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Seasonal and Spatial Variations of Particulate Matter and CO_2 Concentration in Srinagar City, Jammu and Kashmir

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Abstract: This study was undertaken to monitor the seasonal variation of particulate matter (PM) and CO_2 of some selected tourist sites in Srinagar city, Kashmir valley, and to spatially interpolate them using the inverse distance weighting (IDW) technique in the QGIS software. The study/tourist sites include Harwan Garden, Shalimar Garden, Naseem Bagh, Nishat Garden, and Chesmashahi Botanical Garden, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K) Shalimar campus, and Lal Chowk. The air sampling was carried out every fortnight using Aerocet 831-Aerosol Mass Monitor and CDM 901-CO_2 Monitor three times during the day viz., morning, afternoon, and evening with three replications. The data proved that there was a statistically significant variation ($p \leq 0.05$) between the seasonal (winter and spring) average mean and locational mean concentrations of the monitored pollutants. Also, meteorological parameters like average temperature, wind speed, and sunshine hours were negatively correlated with the pollutants' levels at all the sampling sites. Indicating an increase in pollutants' levels as these meteorological parameters decrease. Whereas, relative humidity showed a positive correlation with all the monitored pollutants. Which shows a higher concentration of all monitored pollutants as relative humidity increases.

Keywords: Carbon dioxide, Particulate matter, Monitored pollutants, Meteorological parameters, Spatial interpolation.

Srinagar city in the Kashmir valley is the largest city and the summer capital of the Indian union territory of Jammu and Kashmir. The quality of the ambient air of Srinagar has been deteriorating due to the high number of vehicles most of which use diesel, the domestic and commercial (including industries) burning of coal and fuelwood, road dust, and dust emitted from other developmental activities like construction and demolition of buildings, construction of flyovers, bridges and repairing of roads (Anonymous, n.d.). The IQ*Air* (2021) noted that at the beginning of 2021, Srinagar was experiencing air quality which was categorised as unhealthy for sensitive groups' with a United States' Air Quality Index (AQI) reading of 110. This classification falls in line with recommendations by the World Health Organisation (WHO). Iqbal (2018) mentioned that the data of the state pollution control board of Jammu and Kashmir on the air quality of Kashmir pointed out that “Respirable Suspended Particulate Matter (RSPM), also known as PM_{10}, and Fine Particulate Matter ($PM_{2.5}$), are present in Kashmir air above permissible limits.” As of 2010, Jehangir et al (2010) pointed out that air quality assessment has not received much attention in Srinagar city. With the continuous increase in population, as per the 2011 census, Jammu and Kashmir have a total population of 12,541,302 out of which 1,273,312 people reside in the district Srinagar. This rise in population is bringing in more anthropogenic causes for increasing air pollution due to the build-up of vehicular population, increased biomass burning, lack of proper traffic management, lack of disposal of old vehicles, etc. In the Statistical Year Book India 2017 on motor vehicles, the total number of registered vehicles in Srinagar city as of the 31st March 2015 is 2.36 Lakh. Therefore, this study was conducted to estimate the seasonal (winter and spring) variation of carbon dioxide (CO_2) and particulate matter (PM_1, $PM_{2.5}$, PM_4, PM_{10}, and TSP).

In order to estimate the spatial variation of the monitored pollutants, the inverse distance weighting (IDW) technique was used to map out the pollutant concentrations in nearby unsampled areas. The IDW hypothesizes that areas closer to the sampling points ought to have a high concentration of pollutants than those in remote places. This means that the areas closer to the prediction location are expected to have more influence on the predicted value than those further away (Goutham and Jayalakshmi 2018). This interpolation method has proven to be best for monitoring the ambient air quality of urban sensitive areas (Fontes and Barros 2010) and has also been used for estimating the spatial disparity in pollutant concentrations over widespread urban environments (Lipsett et al 2011). It can therefore be considered a reliable technique in spatially interpolating the air quality data of the selected tourists' sites in Srinagar city as influenced by their seasonal variations.

MATERIAL AND METHODS

Study area: Srinagar is the summer city of Jammu and Kashmir State of India located at coordinate 34°5'24" N and 74°47'24" E and altitude of 5200 feet. It has a very humid and subtropical climatic condition with four seasons (viz. winter, spring, summer, and autumn). The air sampling sites shown in Figure 1 were selected based on the most visited tourist sites in the city with Lal Chowk (N 34.07268°, E 076.81310°) and SKUAST-K Shalimar (N 34.14674°, E 074.87832°) viewed as control sites. These tourist sites are famous gardens, which includes Shalimar Garden (N 34.13518°, E 074.87045°), Harwan garden (N 34.15808°, E 074. 90237°), Naseem Bagh (N 34.13805°, E 074.84006°), Nishat Garden (N 34.12431°, E 074.87881°), and Chesmashahi Botanical Garden (N 34.09262°, E 074.87740°).

Air sampling method: The air sampling was done in the winter and spring seasons from November 2019 to April 2020 on the second and fourth week of each month. Each morning (9:00 am-10:30 am), afternoon (1:00 pm-2:30 pm), and evening (4:30 pm- 6:00 pm) sampling of particulate matter (PM) of sizes 1, 2.5, 4, 10, total suspended particles (TSP) and monitoring of CO_2 were conducted at each sampling point to take three replicate readings. Aerosol Mass Monitor (AEROCET 831, Met One Inc. Washington, USA) which uses the operating principle of particle count to mass conversion using scattered laser light (Remer et al 2005) was held at some height for about 1 minute and then the data was recorded. The CO_2 analyser (CDM 901, Rave Innovations, India) which works with the principle of NDIR (Non-Dispersive Infrared Radiation) and the NDIR sensors operate on the principle of IR radiation being absorbed by a target gas (Baschant and Stahl 2004) was used for monitoring CO_2 concentration in the ambient air. The instruments were held at a point away from disturbances from vehicular movements etc. so that the right concentrations of particulate matter and CO_2 could be estimated. Meteorological data from November 2019 to April 2020 for maximum and minimum temperatures, relative humidity, wind speed, and sunshine hours respectively were obtained from the Agro-meteorological cell of the Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir. The daily meteorological data obtained were brought down to a monthly basis for the prerequisite analysis. The data were then correlated with the air sampling data and a relationship was established with all the pollutants sampled (PM_1, $PM_{2.5}$, PM_4, PM_{10}, TSP, and CO_2).

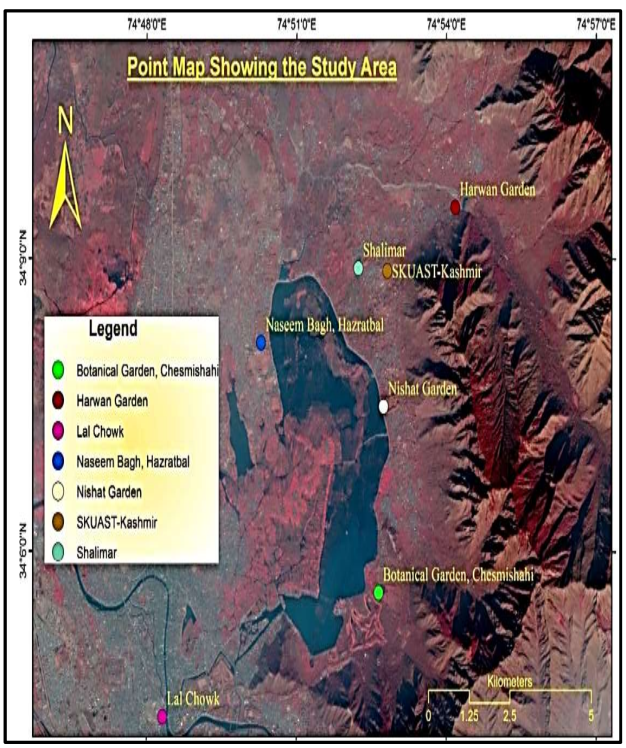


Fig. 1. Digital map showing the air monitoring sites

Inverse distance weighting spatial interpolation technique: The average mean of the results obtained for particulate matter (PM_1, $PM_{2.5}$, PM_4, PM_{10}, and TSP) and carbon dioxide (CO_2) in both winter and spring at the seven sampling sites were interpolated by the inverse distance weighting (IDW) technique available in the QGIS software (version 3.16.3). The IDW interpolation is computed as a function of the distance between the sampling sites and the sites at which sampling has not been done to make predictions of the unsampled sites (Wong and Lu 2008; Arif et al 2015). It is a very flexible interpolation method in executing decent and special interpolation based on the sample size and the spatial distribution of samples.

Statistical analysis: The triplicate data obtained during the sampling period (winter and spring) for the seven locations were analysed by a two-factor analysis.

RESULTS AND DISCUSSION

Variation of particulate matter (PM) and carbon dioxide (CO_2): The winter season recorded a higher concentration of all the monitored pollutants at all the sampling sites than in the spring season (Table 1). These variations of pollutants in both seasons were statistically significant. The quality of air in Srinagar city was worst during the winter than the spring with respect to the monitored pollutants. During the winter months the air quality deteriorates in Srinagar city as the air carries five times more tiny particles than the permissible limit (Savio 2020, IQ*Air* 2021). The higher concentration of particulate

Table 1. Estimation of the levels of particulate matter and carbon dioxide (CO_2) at different tourist sites, of Srinagar city, J&K.

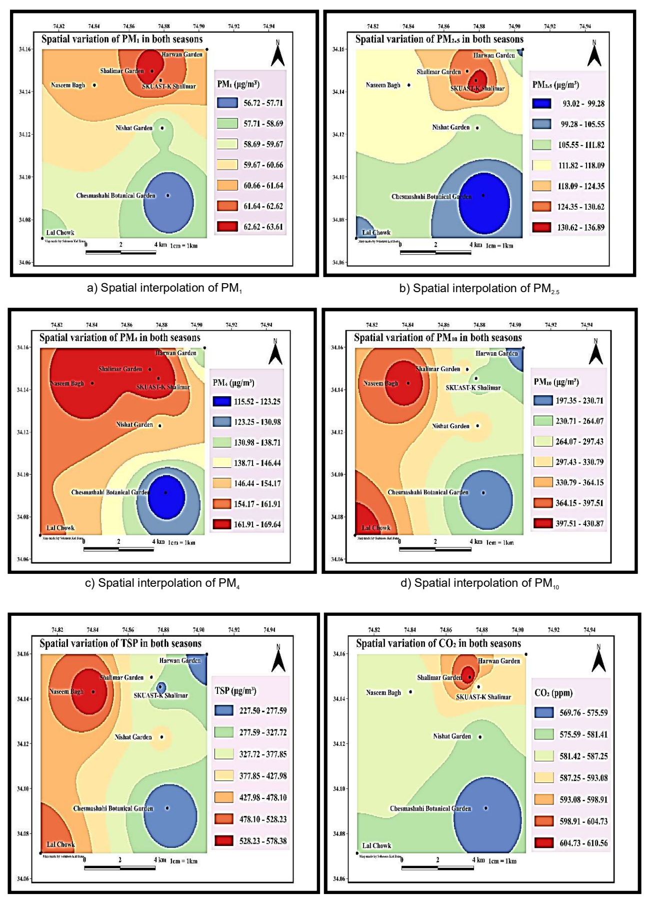
Parameters	Seasons	Monitoring sites										
		Harwan garden	Shalimar garden	Naseem bagh	Nishat garden	Chesmashahi botanical garden	SKUAST-K Shalimar	Lal chowk	Mean (S)	Factors	C.D.	SE(d)
PM_1 (µg m^{-3})	Winter	75.78	78.86	78.06	73.80	73.64	78.97	72.72	75.98	Season (S)	0.65	0.31
	Spring	46.70	48.35	43.70	42.62	39.81	45.41	44.18	44.40	Location (L)	1.21	0.59
	Mean (L)	61.24	63.61	60.88	58.21	56.72	62.19	58.45		S x L	1.71	0.83
$PM_{2.5}$ (µg m^{-3})	Winter	137.68	169.80	158.53	142.53	122.77	192.97	139.22	151.93	Season (S)	1.89	0.64
	Spring	72.10	79.09	73.95	71.77	63.28	80.80	70.56	73.08	Location (L)	3.51	1.20
	Mean (L)	104.89	124.45	116.24	107.15	93.02	136.89	104.89		S x L	4.97	1.70
PM_4 (µg m^{-3})	Winter	167.88	217.40	223.46	187.43	145.20	222.03	195.14	194.08	Season (S)	2.89	1.40
	Spring	94.96	111.24	113.08	118.56	85.83	117.25	116.10	108.15	Location (L)	5.41	2.62
	Mean (L)	131.42	164.32	168.27	153.00	115.52	169.64	155.62		S x L	7.65	3.70
PM_{10} (µg m^{-3})	Winter	253.37	356.98	514.13	313.51	207.98	260.44	474.14	340.08	Season (S)	6.25	3.03
	Spring	155.59	261.47	347.60	304.78	186.71	208.20	367.01	261.62	Location (L)	11.70	5.66
	Mean (L)	204.48	309.22	430.87	309.14	197.35	234.32	420.57		S x L	16.54	8.00
TSP (µg m^{-3})	Winter	277.76	431.95	668.45	375.33	232.03	271.02	589.07	406.52	Season (S)	9.69	4.69
	Spring	177.13	339.85	488.30	404.31	231.02	247.22	467.75	336.51	Location (L)	18.13	8.77
	Mean (L)	227.5	385.90	578.38	389.82	231.53	259.12	528.41		S x L	25.64	12.40
CO_2 (ppm)	Winter	627.98	639.07	590.71	601.05	611.96	585.62	598.67	607.86	Season (S)	3.86	1.87
	Spring	549.48	582.06	573.55	550.65	527.56	585.62	562.95	561.70	Location (L)	7.23	3.50
	Mean (L)	588.73	610.56	582.13	575.85	569.76	585.62	580.81		S x L	10.22	4.95

*Critical Difference (CD) significant at $p \leq 0.05$

matter in the winter might be due to lower temperatures and therefore very cold and cloudy weather which can reduce the dispersion and dilution of pollutants. The stagnation of air caused by temperature inversion and low wind speed causes the pollutants level to worsen the air quality of an area (Kakoli et al 2006, Kgabi and Mokgwetsi 2009, Cichowicz et al 2017). Exposure during short-term episodes of pollution to high levels of particulate matter can aggravate heart and lung conditions, distressing life's quality, and upsurging hospital admissions and deaths (Anonymous 2020; Mehrad 2020).

The variation in CO_2 between winter and spring seasons could be attributed to the temperature variation and plants' photosynthetic processes. During winter, plants are mostly dormant, in other words, their photosynthetic activities are dormant, and respiration is active, and therefore they make less/no use of CO_2. For this reason, CO_2 concentrations were very high during the winter season. But, during the spring season when temperatures are increasing, plants start getting active again; as they start budding, photosynthesis dominates respiration, and therefore they make much use of CO_2 thereby decreasing the atmospheric CO_2 concentration (Jawad and Ahmed 2021). Due to reduced dispersion and dilution of CO_2, caused by low temperatures, high humidity, and low wind speed, CO_2 concentration increased during the winter than in the spring. Furthermore, during winter, engines of any kind use more fuel as compared to spring. This is because, during winter, engines take a much longer time to reach their maximum operating temperature. Therefore, they emit more carbon monoxide (CO) which further reacts with atmospheric oxygen (O_2) forming high volumes of CO_2 which remain stagnated in an area over a long period. Other causes of increased CO_2 in winter as well in spring are burning of fossil fuels and other hydrocarbons using generators, animal respiration, and smokes from households, hotels, roadside confectionaries, etc.

Inverse distance weighting maps of the spatial interpolation of particulate matter and carbon dioxide: Figure 2 shows the inverse distance weighting (IDW) interpolation maps of the locational average means of each of the seven (7) sampling sites for both seasons with respect to particulate matter and carbon dioxide. On each map, the red and blue shaded portions indicate the location that recorded the highest and lowest concentration of each pollutant (Table 1, Fig. 2). The legend on each map in a descending and ascending order shows an increasing and decreasing trend of each monitored pollutant respectively. The prediction of the concentration of each pollutant in the nearby locations of the sampling sites can be determined by the coverage distance of the scaling area on the coordinates on the maps. These maps can be used to make predictive estimates of the pollutant's coverage at the different sites and in Srinagar city as a whole due to the homogeneousness in topography. The data Figure 2 (a, b & c) shows from the spatial interpolation that the concentrations of PM_1, $PM_{2.5}$ and PM_4 respectively were highest at Shalimar Garden, SKUAST-K Shalimar, and Naseem Bagh and the areas surrounding them. Figure 2 (d & e) shows from the spatial interpolation that the concentrations of PM_{10} and TSP were highest at Naseem Bagh and Lal Chowk and the areas surrounding them. The highest concentrations of these pollutants at these sites could be because these sites are located in areas that experience high traffic flow, burning of coal and agricultural residues in the surrounding houses; construction and demolition of buildings, flyovers, bridges, and repairing of roads (Anonymous n.d.) especially at Naseem Bagh and Lal Chowk which are the business hub of the city. Carbon dioxide concentration was high especially at Shalimar Garden and its surrounding areas. This can be attributed to the high traffic flow and burning of biomass especially in the winter season at Shalimar. The lowest



a) Spatial interpolation of PM_1 b) Spatial interpolation of $PM_{2.5}$

c) Spatial interpolation of PM_4 d) Spatial interpolation of PM_{10}

e) Spatial interpolation of TSP f) Spatial interpolation of CO_2

Fig. 2. Inverse distance weighting (IDW) maps of the average mean winter and spring concentrations of particulate matter and Carbon dioxide

Table 2. Correlation of pollutants with the considered meteorological parameters

Weather parameters	Pollutants					
	PM_1	$PM_{2.5}$	PM_4	PM_{10}	TSP	CO_2
Average temperature	-0.764^{NS}	-0.591^{NS}	-0.508^{NS}	-0.220^{NS}	-0.108^{NS}	-0.919^{**}
Relative humidity	0.911^{*}	0.920^{**}	0.864^{*}	0.545^{NS}	0.419^{NS}	0.695^{NS}
Wind speed	-0.803^{NS}	-0.700^{NS}	-0.627^{NS}	-0.345^{NS}	-0.241^{NS}	-0.940^{**}
Sunshine hours	-0.889^{*}	-0.849^{*}	-0.810^{NS}	-0.592^{NS}	-0.495^{NS}	-0.866^{*}

* Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$

concentration of all pollutants was mostly observed at Chesmashahi Botanical Garden which is located at a very secluded location away from traffic flow and human habitations. The data (Table 1) shows that there was a significant spatial variation between most of the sampling sites shown in the spatial interpolation maps and could be attributed to their different location, different traffic flow in the daytime, the different activities that are carried out temporarily in and around them, and the seasonal (winter and spring) effects on the pollutants.

Pollutants correlation with some meteorological parameters: The data on the correlation of the pollutants and the meteorological/weather parameters presented in Table 2 shows that all monitored pollutants were negatively correlated with average temperature, wind speed, and sunshine hours. The correlation of CO_2 was significantly negative with the above weather parameters, and so were PM_1 and $PM_{2.5}$ with sunshine hours. Thus, indicating that the increase or decrease of these weather parameters had an inverse effect on pollutants level most especially CO_2. Conversely, relative humidity was positively correlated with all the monitored pollutants with a significant correlation with PM_1, $PM_{2.5}$, and PM_4. This shows that relative humidity increases/decreases simultaneously with the monitored pollutants with significant effect on PM_1, $PM_{2.5}$, and PM_4. The correlation analysis thus shows that during winter when temperatures, wind speed, and sunshine hours were very low, and relative humidity very high, there was an increase in the concentration of all the pollutants. This is due to the reduced dispersion and dilution of pollutants caused by low temperatures, cold and cloudy weather; and also, the increased consumption of fuel by vehicles during winter enhanced the emission of pollutants. During spring when temperatures, wind speed, and sunshine hours start increasing and relative humidity starts reducing a decrease in the pollutants level was observed.

Owoade et al (2012) observed that in March (dry season) due to atmospheric haze there was an increase in the concentration of particulate matter and in July (rainy season) the lowest concentration of PM was observed. Therefore, meteorological parameters such as rainfall, global radiation, air temperature, and relative humidity play a significant role in day-to-day variations of the mass concentration of PM. Biglari et al (2017) studied the relationship between air particulate matter and meteorological parameters in Qom city of Iran and observed that rainfall, dryness of the air, insufficiency of humidity, high temperature, sources of air pollutants such as lime and plaster factories, brick baking, a large number of industrial cities, and the city proximity to the desert are the potential factors that increased Qom's air pollution.

CONCLUSION

The winter season recorded higher concentrations of pollutants at all the sampling sites and there was a statistically significant variation between the winter and the spring seasonal average mean concentrations of all the monitored pollutants respectively. This might be attributed to the meteorological influence on pollutants concentrations in the ambient air. Thus, lower temperatures and sunshine hours, higher humidity, less wind flow causes less/no dilution of pollutants leading to the stagnancy of pollutants in the atmosphere for a long time in the winter season. The locational average mean of each sampling site and the IDW maps show a very significant variation between most of the sampling sites in both seasons. This might be due to locational distances, variation in spatiotemporal activities, and traffic flow at the monitoring sites.

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