

Seasonal Variations in Chemical Composition and Source Apportionment of Fine Particulate Matter (PM₁) in an Urban Site of Jaipur City, Rajasthan

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Received June 6, 2022; revised and accepted September 13, 2023

Abstract: The present study was conducted with an aim to investigate the seasonal variation in mass concentration of fine particulate matter (PM₁), their chemical composition, (water and soluble and non-soluble ions and other elements) and gaseous pollutants (SO₂, NO₂, CO and O₃) at an urban site of Jaipur city in India. During summers, pollutants showed a reduction of 18.97%, 41.95%, 32.32% and 20.56% for PM₁, NO₂, SO₂ and CO, respectively. In contrast, O₃ showed an increase of 27%. The substantial reduction was also observed in the levels of secondary aerosols SO₄²⁻ (71.15%), NO₃⁻ (21.86%), Cl⁻ (65.63%) and K⁺ (8.16%). The elemental components Al, B, Be, Ca, Cu, Fe, Mn, Ni, and Pb showed a reduction in the range of 15.13 % (Al) to 71% (Cu). On the contrary, an increment was found in the levels of Ag (21.95%), Cd (62.5%), Cr (89.74%), Mg (10.43%) and Na (25.32%). Four factors were extracted by principal component analysis (PCA). In addition to the local sources, three stationary sources have been identified as contributing to the pollution load located in the WNW, NE and ENE direction of the site. It can be concluded that pollutant concentration and chemical composition of any area not only depend on the local emission, but nearby stationary sources and meteorology are significant contributors.

Key words: Fine particulate matter, source apportionment, principal component analysis, meteorology.

Introduction

Fine particles in the atmosphere have been recognised as one of the major pollutants due to their association with numerous negative health impacts (Javed and Guo, 2021). Due to their larger total surface area as compared to larger particles, fine particles carry a higher load of toxicants as compared to coarse particles. An increase of 10 µg/m³ of ambient fine particles may lead to a 0.19% higher risk of non-accidental mortality (Yin et al., 2020) and 12 % higher risk of cardiovascular diseases (Yang et al., 2019) and a prevalence of type 2 diabetes (Peng et al., 2022).

Particulate matter (PM) concentration is highly influenced by meteorological conditions like wind speed, which influences the rate and scale of dispersion of PM, relative humidity and solar radiation, which leads to secondary PM formation and precipitation, influencing the rate of washing PM out of the atmosphere. Water soluble components (ionic species), carbonaceous aerosols (organic and elemental carbon), crustal elements and metals, as well as their primary and secondary components, are all included in atmospheric aerosols (Pipal et al., 2014). The chemicals adhered to the surface of fine particles are of major concern due to their potential to cause several diseases due to their

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toxic nature. The purpose of this study was to quantify seasonal trends of PM_{10} at an urban site, and their chemical constituents and gaseous pollutions along with meteorological parameters and height of the planetary boundary layer (HPBL). Source apportionment of pollutants using principal component analysis (PCA) has been conducted considering the summer and winter seasons.

Methodology

The study has been conducted for a period of 6 months (January-June 2021) considering the winter season (January-March) and (April-June) summer season in Jaipur city.

Sampling Site

The study was conducted at an urban site, Mansarovar, a residential area in Jaipur city, India located at $26^{\circ} 55' 0''$ N, $75^{\circ} 49' 0''$ E and covers an area of 200.4 sq. km. The climate of the city is hot and arid with the highest temperature observed in the months of May and June (42°C - 45°C) and the lowest during the months of December and January (12°C - 16°C).

Data Collection

PM_{10} sampler (Envirotech APM 577) was used for monitoring fine particulate matter in ambient air, placed at a height of 10 meters above the ground with an air flow rate of 10 LPM. A total of 56 samples were collected and analysed for mass concentration and chemical composition of PM. The samples were collected thrice a week on pre-weighed 47 mm PTFE or Teflon filters for 24 hours during winters and summers. The filter papers were desiccated and weighed before and after sampling. Filters were refrigerated until elemental analysis. The 24-hour average data for sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) and carbon monoxide (CO) have been obtained from the Central Pollution Control Board (CPCB), New Delhi website (<https://app.cpcbcr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data>) and meteorological parameters (temperature, relative humidity and wind speed) from World weather online (<https://www.worldweatheronline.com/jaipur-city-weather/rajasthan/in.aspx>).

Calculation of Planetary Boundary Layer

The HPBL was calculated using archived data from NOAA's Air Resources Laboratory (<https://ready.arl.noaa.gov>). NOAA Hysplit trajectory model ([\[ready.noaa.gov/HYSPLIT.php\]\(http://ready.noaa.gov/HYSPLIT.php\)\) considers data for 24 hours for each sampling day.](http://www.</p></div><div data-bbox=)

The satellite images showing variation in air pollutants over the study area have been obtained from the website (<https://earth.nullschool.net/#2021/03/30/1800Z/chem/surface/level/overlay=co2sc/orthographic=74.51,18.96,1235/loc=75.167,23.343>).

Gravimetric and Chemical Analysis for PM_{10} Samples

Gravimetric analysis was conducted for the mass of PM_{10} . For chemical analysis of PM, each exposed filter paper was taken and kept in a digestion vessel (50 mL round bottom flask). Thereafter 10 mL Milli-Q water (resistivity 18.2 M Ω) was added to each flask and digested for one hour in the sonicator. After cooling, 1 mL aqueous extraction was filtered in Eppendorf tubes for ion chromatography, 3 anions: Cl^- , NO_3^- , SO_4^{2-} were analysed using Metrohm 792 basic IC with a conductivity detector. Then, in the same 50 mL flask 1-2 mL of conc. nitric acid (Suprapure, 70% GR grade, Merck) was added and placed over a hot plate and kept for around 2 h at 180°C until most of the nitric acid was almost completely evaporated. The residual was then filtered through a 0.22 μm Teflon filter and diluted to 15 mL with Milli-Q water for subsequent elemental analysis. Each blank filter was digested in the same way as the sample filters. The elemental analysis was performed using ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry, Agilent Technologies 700 series ICP-OES).

Statistical Analysis

The correlation between the selected parameters as well as principal component analysis (PCA) for source apportionment using the Varimax rotation method was analysed using the software SPSS IBM version 22.

Results and Discussion Changes in PM_{10} and Gaseous Pollutants Concentration

Seasonal variations (winter and summer seasons) were observed for the mean concentration of all the studied parameters (Tables 1-3 and Figure 4). All the pollutants were found to be higher during winters with the exception of ozone which was found to be low (Table 3 and Figure 1).

The percent reduction during summers as compared to winters for PM_{10} , NO_2 , SO_2 , and CO was found to be 18.97%, 41.95%, 32.32% and 20.56%, respectively. In contrast, O_3 showed an increase of 27.86%.

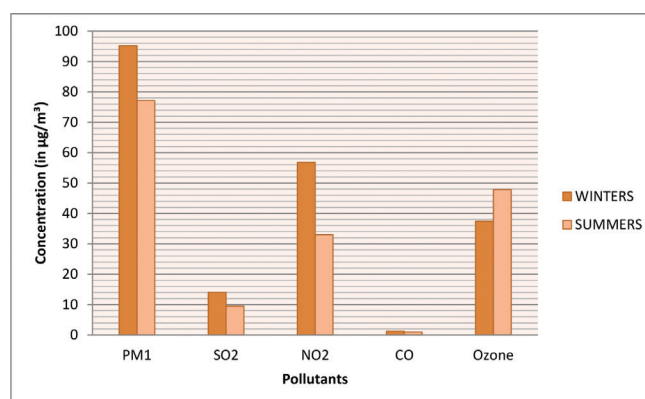
Table 1: Mean and Standard Deviation of PM₁, gaseous pollutants and meteorological parameters during winters and summer season

<i>Variables</i>	<i>Winters</i>	<i>Summers</i>
PM ₁	95.20 ± 11.21	77.14 ± 19.08
SO ₂	14.08 ± 11.71	9.53 ± 2.44
NO ₂	56.80 ± 11.98	32.97 ± 11.91
CO	1.23 ± 0.32	0.97 ± 0.36
O ₃	37.4 ± 7.69	47.82 ± 10.69
Temp.	17.38 ± 2.595	29.23 ± 3.25
RH	52.75 ± 28.20	26.42 ± 7.81
Windspeed	8.71 ± 4.23	14.75 ± 5.82
HPBL	960.24 ± 79.52	1448.47 ± 162.62

Table 2: Mean and standard deviation of elements and anions during winters and summers

<i>Variables</i>	<i>Winters</i>	<i>Summers</i>
Cl ⁻	0.844 ± 0.191	0.29 ± 0.08
NO ₃ ⁻	0.837 ± 0.298	0.654 ± 0.431
SO ₄ ²⁻	2.160 ± 1.41	0.623 ± 0.514
Ag	0.041 ± 0.03	0.05 ± 0.022
Al	0.72 ± 0.26	0.611 ± 0.309
B	1.45 ± 0.82	0.52 ± 0.315
Be	0.049 ± 0.034	0.016 ± 0.025
Cd	0.008 ± 0.005	0.013 ± 0.006
Ca	4.266 ± 2.12	3.18 ± 2.63
Co	0.005 ± 0.015	0.005 ± 0.0144
Cr	0.039 ± 0.012	0.074 ± 0.08
Cu	0.098 ± 0.176	0.028 ± 0.02
Fe	1.85 ± 1.433	1.105 ± 1.09
K	0.87 ± 0.388	0.799 ± 0.525
Mg	0.906 ± 0.55	1.0005 ± 1.05
Mn	0.07 ± 0.022	0.05 ± 0.04
Na	6.08 ± 4.91	7.62 ± 10.56
Ni	0.074 ± 0.071	0.05 ± 0.044
Pb	0.036 ± 0.05	0.016 ± 0.02
Zn	0.39 ± 0.27	0.23 ± 0.18

The reduction in pollutant concentration during summer can be attributed to meteorological processes. In this study, during the summer season, an increase was observed in the mean temperature by 68.18%,

**Figure 1: Variation in the concentration of PM1 and gaseous pollutants (SO₂, NO₂ and CO during winter and summer season).**

wind speed by 69.35% and HPBL by 50.84%, whereas the relative humidity (RH) level was reduced by 49.91% (Table 3). Lower mass concentration of PM in summer can be due to higher windspeed leading to turbulence near the ground causing higher dilution effects and transport of the particulates (Mkoma and Mjemah, 2011). Higher height of PBL also leads to lowering of pollutant levels by increasing the mixing heights. In contrast, the O₃ level increased which can be due to three reasons: (i) the concentration of O₃ depends on the VOCs-NO_x ratio, reduction in NO_x leads to higher VOCs-NO_x ratio and causes an increase in O₃ levels (Ding et al., 2021), (ii) due to the increase of insolation as a result of an increase in temperature and reduction in PM concentration may cause an increase in O₃ levels (Kerimray et al., 2020) and (iii) reduction in NO_x leads to less scavenging of O₃ from atmosphere due to limited reaction (titration, NO+O₃=NO₂+O₂) (Islam et al., 2021).

Table 3: Percentage change of PM1 and gaseous pollutants and meteorological parameters during winter and summer

<i>Variables</i>	<i>Winter</i>	<i>Summer</i>	<i>% Change</i>
PM ₁	95.2	77.14	-18.97
SO ₂	14.08	9.53	-32.32
NO ₂	56.8	32.97	-41.95
CO	1.23	0.977	-20.57
O ₃	37.4	47.82	27.86
Temp.	17.38	29.23	68.18
RH	52.75	26.42	-49.91
Wind speed	8.71	14.75	69.35
HPBL	960.24	1448.47	50.84

Higher concentrations of pollutants during winter (Table 3) can be attributed to a lower temperature and wind speed, high RH resulting in a lower height of planetary boundary layer restricting the dispersion of pollutants and massive biomass burning especially during night time in the winter season (Deshmukh et al., 2011; Liang et.al, 2019). Higher relative humidity in winter leads to moist atmospheric conditions increasing the PM levels (Singh et al., 2021).

While analyzing the results statistically (Tables 9 and 10), PM_{10} showed a strong negative correlation with CO ($p<0.05$) during the summer season. During winters, PM_{10} showed a strong positive relationship with NO_2 ($p<0.05$) and a strong negative correlation with SO_2 ($p<0.05$). Temp and HPBL showed a significant negative correlation with SO_2 ($p<0.05$), NO_2 ($p<0.05$), CO ($p<0.05$) and O_3 ($p<0.05$) whereas, wind speed (WS) showed a positive correlation ($p>0.05$) during the winter period. On the contrary, during the summer season, PM_{10} showed a positive relationship ($p<0.05$) with temperature and WS which indicates that even when temperature increased by 68.18%, the higher wind speed may lead to increase in the PM_{10} concentration due to other nearby sources such as resuspension of crustal

dust (Chakraborty and Gupta, 2010) and transport of fine particles from nearby stationary sources (discussed in the subsequent section of Source apportionment) which is higher in semiarid regions like Jaipur. O_3 was found to exhibit a significant ($p<0.01$) negative relationship with NO_2 during summers indicating an important scavenging role of NO_2 in the atmosphere.

Changes in Chemical Composition

The concentration of ionic species Cl^- , NO_3^- , SO_4^{2-} , Ca^{2+} and K^+ showed a reduction of 65.63%, 21.86%, 71.15%, 25.45% and 8.16%, respectively, whereas an increase in the levels of Na^+ (25.32%) and Mg^{2+} (10.43%) during the summers was observed (Table 4, Figures 2 and 3). The main reason for higher concentrations of water-soluble ions during winters can be attributed to lower temperatures, which favoured ion transformation from gas to particle phase, in addition to lower mixing height and increased anthropogenic activities. On the other hand, lower concentrations of these ions during summer could be due to the ventilation effects of high wind movements (Deshmukh et al., 2011). The higher

Table 4: Percentage change of anions and heavy metals during winter and summer

Species	Winters	Summers	% Change
Cl^-	0.84	0.29	-65.63
NO_3^-	0.83	0.65	-21.86
SO_4^{2-}	2.16	0.62	-71.15
Ag	0.04	0.05	21.95
Al	0.72	0.61	-15.13
B	1.45	0.52	-64.13
Be	0.04	0.01	-67.34
Cd	0.00	0.01	62.5
Ca	4.26	3.18	-25.45
Cr	0.03	0.07	89.74
Cu	0.09	0.02	-71.42
Fe	1.85	1.10	-40.27
K	0.87	0.79	-8.16
Mg	0.90	1.00	10.43
Mn	0.07	0.05	-28.57
Na	6.08	7.62	25.32
Ni	0.07	0.05	-32.43
Pb	0.03	0.01	-55.55
Zn	0.39	0.23	-41.02

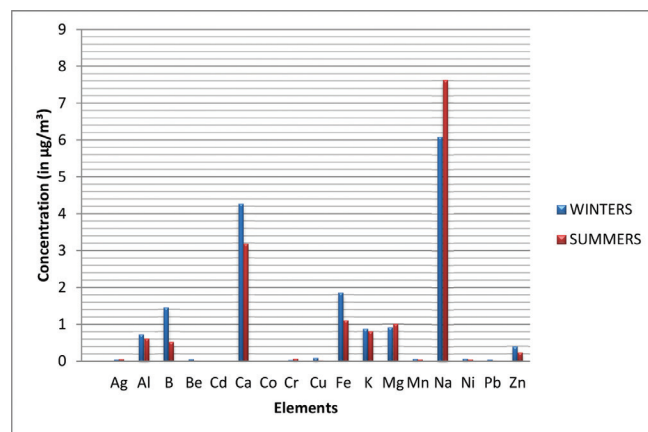


Figure 2: Variation in the concentration of elements during pre-lockdown and lockdown phases.

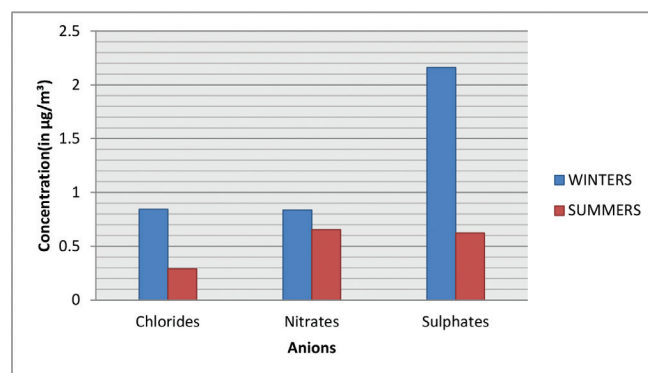


Figure 3: Variation in the concentration of anions during winters and summer seasons.

levels of Mg and Na can be attributed to road dust resuspension (Skorbiłowicz and Skorbiłowicz, 2019) and the transport of salts from nearby stationary sources as a result of higher wind velocity during the summer season. Among the elements, a decline in concentration was observed in Al (15.13%), B (64.13%), Be (67.34%), Cu (71.12%), Fe (40.27%), Mn (28.57%), Ni (32.43%), Pb (55.55), Zn(41.02%) during summers. In contrast, Ag, Cd and Cr showed an increase in the concentration by 21.95%, 62.5% and 89.75%, respectively, which can be attributed to other nearby stationary sources explained in the PCA section. Statistically, no specific trend of correlation was observed among the elements.

Source Apportionment Using Principal Component Analysis Technique (PCA)

In the present study, source apportionment was conducted using the PCA technique with Varimax rotation and Kaiser Normalization using SPSS version 22.0 software. PCA was applied to the data collected for the winter and summer periods. The principal factors with the Eigenvalue > 0.5 were estimated by extraction of eigen values and eigen vectors from the correlation matrix. Ionic and crustal element concentration was used to extract the principal components. Four factors were extracted for each period, which were used to explain the sources of PM₁ and its chemical constituents in the ambient air. The overall variance of all the factors explained was 95 % during winter and 90% during the summer period (Tables 5 to 8).

Source Identification of Elements

The major stationary sources of emission in the proximity of the study site were identified by superimposing the wind rose on the satellite images of the study site obtained by Google Maps (<https://www.google.com/maps>). As per the wind rose (Figure 5), the winds in the study period have blown from WNW for 24% of the duration, 10% from the NE direction and 12% from the ENE direction.

Factor 1

During the winter season, factor 1 was loaded with Na⁺, Mg²⁺, Ca²⁺, Fe, Al, Pb, SO₄, NO₃, Co, K⁺, Cl⁻, Ni, Mn, and Cr explaining 40% of the total variance. During the summer season, factor 1 was loaded with Mg²⁺, Ca²⁺, Mn, Na⁺, Cr, Fe, Al, Ag, Pb and K⁺ explaining a 40% variance. During the summer period, the factor

Table 5: Rotated factor component matrix during winters

Species	Factors				
	1	2	3	4	5
Ag	-.063	.758	-.492	-.274	.158
Al	.849	.140	.103	-.009	.498
B	.316	-.447	-.662	-.316	.282
Be	.150	.824	-.192	.342	.257
Ca	.921	.309	.016	.017	.237
Cd	-.405	.742	-.277	.180	-.064
Co	.620	-.511	-.052	-.518	.284
Cr	-.551	-.519	-.203	.591	.189
Cu	-.295	-.389	.239	.720	.418
Fe	.879	.050	.051	.185	-.426
K	.517	.650	.409	-.140	-.082
Mg	.932	-.123	.103	-.045	.321
Mn	.577	.033	.280	.701	.191
Na	.950	-.183	.054	-.191	.127
Ni	-.520	.197	-.622	.229	.265
Pb	.747	-.442	.191	.304	-.335
Zn	.216	.745	.528	.144	.004
Cl-	-.658	-.128	.667	-.071	.286
NO ₃ ⁻	-.636	.158	.455	-.413	.436
SO ₄ ²⁻	-.722	-.077	.602	-.328	-.010

Table 6: Percentage variance by extracted factors during winters

Component	Initial Eigen values			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	8.012	40.060	40.060	8.012	40.060	40.060
2	4.112	20.561	60.622	4.112	20.561	60.622
3	2.884	14.421	75.043	2.884	14.421	75.043
4	2.494	12.472	87.515	2.494	12.472	87.515
5	1.568	7.839	95.353	1.568	7.839	95.353
6	.929	4.647	100.000			

showed an absence of the secondary aerosols SO_4^{2-} and NO_3^- indicating the volatilisation of NH_4NO_3 . The volatilisation of NH_4NO_3 increases as the temperature increases and relative humidity decreases (Chakraborty and Gupta, 2010). Comparable levels of other elements

during both seasons (winters and summers) explain their common sources of emission.

Coal combustion is a large contributor to Pb, Cl⁻, Fe, Ni and Pb which can be both from local sources or can originate from long range transportation of emissions from coal combustion (Gupta and Mandariya, 2013; Singh and Sharma, 2012). In the case of the present study, the transport of elements can be from the stack of coal-fired furnaces of brick kilns found in clusters at *Kanota* about 15 km in ENE and NE, (Figure 6b) from the receptor site when the wind had blown from this direction.

Considering the long distance transport of fine particulate PM_{10} , the major sources of Na^+ , Mg^{2+} , Ca^{2+} can be attributed to the presence of *Sambhar* salt lake in the WNW direction of the study site (Figure 6a) with approximate aerial distance of 80 km as well as from road dust (Chakraborty and Gupta, 2010). The sources of Cr, Fe and Pb can be attributed to the resuspended dust from the *Ghat ki guni* area having eroded and exposed land left after the construction of a tunnel (*Ghat ki guni* tunnel) (Figure 6d) and the emissions from coal combustion in brick kiln furnace located in the NE and ENE direction of the study site 11 km away (Figure 6b & c).

Factor 2

In factor 2, during winters, Be, Ag, Zn, K and Cr were the dominating species explaining a 20% variance. Secondary aerosols were found to be absent during this season. Summer season showed the presence of NO_3^- , Be, Ni, SO_4^{2-} and Cl^- explaining 23% variance. During winter the loading of Be, Zn, K and Cr, can be attributed to vehicular emissions, construction activities and industrial emissions and windblown crustal dust from the *Ghat ki Guni* area in the NE direction. During the summer phase, Cl⁻ contribution can be majorly from emission due to coal combustion (Singh and Sharma,

Table 7: Rotated factor component matrix during summer

Species	Factors			
	1	2	3	4
Ag	.768	.241	.193	-.378
Al	.793	-.021	.291	.089
B	.070	-.358	.767	-.484
Be	.494	.805	-.070	-.253
Ca	.926	.202	-.201	-.206
Cd	.354	.065	.800	-.294
Co	.197	.731	.152	.543
Cr	.841	-.334	-.325	.239
Cu	.410	-.078	.757	.443
Fe	.840	-.450	-.161	.224
K	.624	.409	-.145	-.556
Mg	.948	.054	-.286	-.068
Mn	.904	-.339	-.167	.165
Na	.901	-.031	-.346	-.159
Ni	-.030	.785	-.206	-.243
Pb	.748	-.494	-.342	.249
Zn	.377	.162	.790	.117
Cl ⁻	-.426	.629	-.518	.050
NO_3^-	.199	.890	-.079	.314
SO_4^{2-}	.336	.736	.427	.364

Table 8: Percentage variance by extracted factors during summer

Component	Initial Eigen values			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.023	40.117	40.117	8.023	40.117	40.117
2	4.637	23.187	63.304	4.637	23.187	63.304
3	3.613	18.067	81.371	3.613	18.067	81.371
4	1.912	9.558	90.929	1.912	9.558	90.929
5	.954	4.769	95.698			
6	.618	3.091	98.789			
7	.242	1.211	100.000			

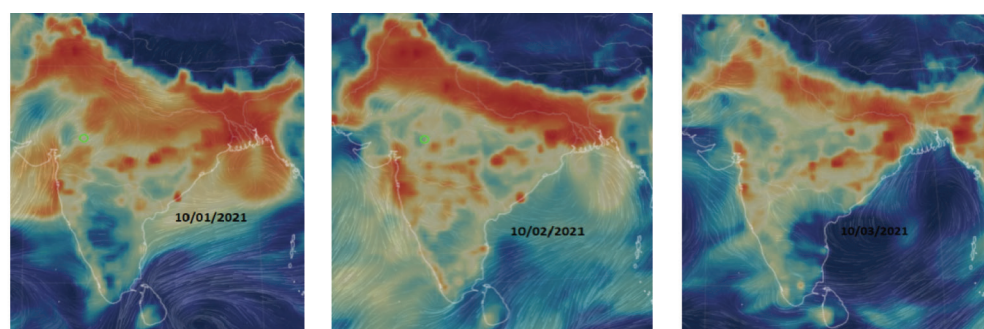
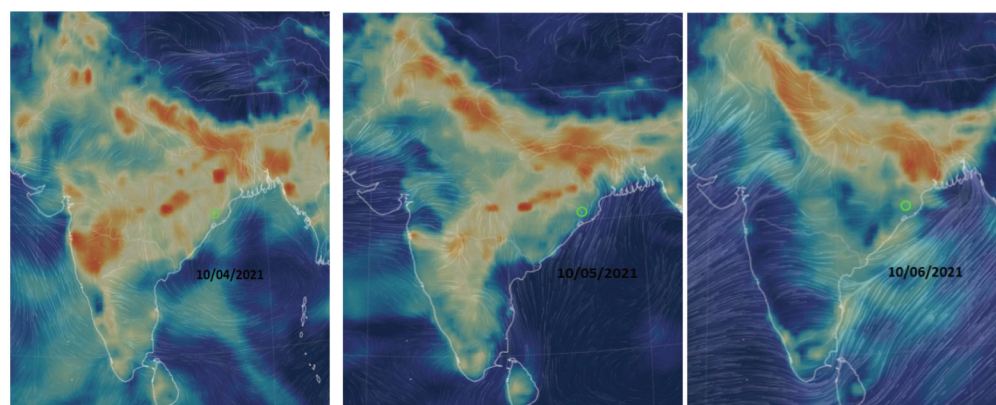
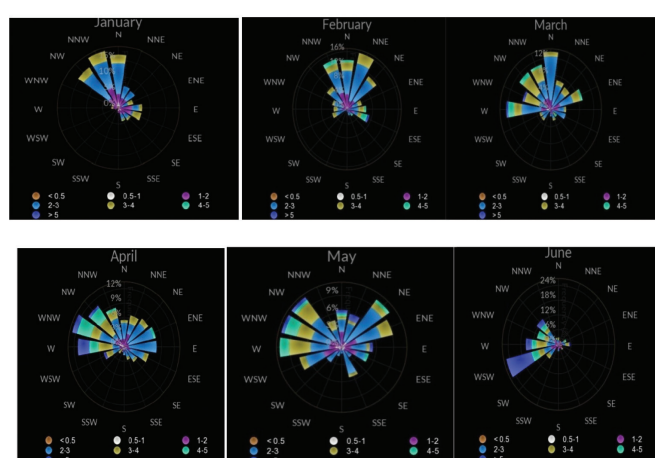
PM₁ during winter season (January-March) 2021PM₁ during summer season (April-June) 2021Figure 4: Variations in PM₁ during winter and summer seasons.

Figure 5: Wind rose diagrams.

2012), in addition to Be, Co and Ni, which can also be attributed to the coal combustion emissions transported from the brick furnace kilns located in NE direction at

Kanota. Whereas NO_3^- and SO_4^{2-} can be attributed to photochemical reactions occurring due to the presence of primary pollutants.

Factor 3

This factor was dominated by Co, Be, Ag, Zn, Cd and K explaining 14% variance during the winter period. Summers were dominated by Cl^- , Cd, Zn, B and Cu explaining 18% variance. This factor presented some of the common elements Cd and Zn during both seasons indicating their contribution from vehicular exhaust and coal combustion emissions transported from brick kiln furnace stack located at *Kanota* ENE and NE direction and other small industries and windblown crustal dust from *ghat ki guni* area in the ENE direction.

Factor 4

In this factor Co, Cu, Mn, and Cr explained a 12% variance during the winter period and K^+ and Co

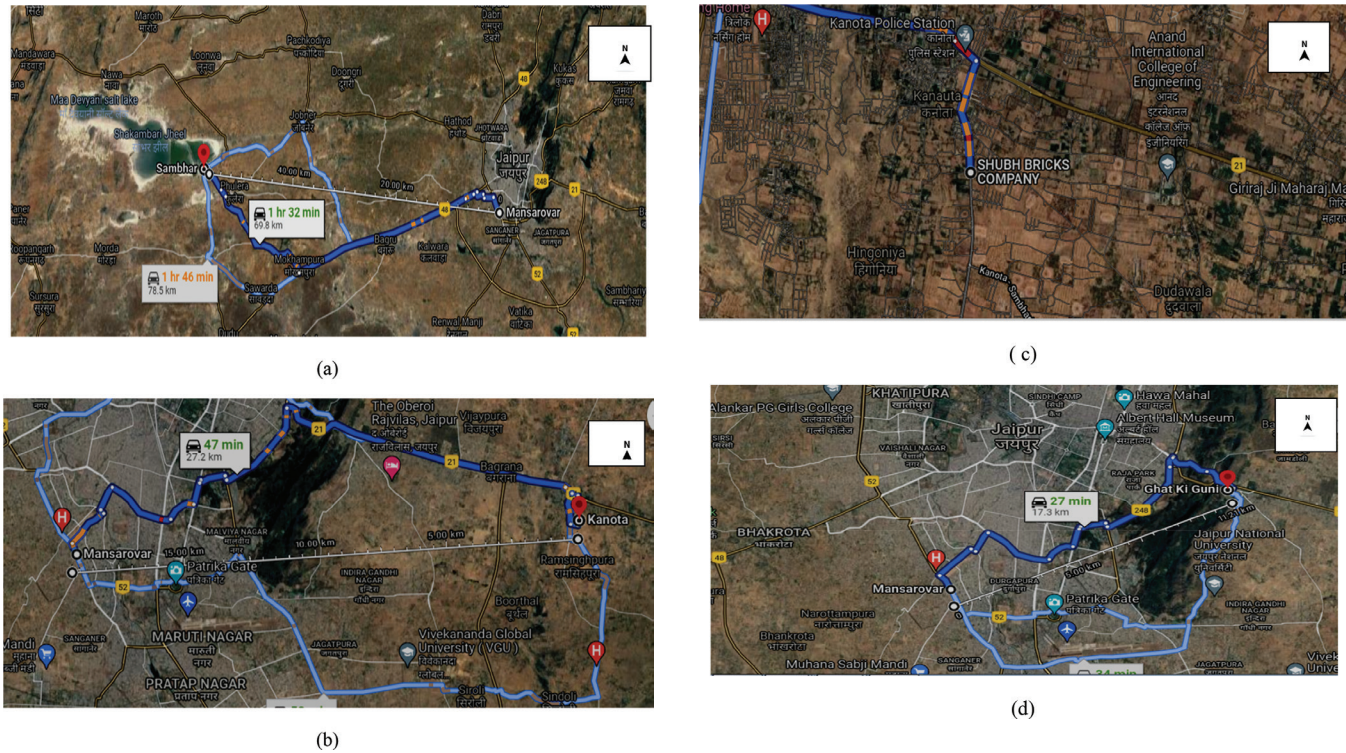


Figure 6: Satellite image showing stationary source of emission near Mansarovar. (a) *Sambhar* salt lake with aerial distance 40 km (WNW direction), (b) *Kanota* at aerial distance 15 Km (ENE & NE direction) and (c) Cluster of brick kilns at *Kanota*, Jaipur (d) *Ghat ki guni* 11 km (ENE Direction).

Table 9: Correlation between gaseous pollutants, meteorological parameters and PM_{10} during pre-monsoon season

	PM_{10}	SO_2	NO_2	Ozone	CO	Temp	RH	WS	HPBL
PM_{10}	1								
SO_2	-.368	1							
NO_2	-.268	.317	1						
Ozone	.267	-.073	-.588**	1					
CO	-.464*	.219	.345	-.302	1				
Temp	.300	-.225	-.747**	.388	-.264	1			
RH	-.114	.025	-.077	-.003	-.391	-.067	1		
WS	.178	-.299	-.086	.027	-.068	-.155	.083	1	
HPBL	-.881**	.376	.248	-.291	.501*	-.368	.086	.017	1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

explained a 9% variance during the summer. Co being common in both seasons can be attributed to originate from coal combustion and vehicular exhaust. Whereas the contribution of all the other elements can be from resuspension of road dust and eroded open region at *ghat ki guni* area.

Conclusions

In the study conducted to evaluate the mass concentration

and chemical characteristics of PM_{10} along with gaseous pollutants, a distinct effect of seasonal variation and meteorological parameters was observed. PM_{10} , along with their chemical constituents and the gaseous pollutants SO_2 , NO_2 , and CO showed a decrease during the summer season exhibiting a negative correlation with temperature, wind speed and relative humidity and the height of the planetary boundary layer. In contrast, O_3 increased during the summers as compared to winters due to complex chemical reactions. Stationary

Table 10: Correlation between gaseous pollutants, meteorological parameters and PM1 during winters

	PM_1	SO_2	NO_2	Ozone	CO	Temp	RH	WS	HPBL
PM_1	1								
SO_2	-.518*	1							
NO_2	.533*	-.441*	1						
Ozone	-.023	-.117	-.153	1					
CO	-.237	.529*	-.142	-.091	1				
Temp	-.267	.253	.031	-.241	.148	1			
RH	.685**	-.379	.511*	-.181	-.381	-.149	1		
WS	.504*	-.464*	.364	.304	-.473*	-.112	.473*	1	
HPBL	-.837**	.528*	-.253	-.105	.077	.406	-.477*	-.426*	1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

distant sources in addition to local sources were identified by principal component analysis (PCA). PCA studies explained three common contributing sources of pollutants; coal combustion, dust resuspension and salt aerosols under four identified factors. Stationary sources like brick kiln furnaces, salt lake aerosol and eroded land located in WNW, NE and ENE were found to be the major contributors of pollutants at the receptor site.

Acknowledgements

The authors are thankful to the Department of Environmental Science, IIS (Deemed to be University), Jaipur for providing the necessary facilities for sampling and analysis of air samples. We are also thankful to the Quality Research & Analytical Testing Laboratory, New Delhi for providing facilities for the determination of elemental composition of Particulate matter.

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