists of approximately 12.5 sq km. Here the river Ganga finds plain area after flowing about 250 km in the mountain and hill areas. The Rishikesh tow is having altitude of 370 m and situated at 30.10 °N and 78.29 °E. This holy city attracts thousands of pilgrims, foreign tourists from all over the world throughout the year and is the gateway for five hill districts, viz., Tehri, Uttarkashi, Pauri, Chamoli & Rudraprayag under Garhwal region. These connections lead it to become center of commercial and pilgrimage activities over these districts. On the other

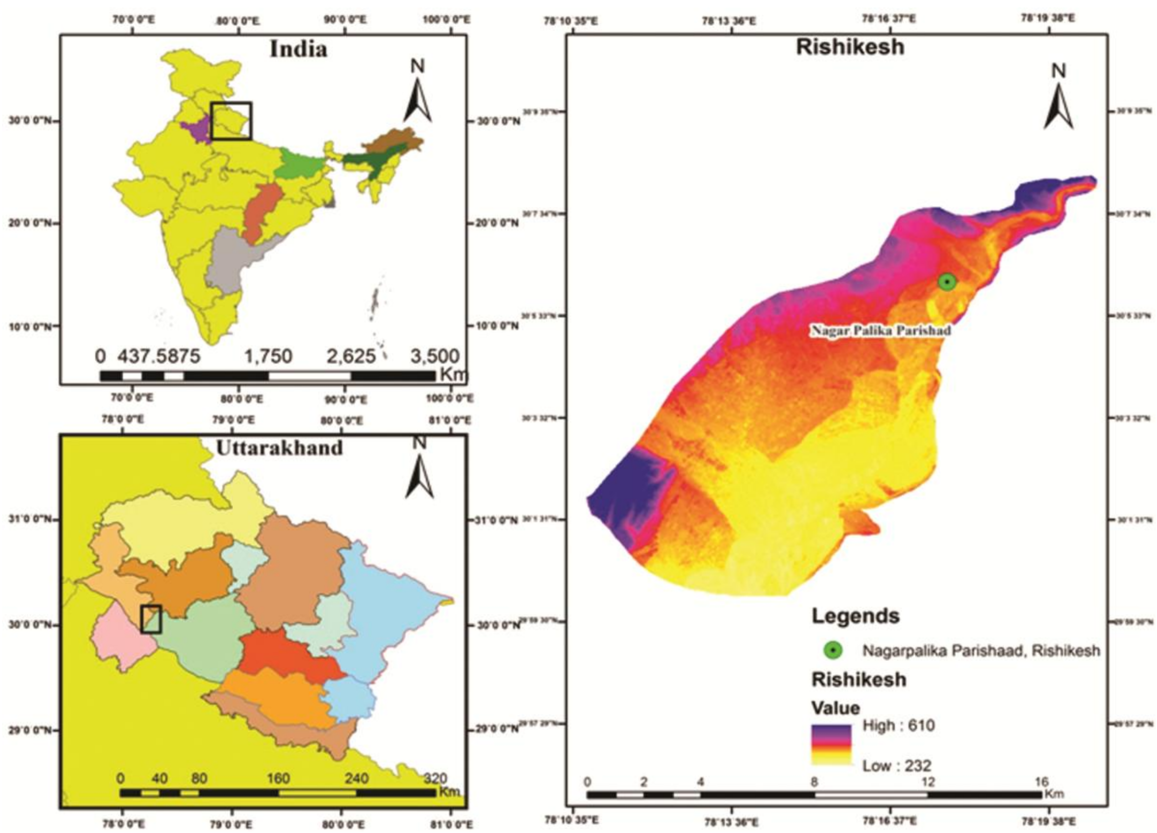

Fig. 1 — Location of the study site Rishikesh city in Uttarakhand, India.

hand, being in plain area having moderate climate, it has become the place of major health/medical related facilities.

Increasing human activities are polluting the ambient air of this town in course of time. The population of the town is nearly 0.1 million as per 2011 census. During the last decade, the population of this town has increased with the addition of about 4500 per year. Moreover, there is unpredicted floating population that comes and lives for short time and contributes towards adding pollutants as compare to the permanent residents. Thus there is a need to keep watch on the increasing rate of pollution and find the means to mitigate the same.

3 Instrumentations and data analysis

In the present study, quality of ambient air in terms of different pollutants in the form of gaseous pollutants, viz. SO_2, NO_2 and the particulate matter RSPM and SPM was analyzed. The data for these pollutants were obtained from the Central Pollution Control Board (CPCB), Dehradun from 2011-14. The meteorological data were collected from the India Metrological Department (IMD), Dehradun for the same period. Collection of the data of air pollutants is done with the help of a respirable dust sampler (RDS) Envirotec APM (460) NL. This Dust Sampler was used to monitor particulate matter of 10μm (PM_{10}) size under ambient air quality monitoring. This is based on filtration-gravimetric method in which Whatman filter papers (20.3cm×25.4 cm) are used which needs calibration at least one time in a year for precise measurements.

The concentrations of SPM and RSPM were determined using high efficiency filter paper method by passing air at high flow rate, which retains the particles. The gaseous pollutants such as SO_2 and NO_2 were also monitored simultaneously in an attached impinger with the Dust Sampler. The collected samples were then put in iceboxes immediately after sampling and afterwards kept in a refrigerator prior to their analysis. Finally, all the samples were analyzed in the lab. Modified methods of West and Gaeke (1956)[15] and Jacobs and Hochheiser (1958)[16] were followed for the analysis of different gaseous pollutants. Data of gaseous pollutants are collected four times a day, whereas collection of the data of particulate matter was carried out three times a day (duration 8 hours). Using these data-sets, correlation between gaseous pollutants and particulate matter was calculated. Pearson's product-moment and Spearman's rank methods were used in finding these correlations.

4 Results and Discussion

4.1 Monthly Variation

Monthly variations of air pollutants and rainfall for the study period are shown in Fig. 2. It shows the maximum concentration of SO_2 during April-May in all the years. In the year 2011 the minimum concentration of SO_2 was observed in July (12.93 μgm^{-3}) indicating that scavenging due to rain plays an important role in keeping the pollution parameters in limits. Similarly, Fig. 2 (b) shows monthly mean variability in NO_2 at Rishikesh during the study period. It shows the maximum concentration of NO_2 during April-May, in all years except 2013. However, increase in the mass concentrations is observed from September onwards. It is evident from Fig. 2 (c) that during the study period PM_{10} is found to be maximum 144.81 μgm^{-3} in May 2013 and the minimum 33.87μgm^{-3} is observed in the month of August 2011. Similarly, the maximum concentration of SPM was recorded in May 2013, whereas the minimum value is found to be 81.69 μgm^{-3} during peak monsoon in the year 2011.

4.2 Seasonal Variation

Seasonal Variation of particulate matter and gaseous pollutants are depicted in Fig. 3. It show seasonal mean of PM_{10}, SPM, SO_2 and NO_2 for the period of four years. Seasons are categorized as per India Meteorological Department (IMD)[18] classification, i.e. winter (December, January and February), pre-monsoon (March, April and May), monsoon (June, July, August and September), and post-monsoon (October and November). Fig. 3 show the variation in gaseous pollutant and concentration of particulate matter with the changes in seasons. The gaseous pollutant SO_2 was maximum (24.68 μgm^{-3}) during pre-monsoon and similar trend was observed for NO_2 in all the years of study, with maximum seasonal average of 26.90 μgm^{-3}. The maximum and minimum values of particulate matter are shown in Figs. 3(c) and (d) respectively. The maximum concentration of PM_{10} is observed during the pre-monsoon seasons during the entire period of study, while minimum concentration was recorded during the winter and monsoon seasons. Similarly, the maximum concentration of SPM is observed during pre-monsoon season and the minimum concentration was found during the

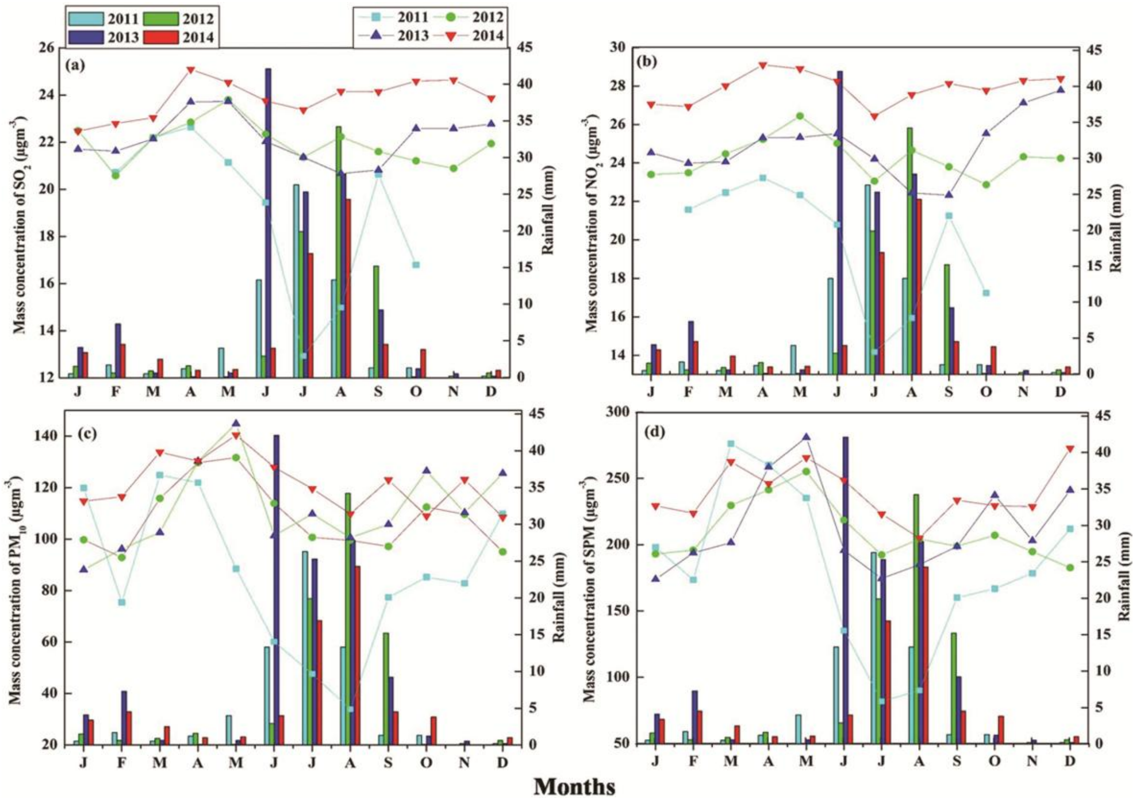

Fig. 2 — Monthly variations of air pollutants and rainfall at Rishikesh in Uttarakhand during 2011-2014.

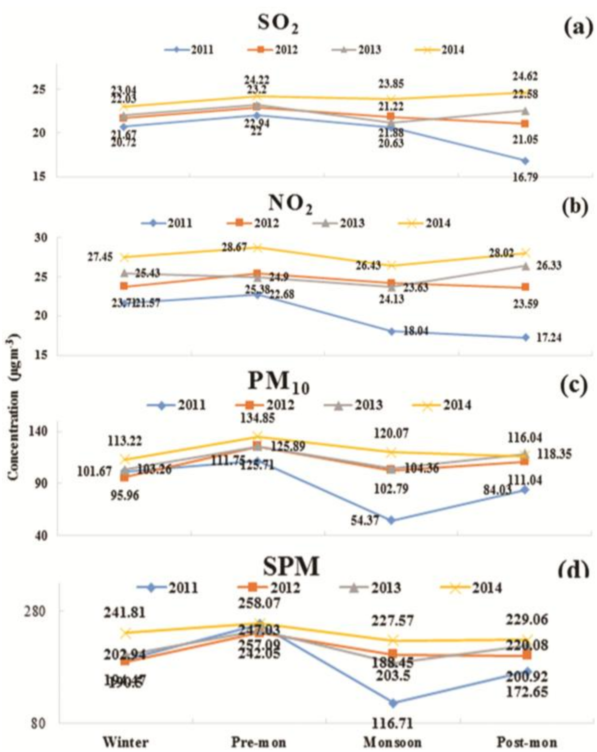

Fig. 3 — Seasonal variation of air pollutants on the selected site during 2011-2014.

monsoon seasons, except in the year 2012 where it was maximum during the winter season. This unusual enhancement in air pollution level may take place due to manifold increases in the number of vehicles and traffic congestion, during Chardham Yatra which is a pilgrimage originating from Rishikesh and leading towards four holy shrines in Garhwal Himalaya of Uttarakhand.

4.3 Annual Variability of Air Pollutants

The Tables 1 and 2 show the annual statistical variability of air pollutants over the study site. The statistical analysis includes different values of pollutants (minimum, maximum, & mean), standard deviation and standard error. During the study annual average concentration of PM_{10} was found to varied from a minimum of 85.60 µgm^{-3} to the maximum 125.87 µgm^{-3} for all the four years. The minimum observed value of PM_{10} was found 33.86 µgm^{-3} in the year 2011 and maximum value was found 168.87 µgm^{-3} in the year 2014. Similarly, the annual average concentration of SPM was varied from 180.56 µgm^{-3} to 239.04 µgm^{-3} in the selected site.

The lowest annual recorded concentration of SO_2 was 12.92 µgm^{-3}in 2011 and the highest 25.09 µgm^{-3}

Table 1 — Annual statistics of particulate matter at Rishikesh city in India.

Years	PM_{10} concentrations (μgm^{-3}) 2011–2014					Years	SPM concentrations (μgm^{-3}) 2011–2014				
	Min	Max	Average	SD	SE		Min	Max	Average	SD	SE
2011	33.86	124.84	85.6	29.5	8.51	2011	81.69	276.12	180.56	60.611	17.49
2012	92.83	131.64	108.19	12.976	3.746	2012	182.6	255.13	209.46	22.205	6.41
2013	88.06	144.81	111.8	16.528	4.771	2013	173.9	280.92	211.99	34.31	9.907
2014	108.5	168.87	125.87	16.898	4.888	2014	204.9	272.81	239.04	20.249	5.845

Table 2 — Annual statistics of gaseous pollutant at Rishikesh city in India.

Years	SO_2 concentrations (μgm^{-3}) 2011–2014					Years	NO_2 concentrations (μgm^{-3}) 2011–2014				
	Min	Max	Average	SD	SE		Min	Max	Average	SD	SE
2011	12.92	22.64	19.05	3.388	0.9781	2011	14.16	23.23	19.88	3.253	0.939
2012	20.58	23.8	21.96	0.8951	0.2584	2012	22.87	26.44	24.25	1.02	0.294
2013	20.67	23.73	22.14	0.9897	0.2857	2013	22.33	27.78	24.85	1.627	0.469
2014	22.47	25.09	23.87	0.8132	0.2347	2014	26.43	29.1	27.9	0.7928	0.229

Table 3 — Annual Registered Vehicles in Uttarakhand during study period (source: State Transport Department).

(a)

Vehicle Type	Years			
	2011	2012	2013	2014
Two Wheeler	109363	126025	125082	132679
Cars/Jeep	29367	36125	36490	33608
Buses	650	723	664	700
Trucks	1669	2117	1554	1491
4 Wheeler Loader	3881	4151	3758	3667
Tax	3427	4364	3826	3300
Auto	2527	1865	1289	1066
Tractors	3348	2864	2790	3529
Trailers	189	507	634	1222
Others	245	373	587	414
Total	154666	179114	176674	181676

(b)

Months/ Years	Number of visitors		
	2012	2013	2014
Jan	22122	18464	13402
Feb	20620	18687	13916
Mar	23215	22291	19788
Apr	40409	14535	19888
May	70623	74476	26188
Jun	252766	115854	37883
Jul	168161	19244	30143
Aug	68686	26335	30696
Sep	13219	12599	71680
Oct	25092	12553	23941
Nov	9546	12819	23379
Dec	15447	15867	21011
Total	729906	363724	331915

in the year 2014. On the other hand, the maximum and minimum annual average concentration of NO_2 varied from19.88 μgm^{-3} to 27.90 μgm^{-3}.

According to the data available with the State Transport Department, the registrations of different types of vehicles have shown significantly an increasing trend from 2011 to 2013. But due to the natural calamity in 2013, the registration of cars, trucks and taxies reduced in 2014. It reveals that the difference in the number of registration of the vehicle between 2012 and 2013 was very low as compared to other years. This may be attributed to the decrease in the concentration of air pollutants during the same period, (i.e. year 2012-13). This suggests that an increase in the number of vehicles correspondingly increased the level of air pollutants in this region.

Data of number of visitor in Rishikesh from the Rishikesh tourist office during 2012-14 shows that the maximum visitors came in 2012 and the minimum in 2014 and is depicted in Table 3(b). But due to the natural calamity in 2013 the number of visitors, reduced in subsequent years of study. This may be attributed to the number of significant changes in the concentration of air pollutants during same period.

4.4 Local Metrological condition

Figure 4 shows relative humidity (%), rainfall (mm) and maximum temperature (°C) of the city during the study period. Temperature of Rishikesh city during pre-monsoons remains warmer while during winter becomes colder. The temperature is rise up to about 41 - 42°C in pre-monsoon season whereas in winter temperature dips up to 8-9°C. However, the average temperature remains around 25-30^{o}C.

The highest temperature is observed in the month of May, whereas the highest rainfall (mm) observed in July and August every year. But there is sudden increase in the rainfall in the month of June- 2013 (Fig. 4).

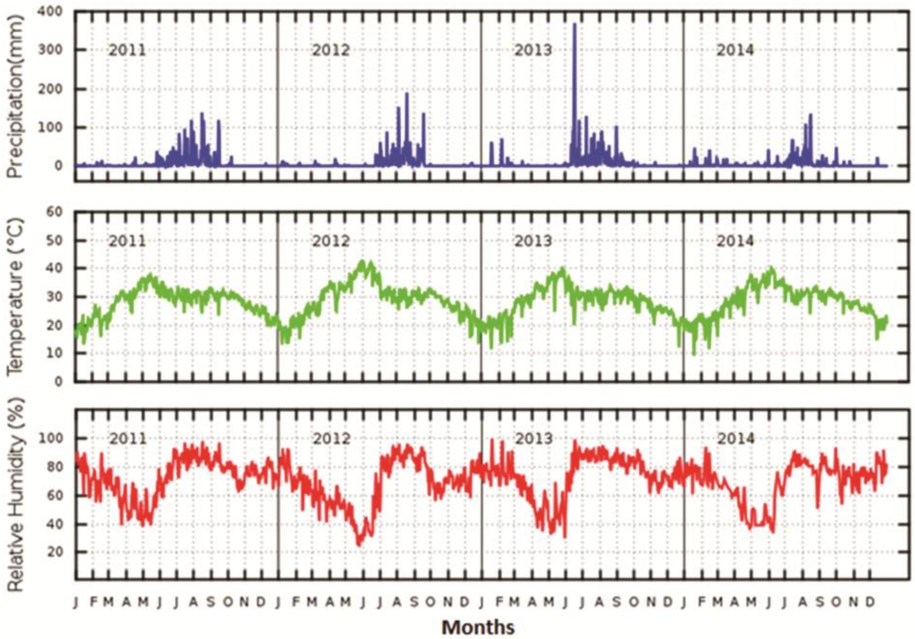

Fig. 4 — Local meteorological parameters of selected site: Precipitation (mm), Temperature (^{0}C) and Relative Humidity (%)) respectively, during 2011 – 2014.

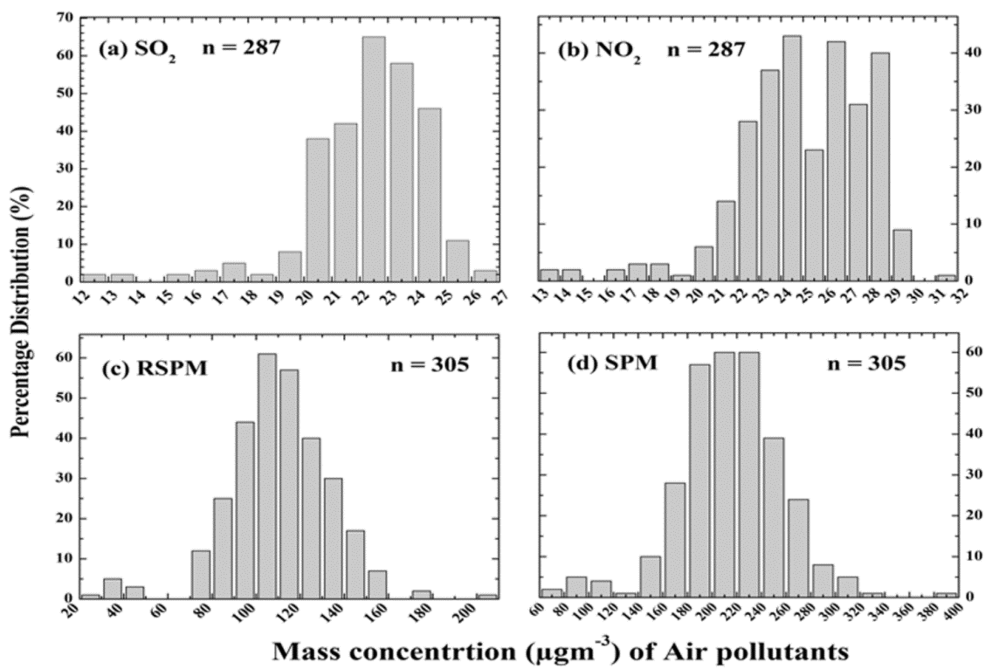

Fig. 5 — Frequency distribution of mass concentrations of (a) SO_2, (b) NO_2, (c) RSPM and (d) SPM selected site.

Relative humidity during all seasons is above 30% with a maximum about 90% during monsoon months.

4.5 Frequency distribution of air pollutants

Frequency distribution of daily mass concentration of measured air pollutants during the study period is shown in Fig. 5 (a-d). It is observed that SO_2 shows the highest percentage (65%) with mass concentration in the range of 22-23 µgm^{-3}. Here the mass concentration was dividing in 14 segments ranging between 12 and 27 µgm^{-3}. For NO_2, frequency distribution of mass concentration was divided into 17 different categories between 13-32 µgm^{-3}. The highest concentration (40-45%) of NO_2 was found in the range of 24-29 µgm^{-3}, which is less than the corresponding value for SO_2. Percentage distribution for both gases SO_2 and NO_2 showed the increasing pattern with the increase in mass concentration. Frequency distribution of the RSPM is shown in Fig. 5(c). In this, mass concentration was divided in 14 segments. The NAAQS limit is between 20 and 200µgm^{-3}. Maximum frequency percentage (60%) was between 100 and 120 µgm^{-3}. This decreases uniformly on the lower as well as upper values of mass concentration. Fig. 5(d) represents variation in the frequency distribution of SPM with its mass concentration. The National Ambient Air Quality Standard (NAAQS)[18] limits are between 60 and 400 µgm^{-3}. This limit was divided in 15 segments, having interval of 20µgm^{-3} after each segment. Here the highest frequency distribution was 59-60% at the concentrations 200 to 400 µgm^{-3}. For other concentrations the percentage frequency distribution was much less than these values.

4.6 Correlation Co-efficient and Linear Regression

The correlation among different parameters of air pollutants was investigated by calculating the correlation coefficient (r) using Pearson's product-moment. The regression estimates are also computed by using the following well-known relation,

$$Y = MX + C \qquad \ldots (1)$$

where, Y is an estimated (or a dependent variable), X is an independent variable, C is a constant and M is regression coefficient (i.e. slope of the linear graph in the scatter plot in (Fig. 6).

Here, Table 4 shows the correlation between air pollutants and meteorological parameters. We observed that SO_2 and NO_2 showed a good positive correlation (0.842), while the correlation between SO_2 and PM_{10} is 0.592, which is also a good positive

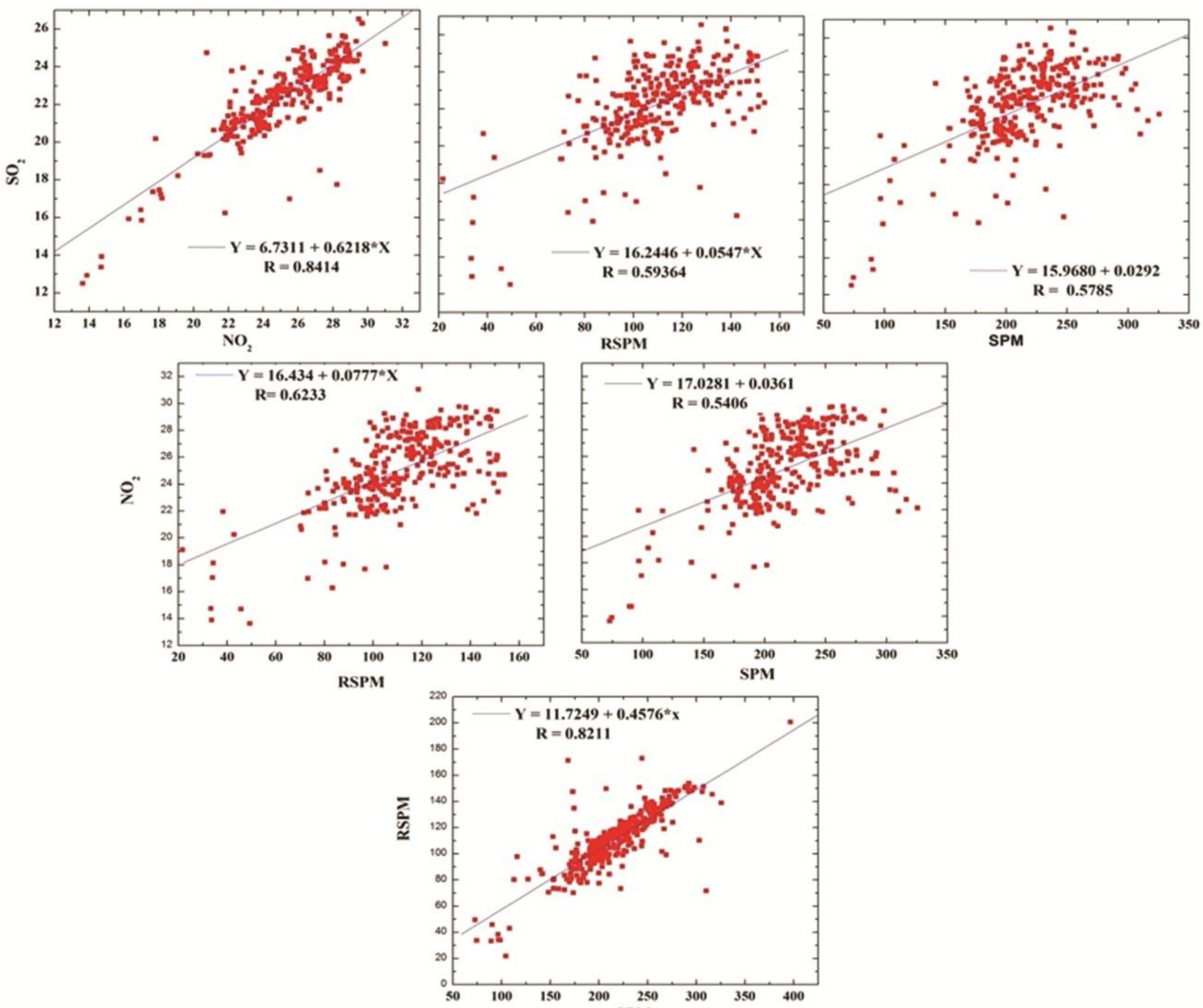

Fig. 6 — Linear regression of air pollutants parameter at Rishikesh in India.

Table 4 — Correlation coefficient between air pollutants and meteorology parameters for Rishikesh in India

Parameters	Parameters (Using Pearson's product-moment correlation method)								
	SO_2	NO_2	RSPM	SPM	RF	Temp	RH	WD	WS
WS									1
WD								1	0.502
RH							1	-0.471	-0.342
Temp						1	-0.373	0.219	0.188
RF					1	-0.183	-0.336	-0.173	-0.081
SPM				1	-258	-0.175	-0.523	0.268	-0.226
RSPM			1	0.829	-0.214	-0.126	-0.448	0.341	-0.229
NO_2		1	0.633	0.538	-0.239	-0.113	-0.226	0.208	0.031
SO_2	1	0.842	0.592	0.547	-0.004	-0.007	-0.313	0.202	-0.109

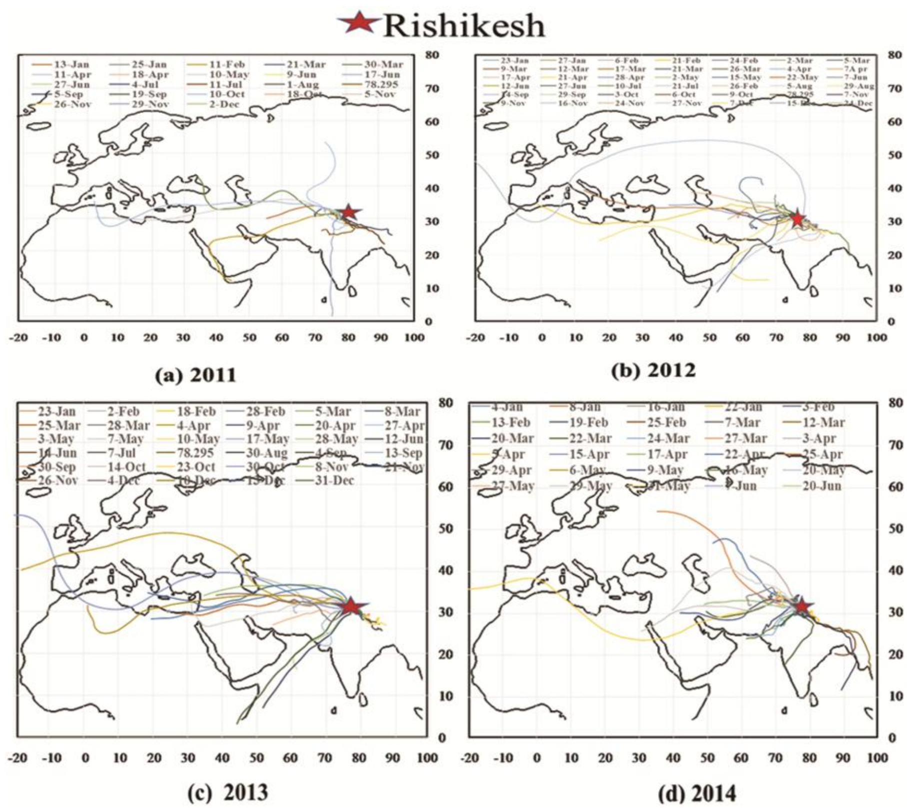

Fig.7 — Backward air mass trajectory started of 800 meters 0:00 UTC at Rishikesh in Uttarakhand, India during 2011-14

correlation. SO_2 and SPM are also positively correlated (0.547) in the selected site. Similar correlation was found between NO_2 and PM_{10} which indicates that increase in one parameter is associated with increase in the other parameter. In addition, Table 4 shows that the meteorological parameters like rainfall (RF), temperature (Temp) and relative humidity (RH) showed a negative correlation with air pollutants, while wind direction (WD) and wind speed (WS) showed a positive correlation except that with NO_2.

In Fig. 6, one can easily notice that SO_2 and NO_2 was more dependent to each other as compared to the particulate matter and similarly, SPM and RSPM were also found highly dependent on each other.

4.7.1 Air mass backward trajectory analysis and wind rose

On the basis of the amount of the particulate matter days of high mass concentration in each month in all the four years were chosen. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model[21] is used to analyze 7 days isosigma back air trajectory simulations. The mass trajectories are shown in Fig. 7 are drawn at the height of 800 m above the sea level. All the four trajectories indicates that the western flow might have added in making the mass concentration slightly higher.

Figure 8 represents the backward air trajectory at three different heights 600 m, 2500 m and 5000 m above mean sea level (AMSL) at monitoring site. Peak values are found on 25 Jan, 21 Mar in 2011 Fig. 7 (a,b), 30 Mar, 24 Nov in 2012 Fig. 7 (c,d), 10 May, 14 May in 2013 Fig. 7(e,f) and 31 May, 12 Jun in 2014 Fig. 7(g,h) respectively. Similarly, the concentration of particulate matter was very high during above mention days. These figures indicate that the long range transport of air mass may carry the particle pollutants from Saudi Arabia, North African continent and major portion of central Asia. Besides this the local sources also significantly contribute to the existing air pollutants.

Figure 9 (a) and (b) shows the seasonal wind rose diagram for 2012 and 2013 respectively. These figures represent the wind speed and wind direction near the Rishikesh city which clearly indicats that the prevailing wind was mainly from westerly that brings the pollutants to the Himalayan foothill during winter and pre-monsoon seasons. In the pre-monsoon and winter seasons the wind direction showed the external air pollutants coming from western countries.

4.7.2 Aerosols Optical Depth

In present study, MODIS level-2 aerosols optical depth (AOD) data obtained from MOD08_D3_6 L2 (data collected from Terra platform) and MYD08_ D3_6L2 (data collected from Aqua platform) products were used during 2011-14. MODIS at 550 nm have spatial resolution of 1°×1°. The variation of AOD Aqua platform and Terra platform are depicted in Fig. 10 (a) and (b) respectively. It was found that the variation in AOD is in proportion to the concentration of particulate matter. With the help of MODIS the maximum value of AOD came out to be 0.58 in the selected sampling days as

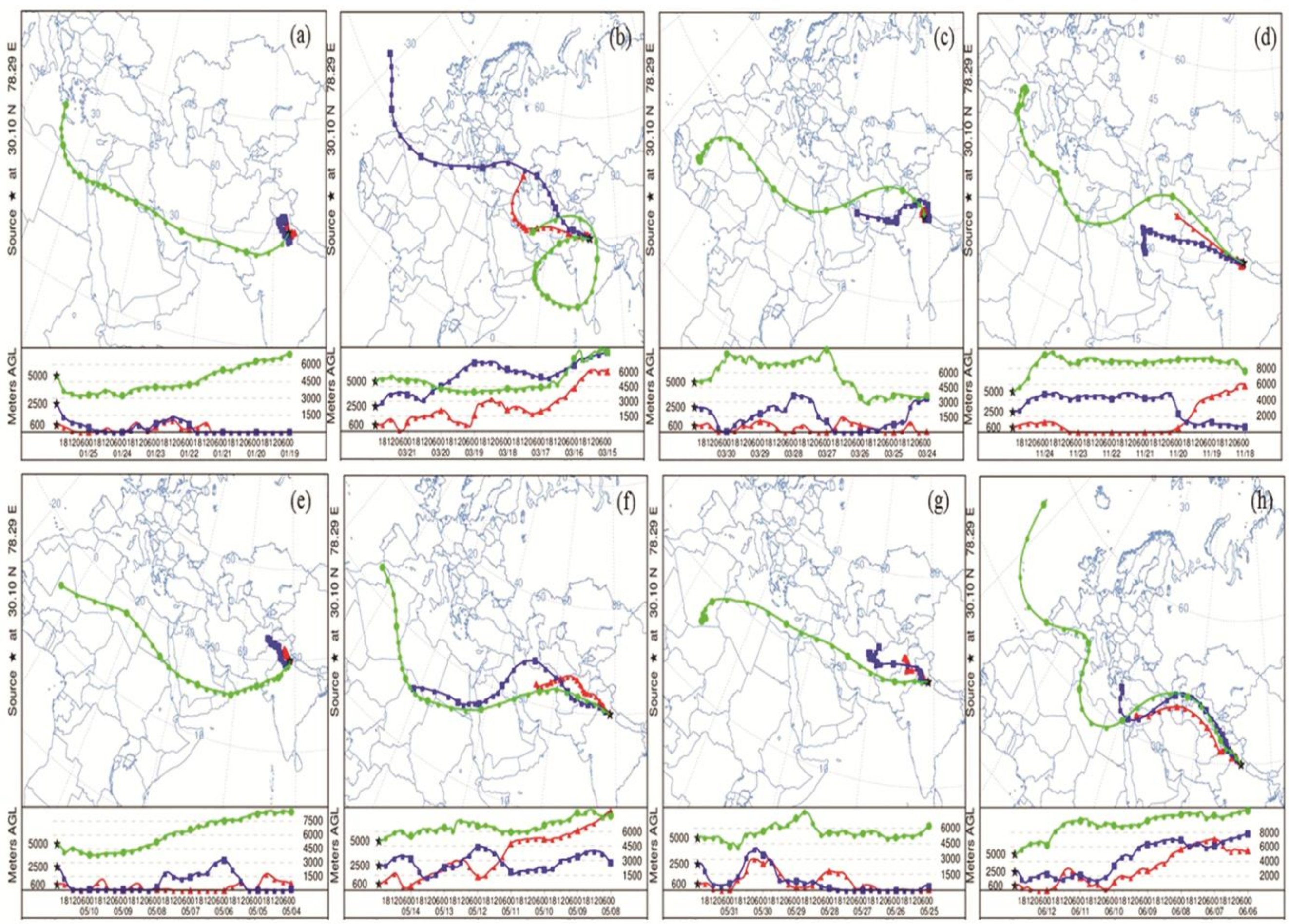

Fig. 8 — HYSPLIT model simulated 7days backward air mass trajectory considered for 600, 2500 and 5000 meters above sea level at Rishikesh in Uttarakhand, India.

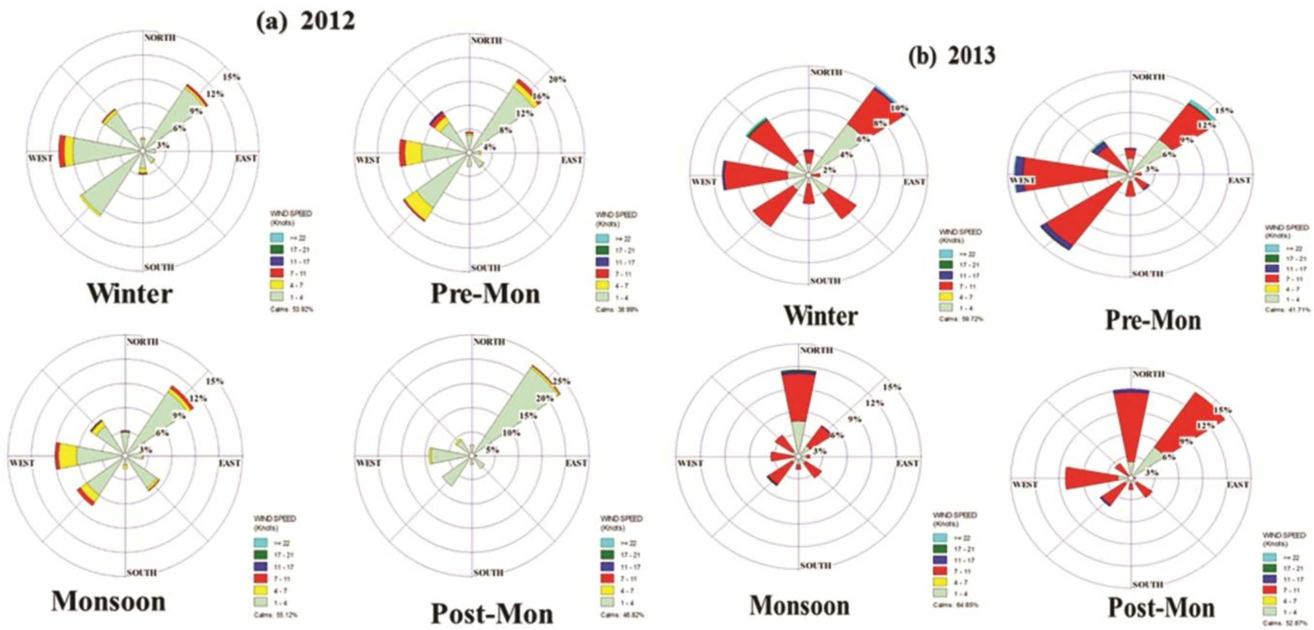

Fig. 9 — Wind rose diagram for the year 2012 and 2013, representing different seasons of the years.

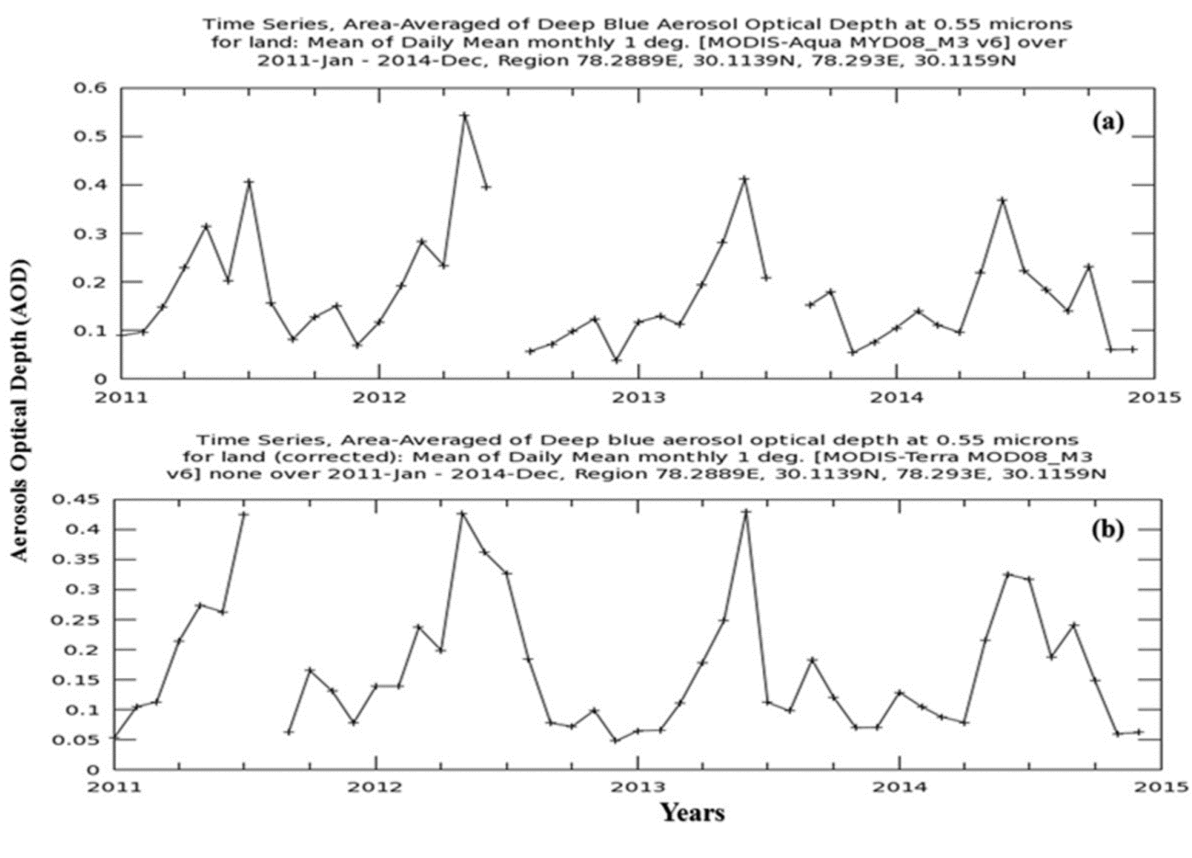

Fig. 10 — AOD value during study period at selected site.

shown in the graphs in Fig. 10. This result reveals the higher concentration of air pollutant in the sampling area.

4.7.3 Air Quality Index (AQI)

The air quality index (AQI) is a numeric rating which is defined for daily and annual air quality[11, 20].

Table 5 — AQI values and level of health concerns.

S.N.	AQI	Level of health concern (AQI)
1	0-50	Good
2	50-100	Moderate
3	101-150	Unhealthy for sensitive group
4	151-200	Unhealthy
5	200-300	Very Unhealthy
6	301-500	Hazardous

Table 6 — Level of seasonal Air Quality Index in Rishikesh city during 2011–14.

Seasons	Level of Air quality Index			
	2011	2012	2013	2014
Winter	128.3	147.9	153.2	178.6
Pre -Monsoon	167.6	186.1	186.0	201.0
Monsoon	98.5	160.3	160.4	184.4
Post-monsoon	105.7	166.8	179.5	181.8

Environmental Protection Agency (EPA) has set different limits (Table 5) for this on the basis of its effect on living beings. Knowledge of the AQI is necessary for taking the precautions due to increasing pollution that can be harmful for our health. Air quality Index computed by this formula

$$AQI = \left[\frac{Vo}{Vs}\right] \times 100 \quad \ldots(2)$$

Where, Vo = Observed values of air pollutants, Vs = Standard values recommended for the NAAQS (CPCB).

The values of the AQI calculated on the seasonal basis from data are shown in the Table 6. High value of AQI in pre-monsoon seasons and low in monsoon seasons during study is seen. It is seen that the values of AQI are in the very unhealthy level given by EPA. This value has continuously increased year by year.

5 Conclusions

The variability, in the measurement of ambient air pollutants at the sampling site is mainly occupied with higher number of heavy vehicles because the sampling site is located along the national highway (NH-58) which is very busy during whole year. As the city is called as gateway to all the shrines like Badrinath, Kedarnath and Hemkund Sahib as well as to the valley of flowers, a large number of devotees and tourists visit here throughout the year. But during pre-monsoon season this number becomes very large mainly due to the rise in the number of vehicles and commercial and as a result of intensive human activities the pollution level increases significantly.

Increasing trend of air pollutants as $SO_2 < NO_2 <$ RSPM < SPM is seen over the study period particularly in the pre-monsoon. Correlation coefficient between particulate matter and gaseous pollutants to be 0.839 and 0.857 respectively. During the study period, 30 March 2012 showed an anomaly in which particulate matter mass concentration had a very high level compared to the remaining period. This was evident from the trajectory shown which reveals that the pollutant air flowing from North African continent and major portion of central Asia dominate and might have contributed significantly. The study showed that the air quality index (161.5-181.4) in Rishikesh falls in the unhealthy category, according to Environment Pollution Agency (EPA). Therefore, immediate measures are needed to be taken, in order to further restrict the pollution levels and help mitigating the climate related issues. Pollution free mode of transport is needed along with the awareness programmed during the Yatra seasons.

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