



Study on the effect of vehicular pollution on the ambient concentrations of particulate matter and carbon dioxide in Srinagar City

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Abstract The present study was carried out to monitor the ambient concentrations of particulate matter and carbon dioxide caused by vehicular pollution in Srinagar City of Jammu and Kashmir, India, for a period of 12 months from June 2019 to May 2020 as the major contributions in these areas are due to vehicular movement. Out of five, four locations (viz. Dalgate, Jehangir Chowk, Parimpora and Pantha Chowk) had highest traffic density in the city and the fifth location (Shalimar) had low traffic volume. The sampling was done on every fortnight using AEROCET 831—aerosol mass monitor and CDM 901—CO₂ monitor with each sampling being carried out three times a day, i.e. morning (9:00 am–10:30 am), afternoon (1:00 pm–2:30 pm) and evening (4:30 pm–6:00 pm) with three replications at each site based on the peak traffic hours. The results

show that during the whole period, average PM₁ concentrations ranged from 15.10 to 108.9 µg/m³, PM_{2.5} (28.70–577.50 µg/m³), PM₄ (44.50–780.87 µg/m³), PM₁₀ (57.13–1225.53 µg/m³), total suspended particulates (77.77–1410.27 µg/m³) and CO₂ (332.4–655.0 ppm). The average concentrations of these parameters showed that the maximum PM₁ concentration was found at Dalgate (53.77 µg/m³) and PM_{2.5} had its maximum average concentration at Jehangir Chowk (140.13 µg/m³). Other parameters like PM₄, PM₁₀, TSP and CO₂ had a maximum average values at Jehangir Chowk (240.23 µg/m³, 633.40 µg/m³, 853.50 µg/m³ and 533.20 ppm, respectively). The pollution load was observed to be maximum during winter season followed by autumn, summer and spring. The lowest concentration of all pollutants except CO₂ was observed in April 2020 and this might be due to COVID-19 lockdown observed in the country during the same period.

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Introduction

This century has witnessed air pollution to be one of the major environmental concerns with the impacts becoming prominent with time. It severely affects the human health, quality of life and is ranked as the greatest environmental risks to human

health (UNECE, n.d) and is the most dangerous form of pollution (World Bank, 2016). Air pollutants are mainly classified as (1) particulate matter (dust, smoke, fume, mist, fog, smog and haze) and (2) gases and vapours (oxides of sulphur, oxides of nitrogen, oxides of carbon, hydrogen sulphides, chlorine, fluorine etc.). Particulate matter based on size is categorized into two types: (i) particles less than 2.5 μm in diameter (fine particles) and (ii) particles greater than 2.5 μm in diameter (coarse particles). The respirable fraction has also been described by medical experts as particles with diameter of less than 10 μm (Cohen, 1998). Particles larger than 10 μm settle rapidly while those in the range 0.1–1.0 μm normally remain suspended in air for several months (Agarwal, 2002). Based on the size range, particulate matter (PM) has been classified as PM_{10} , $\text{PM}_{2.5}$, PM_4 and PM_{10} . Many atmospheric phenomena, such as cloud formation, visibility radiation and solar radiation transfer, are influenced by atmospheric aerosols; they play a crucial role in the acidification of the clouds, rain and fog (Pueschel et al., 1986). Both gaseous pollutants and atmospheric aerosols contribute to the deterioration of air quality (Parmar et al., 2001).

Besides the major concern of increasing population, the exponential increase in vehicular number following the population explosion is commendable in our country. Roadside dust stands out to be the most crucial factor for inducing air pollution. Harmful substances emitted by exhausts and automobile emissions are deposited and accumulated daily in the urban dust on road pavement together with primary and secondary particles from other anthropogenic and natural sources (Amato et al., 2009). This can have tremendous impact on the respiratory health of humans especially in a city like Srinagar where congestion near the roads and lack of management of traffic can add to it. Non-exhaust emission sources of PM involve road surface abrasion, road dust resuspension, vehicle component wear and tear, tyre clutch and brake wear (Amato et al., 2011; Hjortenkrans et al., 2007). A study conducted for percentage contribution of different anthropogenic sources shows that traffic or automobiles contributed 34 and 37% in PM_{10} and $\text{PM}_{2.5}$ pollution load, respectively (Karagulian et al., 2015). Factors like traffic volume and vehicle speed also add up to the non-exhaust emission sources of pollution (Chen et al., 2006a,

b; Gustafsson et al., 2008). PM with a diameter of less than 10 μm is released into the atmosphere along with PTEs (potential toxic elements) from brake wear, which includes brake lining and disc abrasion caused by grinding, volatilization and condensation of brake pad material (Garg et al., 2000; Varrica et al., 2013; Wahlin et al., 2006). According to previous research, a passenger car can emit 44 $\text{g car}^{-1} \text{ year}^{-1}$ of brake dust (Iijima et al., 2007). PM from exhaust emissions is emitted as a result of combustion and is primarily caused by the agglomeration of small particles from partially burned fuel and lube oil, fuel oil ash content, sulphate and water. Particles released are mostly fine, with diameters less than 2.5 μm . Particles emitted by diesel exhaust have a diameter of 15–40 nm, with 90% of the PM having a diameter less than 1 μm (Bukowiecki et al., 2009; Thorpe & Harrison, 2008). A study conducted in Berlin revealed elevated levels of PM at roadside locations, with vehicle exhaust accounting for 50% of the PM emission while others have showed that out of 82% PM_{10} emissions 21% was due to diesel exhaust and 12% was due to petrol exhaust emission (Lawrence et al., 2013). A 37% increase was seen in the PM_{10} and $\text{PM}_{2.5}$ emissions from 1995 to 1998 in Beijing. The vehicle exhaust of PM_{10} and $\text{PM}_{2.5}$ were 2445 tons and 1890 tons respectively in 1995 which rose to 3359 tons and 2694 tons in 1998 (Wu et al., 2002). In a place which lack proper management of roads and less systematically constructed dusty roads, the problem of resuspension of dust occurs more frequently. Particles that have previously been deposited can be resuspended as a result of tyre stress, vehicular turbulence and other activities such as wind and pedestrian activities (Chiou & Tsai, 2001; Kupiainen, 2007). Particles within turbulent boundaries with settling velocity less than vertical velocity remain suspended for a long time, which is common for particles less than 20 μm (Kupiainen, 2007; Kupiainen et al., 2005). Aerodynamic drag from moving vehicles induces larger turbulent activation than adhesive forces between particles, resulting in suspension (Karim et al., 1998; Moosmueller et al., 1998). There is a clear relationship between car speed and particle resuspension; as speed rises, so does the rate of resuspension (Amato et al., 2017; Nicholson & Branson, 1990; Thorpe et al., 2007). Due to the rolling force of the tyres, as well as the shearing generated by tyre rotation, air is squeezed

beneath them, causing turbulence that aids particle resuspension (Kastner-Klein et al., 2000). Driving speed and the vehicle's aerodynamic qualities are two important aspects that influence automobile turbulence and the resuspension of deposited particles (Guevara, 2016; Moosmueller et al., 1998) which is basically the case happening in case of Srinagar City.

Since the rate of rise in air pollutant concentrations in growing countries like India is faster than in developed nations, atmospheric pollution in developing countries throughout the world is typically severe and ever growing (Bhaskar & Mehta, 2010; Mage et al., 1996). Combustion of fossil fuels and deforestation have caused the concentration of CO₂ to increase by 43% after the industrialization (NOAA, 2017). In addition, black carbon is an important constituent of air borne particulate matter that is often emitted as product of incomplete combustion of fossil fuels and burning of biomass and biofuels (Koelmans et al., 2006). The amount of CO₂ released by the combustion of 1 L of petrol and 1 L of diesel fuel varies depending on the chemical composition of the fuels, but it is around 2.36 kg and 2.60 kg, respectively. The road transport in India contributes 243.82 Tg CO₂ emissions which accounts for 94.5% of all the emissions with smaller quantities of CO, CH₄, NO_x, SO₂, HC and PM. Even black carbon containing particles are associated with causing adverse health effects (Badrinath et al., 2007; Mauderly & Chow, 2008). Due to its adverse health effects, it requires regular monitoring so as to regulate the concentrations of particulate matter and carbon dioxide in air. However, work on air quality in Kashmir valley has received little attention till date (Jehangir et al., 2010) and no information exists on the air quality with respect to particulate matter and CO₂ levels of Srinagar City.

The Ministry of Roadways and Transport have shown the registered number of vehicles in the country to have increased from 0.3 million in 1951 to 253 million in 2017. The compounded annual growth rate of registered vehicles was 10.1% in the country for last 10 years outpacing the CAGR of national highways of 5.54% (Anonymous, 2016–2017). This tremendous increase in the vehicular density indirectly affects the air quality. The CPCB in 2010 stated that 14% of the global greenhouse gas emissions are due to the transport sector and 60–70% of the total urban air pollution is contributed by motor vehicles (Dwivedi

& Tripathi, 2008). The vehicles registered in Jammu and Kashmir during 1975 were a mere 35,000 which have now considerably increased to almost 1,510,000 till March 2018 (Anonymous, 2018). Out of the total registered vehicles in Kashmir, i.e. 660,627, 315,797 vehicles are registered in Srinagar City. The percentage vehicle distribution based on the different types in Srinagar City is given in Fig. 2. This enhances the congestion rate of vehicular movement in the city at major junctions and this account for causing major air pollution instances. This is one of the major contributors of CO₂ concentrations in the valley besides other sources like biomass burning and deforestation.

Several epidemiological studies conducted have indicated a strong association between elevated concentrations of inhalable particles (PM₁₀ and PM_{2.5}) and increased mortality and morbidity (Perez & Reyes, 2002; Lin, 2004; Namdeo & Bell, 2005). Epidemiological studies (Schwartz et al., 1996; Pope & Dockery, 2006) have suggested that there is a close association between health effects and ambient fine particle concentrations, especially submicron particles (PM₁) that can penetrate deep into the alveolar sacs of lungs. PM₁ mainly arise in urban area due to the gas particle conversion processes within the atmosphere originating mainly from the vehicular traffic (Hildemann et al., 1991; Kleeman & Cass, 1998; Schauer et al., 1996). Based on these astute observations, priority is now given by regulatory bodies and researchers to study the potential impacts of these particulate matter on health, global warming and long-range transport of pollutants (Dockery & Pope, 1994; IPCC, 2001). Studies of long-term exposure to air pollution especially particles continues to threaten public health suggesting an increased risk of chronic respiratory illness (Dockery & Pope, 1994; Pope et al., 1995; Schwartz, 1994) and for developing various types of cancers (Knox & Gilman, 1997; Hemminki & Pershagen, 1994; Nyberg et al., 2000).

Keeping in view of the ever increasing air pollution in Kashmir valley, especially in Srinagar City, the following study was carried out to monitor the ambient air quality at some selected sites. This can help in understanding as to how much grave the situation is and what kind of further measures should be taken to bring down the pollution level in the city and also the overall pollution status of Kashmir.

Methods

The present study was carried out in Srinagar City which is the largest city and the summer capital of Jammu and Kashmir, India. The city lies within the coordinates 34.0837° N and 74.7973° E on the banks of the Jhelum River, a tributary of the Indus, and Dal and Anchar lakes. Srinagar has a humid subtropical climate surrounded by Himalayas on all sides. The winter daytime temperature averages to 2.5 °C and night temperature goes below freezing point with frequent snowfall during the season. Summers are warm with average day time temperature reaching 24.1 °C. The average annual rainfall is 720 mm. The average rainfall is generally seen to be highest during the winter months due to snowfall. The study area for the current research was selected based on higher number of vehicular movement during the peak hours in the city, traffic congestions, major crossroads or junctions, higher populations, etc. so that the major contributions of pollution can be attributed to the vehicles whereas Shalimar campus of SKUAST-K was taken as a control which

is a site at a distance of 15 km to the north-east of Lalchowk, the main business hub of Srinagar City where the traffic movement is very less compared to the city limits. The locations Shalimar, Dalgate, Jehangir Chowk, Parimpora and Pantha Chowk have been depicted in the figure with the corresponding coordinates on the map (Fig. 1). Five locations were selected for sampling of air for a year from June 2019 to May 2020. The data were recorded based on a 1-min average value at each location (with 3 replications for a single sampling at each location) for a period of 12 months from June 2019 to May 2020. The sampling was done twice a month on the second and fourth week respectively by using stratified random sampling. To understand the variability of the pollution load during a day at the respective locations, the sampling was done three times, i.e. morning (9:00 am to 10:30 am), afternoon (1:00 pm to 2:30 pm) and evening (4:30 pm to 6:00 pm). The time period chose for the sampling were based on the vehicular load on these locations. The number of vehicles varied in number and movement based on the time of the day.

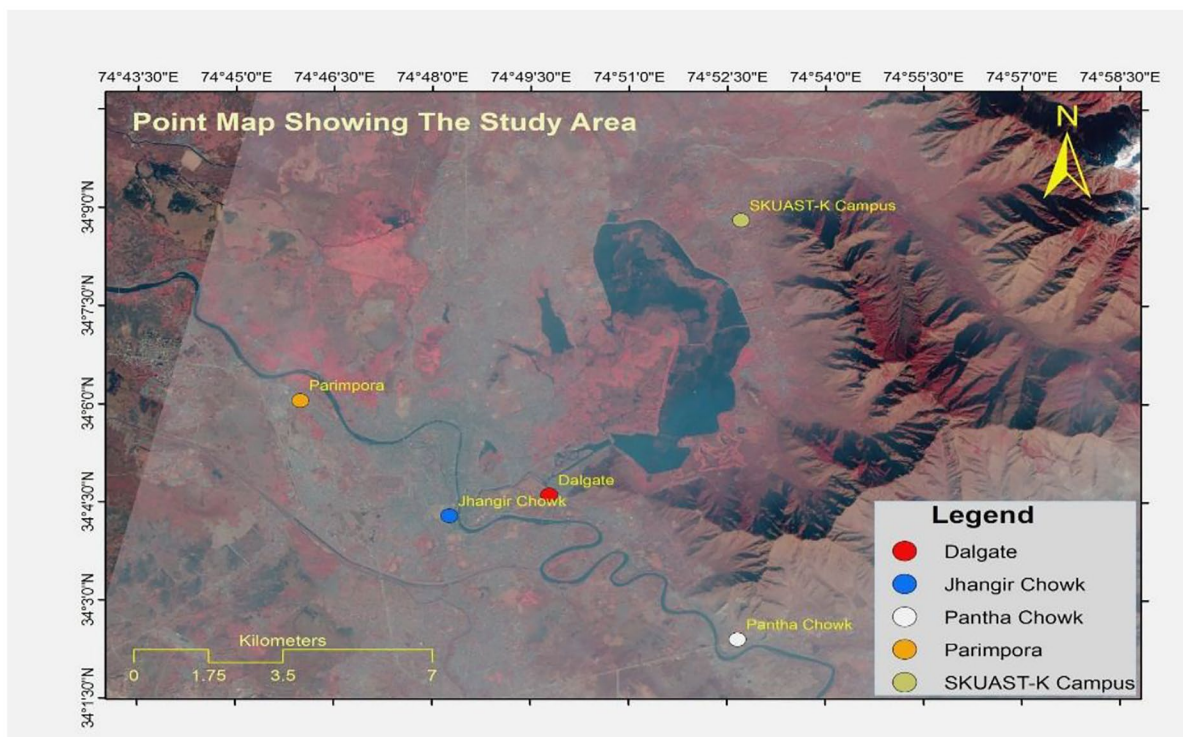


Fig. 1 Point map showing the study area in Srinagar City

The sampling was done using two instruments, aerosol mass monitor (AEROCET 831, Met One Inc., WA, USA) (Fig. 2) for particulate matter assessment (PM₁, PM_{2.5}, PM₄, PM₁₀ and TSP) and CO₂ analyser (CDM 901, Rave Innovations, India) (Fig. 3) for monitoring CO₂ concentration in the ambient air. The AEROCET 831 counts and sizes particles in 7 different size ranges then uses a proprietary algorithm to convert count data to mass measurements (µg/m³). Fundamentally, the instrument calculates a volume for each detected particle then assigns a standard density for the conversion. The standard density value is augmented by the K-factor setting to improve measurement accuracy. A separate K-factor setting for each measurement range is provided which can be modified with Comet software provided along with the instrument. The accuracy of the instrument is ± 10% to the calibration aerosol, and the sensitivity ranges from a high of 0.3 µm and a low of 0.5 µm. A laser diode light source is used in the instrument. The CO₂ analyser CDM 901 is a micro-controller based instrument which shows real time CO₂ which works on sensor technology and the measuring principle being non-dispersive infrared (NDIR). The instrument has a resolution of 1% to the full-scale reading with a response time for a reading being approximately 30 s. The basic criterion of the study was to analyse the ambient air quality at the major traffic intersections. The limitations of the instruments in extracting the air sample deprive the study from source apportionment. But since the major contributor of pollutants is due to the vehicular movement, the study was carried out. This can open an opportunity for further research on this concern. The sensitivity and various restrictions of these locations deprived the study of calculating a steady flow count of the passing vehicles. Meteorological parameters like temperature (both maximum and minimum temperature) and rainfall data were procured from the agro-meteorological cell of the Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K). These weather parameter data were later on correlated with the air sampling data and a relationship was established with all the pollutants sampled. The basic need for the correlation of the pollutant data was to know the changes in pollution load based on local weather patterns.

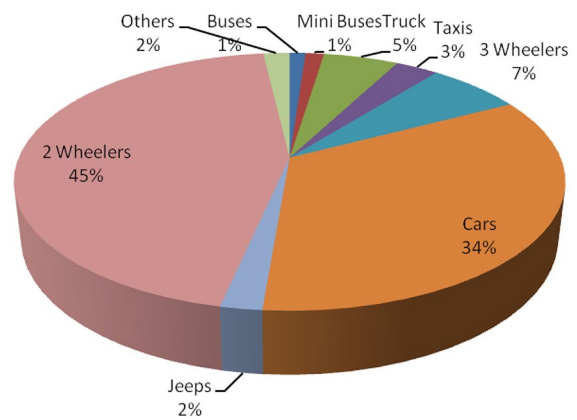


Fig. 2 Categorization of vehicles in Srinagar City

Results and discussion

Monthly, seasonal and annual concentrations of PM₁ in the selected locations

The data on the ambient air quality with regard to particulate matter (PM₁) in the selected five locations, namely, Shalimar campus, Dalgate, Jehangir Chowk, Parimpora and Pantha Chowk, for a period of 12 months from June 2019 to May 2020 is given in Fig. 4. The values were statistically analysed. The



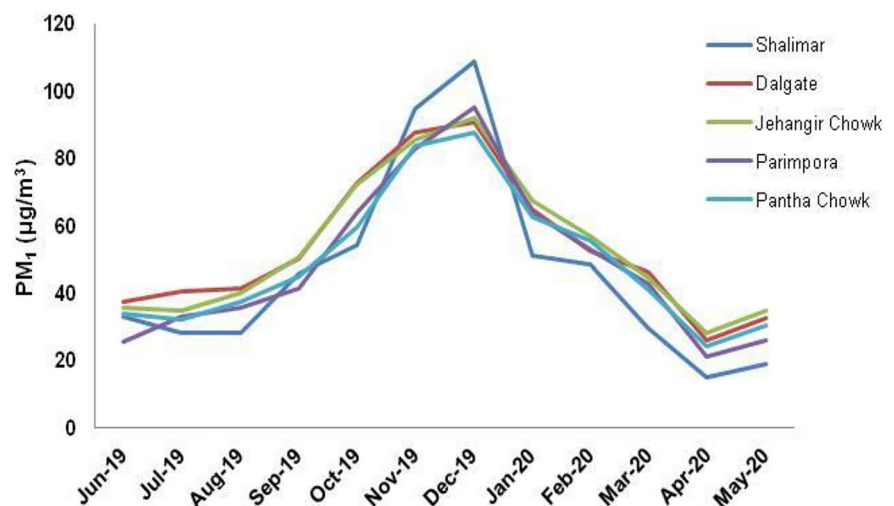
Fig. 3 AEROCET 831— aerosol mass monitor



Fig. 4 CDM 901—CO₂ monitor

data showed that the maximum average concentration of PM₁ was found to be at Shalimar (108.90 $\mu\text{g}/\text{m}^3$) during December month of the winter season followed by Parimpora (95.33 $\mu\text{g}/\text{m}^3$), Jehangir Chowk (92.20 $\mu\text{g}/\text{m}^3$), Dalgate (90.83 $\mu\text{g}/\text{m}^3$) and Pantha Chowk (87.80 $\mu\text{g}/\text{m}^3$) even though the location was devoid of any major traffic movements. On the other hand, the lowest values for PM₁ were recorded during the month of April 2020. Shalimar (15.10 $\mu\text{g}/\text{m}^3$) recorded the lowest value while the concentrations

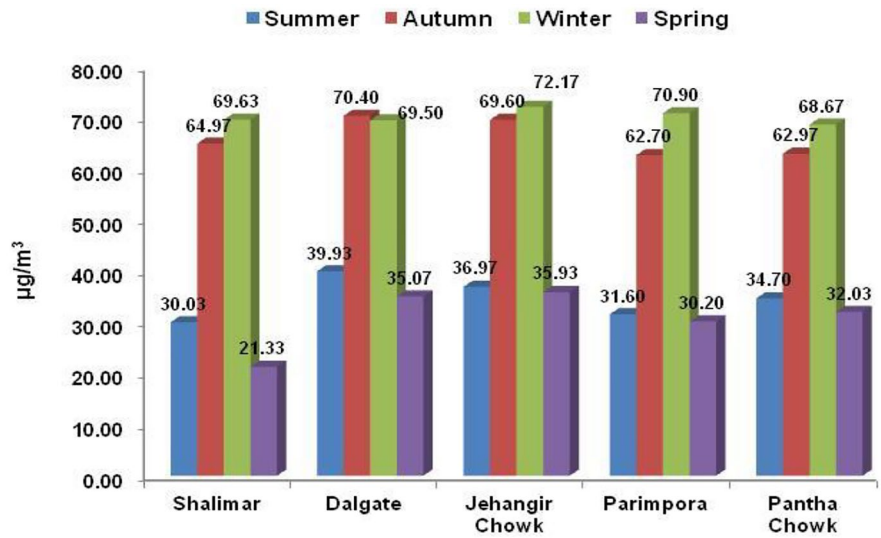
Fig. 5 Concentration of PM₁ ($\mu\text{g}/\text{m}^3$) at different locations in Srinagar City on monthly basis



at other locations were Parimpora (21.23 $\mu\text{g}/\text{m}^3$), Pantha Chowk (24.47 $\mu\text{g}/\text{m}^3$), Dalgate (26.30 $\mu\text{g}/\text{m}^3$) and Jehangir Chowk (28.40 $\mu\text{g}/\text{m}^3$). The average seasonal value of PM₁ particle shows that the pollutant was highest during the winter season and exhibited its maximum mean average value of 72.17 $\mu\text{g}/\text{m}^3$ at Jehangir Chowk and the lowest average in the winter season was at Pantha Chowk at 68.67 $\mu\text{g}/\text{m}^3$. Besides on an average the PM₁ recorded during the winter season in the Srinagar City stands at 70.17 $\mu\text{g}/\text{m}^3$, whereas the lowest concentration was seen during the spring season. The spring season recorded a maximum average value of 35.93 $\mu\text{g}/\text{m}^3$ at Jehangir Chowk and the lowest average value of 21.33 $\mu\text{g}/\text{m}^3$ at Shalimar (Fig. 5). The average value during the spring season in the city was 30.91 $\mu\text{g}/\text{m}^3$. The observations showed that PM₁ had the highest annual average concentration in the morning at Dalgate which was 59.40 $\mu\text{g}/\text{m}^3$ and the lowest annual morning average was at Shalimar with concentration of 52.33 $\mu\text{g}/\text{m}^3$ (Fig. 6). Based on the annual data observations during June 2019 to May 2020, it was observed that the PM₁ recorded an annual average of 53.77 $\mu\text{g}/\text{m}^3$, 53.63 $\mu\text{g}/\text{m}^3$, 49.60 $\mu\text{g}/\text{m}^3$, 48.87 $\mu\text{g}/\text{m}^3$ and 46.50 $\mu\text{g}/\text{m}^3$ at Dalgate, Jehangir Chowk, Pantha Chowk, Parimpora and Shalimar, respectively (Fig. 7).

PM₁ particulates originate from a wide range of sources both natural and anthropogenic and are the result of chemical conversions in the gas phase, heterogeneous and multiphase reactions (Hamed et al., 2010). Due to the small size of these particles, they

Fig. 6 Seasonal variation of PM₁ (µg/m³) at different locations in Srinagar City



can be transported to a longer distance and also remain in the lower atmosphere for a longer period of time (Kappos et al., 2004). The reason for the higher concentration of PM₁ in Shalimar location was due to the interference of biomass burning in the agricultural fields of the university campus and also in the nearby household for heating requirements. This enhances the pollution in this location during winter season in comparison to other locations in the city. The values of PM₁ during winter suggest considerable increase in the pollutant level because of cloudy weather during the colder season which lowers the diffusion and dispersion rate of the pollutants with the upper

atmosphere. The low turbulence and mixing volume causes stagnation of the pollutants in air. This happens due to the stable or inversion atmospheric lapse rate characterized by calm or light winds (Reddy & Ruj, 2003). The lowest values of PM₁ were recorded during the month of April 2020 with lowest values 15.10 µg/m³ observed at Shalimar. The above said observations in the month of April is primarily due to the lockdown imposed due to COVID-19 pandemic which reduced the traffic movement to almost nil. Besides the higher temperature and clear sky cause diffusion of the pollutants faster as compared to the winter or autumn season and avoid stagnation of the

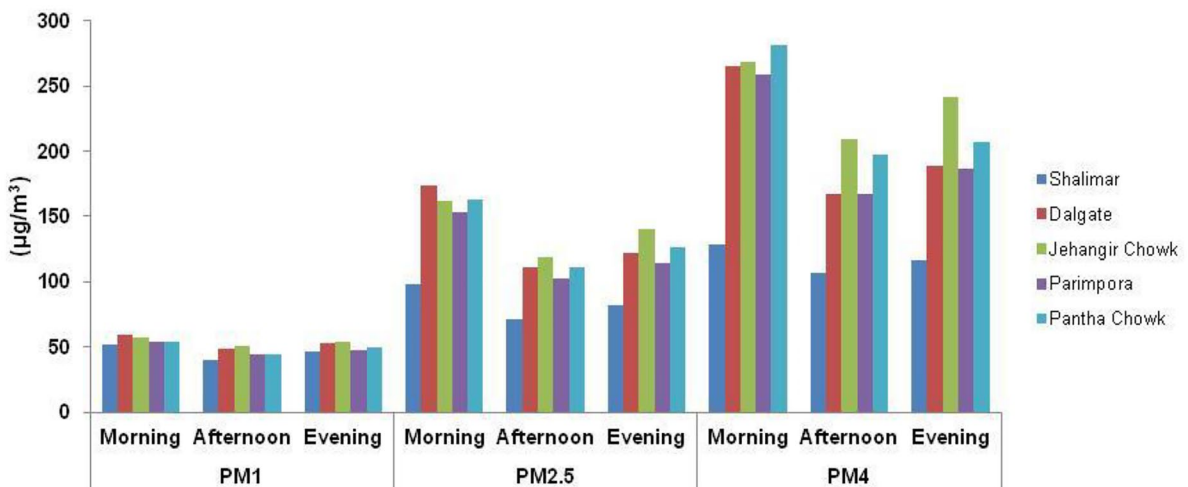


Fig. 7 Annual average concentrations of PM₁, PM_{2.5} and PM₄ based on time period of sampling during a day

pollutants in the air. This is the reason why the pollutant level was recorded to be low during the spring season.

Data also shows that Dalgate recorded the highest annual morning average $59.40 \mu\text{g}/\text{m}^3$ whereas the lowest annual morning average $52.33 \mu\text{g}/\text{m}^3$ was recorded at Shalimar. The morning values at all sites were found to be higher as compared to afternoon and evening time. The reason behind this might be the higher number of traffic volume during the morning time compared to other period. Besides, morning time accounts for more combustion emissions from households, hotels, confectionaries, etc. which might interfere with enhancing pollutant load in air.

Monthly, seasonal and annual concentrations of $\text{PM}_{2.5}$ in the selected locations

$\text{PM}_{2.5}$ pollutants are being recently investigated extensively across the globe due to its increasing effect on human health like respiratory ailments and cardiovascular problems. The present study contemplates the need for the ambient air quality monitoring as acute particulate pollution can cause extreme poor visibility and also sharp increase in respiratory diseases. The experimental details showed similar trend in $\text{PM}_{2.5}$ concentration as in case of PM_1 . The concentrations were recorded maximum at Dalgate ($577.50 \mu\text{g}/\text{m}^3$) in December which is significantly higher compared to the other months and also the prescribed national standards. The maximum average $\text{PM}_{2.5}$ values for

other locations were $233.67 \mu\text{g}/\text{m}^3$, $569.7 \mu\text{g}/\text{m}^3$, $497.00 \mu\text{g}/\text{m}^3$ and $571.43 \mu\text{g}/\text{m}^3$ in Shalimar, Jehangir Chowk, Parimpora and Pantha Chowk, respectively (Fig. 8). The data also shows that on seasonal basis, winter season had the worst air quality. The average maximum winter concentration was seen to be highest in Jehangir Chowk ($283.10 \mu\text{g}/\text{m}^3$) and the average for the same season was lowest at Shalimar ($129.43 \mu\text{g}/\text{m}^3$) (Fig. 9). The higher pollution in winter is due to higher fuel consumption by the combustion engine and local biomass burning. Higher concentration of $\text{PM}_{2.5}$ is mainly due to low wind speed and high humidity during the winter in comparison to other seasons so the removal of aerosol particles by wet scavenging is reduced (Kulshreshtha et al., 2009). The short snowfall or insufficient rains during the period is only effective for a shorter while. The succeeding period shows increased emissions due to slower movement of vehicles which in turn accounts for more pollution.

The lowest average concentrations were recorded during April in Shalimar ($28.70 \mu\text{g}/\text{m}^3$). The lowest average concentrations observed for Dalgate, Jehangir Chowk, Parimpora and Pantha Chowk were $50.13 \mu\text{g}/\text{m}^3$, $51.83 \mu\text{g}/\text{m}^3$, $39.90 \mu\text{g}/\text{m}^3$ and $45.43 \mu\text{g}/\text{m}^3$, respectively (Fig. 8). The lowest concentration of the pollutant was observed in spring season with Dalgate showing the maximum average value of $65.57 \mu\text{g}/\text{m}^3$ whereas the lowest value was observed at Shalimar ($36.80 \mu\text{g}/\text{m}^3$) (Fig. 9). Overall the mean values for winter and spring season in the city were $238.97 \mu\text{g}/$

Fig. 8 Annual average concentrations of various pollutants in Srinagar City during the study period

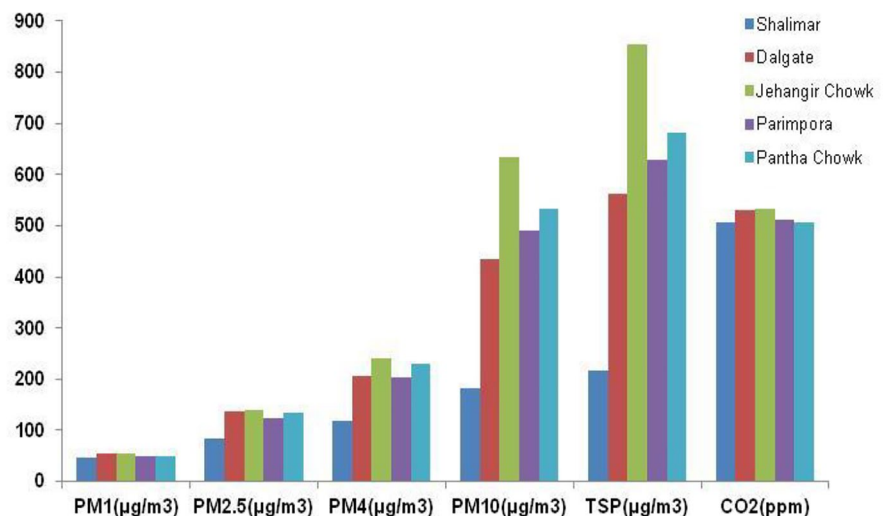
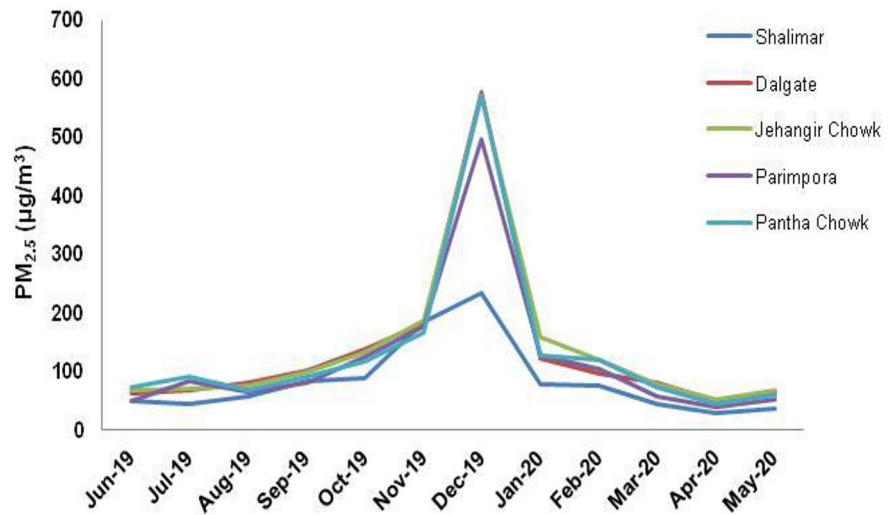


Fig. 9 Concentration of PM_{2.5} (µg/m³) at different locations in Srinagar City on monthly basis



m³ and 56.50 µg/m³, respectively. The spring season shows lower values due to clear sky which increases the average mixing height and maximum atmospheric dispersion of pollutants. The wet deposition of the pollutants is avoided due to higher winds also. It is also seen that a sunny day indicate better weather conditions with less cloud cover or strong winds, which favourably diffuses and eliminates air pollutants (Sanchez-Romero et al., 2014; Yang et al., 2008). These conditions are exactly opposite in winter increasing the pollutants by double the rate in the locations. The annual average morning concentrations showed highest in Dalgate (173.77 µg/m³) and lowest at Shalimar (98.07 µg/m³) (Fig. 6). The highest morning averages are due to the same conditions as mentioned in case of PM₁. PM_{2.5} annual average concentrations were 140.13 µg/m³, 135.70 µg/m³, 133.50 µg/m³, 123.40 µg/m³ and 83.83 µg/m³ at Jehangir Chowk, Dalgate, Pantha Chowk, Parimpora and Shalimar, respectively (Fig. 7).

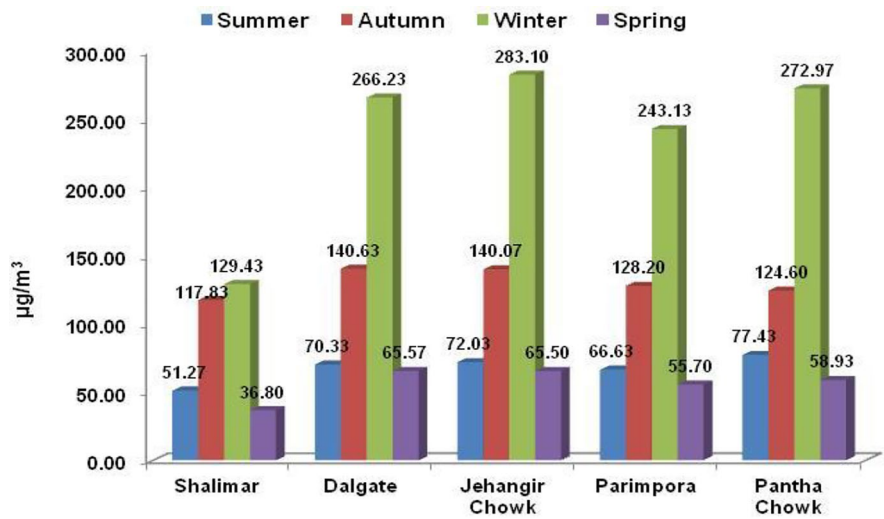
Monthly, seasonal and annual concentrations of PM₄ in the selected locations

PM₄ particle has not been extensively studied in the world, although the behaviour of the particle is similar to other particulates. The results of the present study show similar pattern in the concentration of PM₄ pollutants in the ambient air. The maximum average concentration of PM₄ in December was found to be at Dalgate with a mean value of 780.87 µg/m³ followed

by Jehangir Chowk (772.97 µg/m³), Pantha Chowk (769.10 µg/m³), Parimpora (668.13 µg/m³) and Shalimar (278.77 µg/m³) (Fig. 10). The reason for this is the foggy nature of the weather which caused stagnation of the particulates. The unusually high value in Pantha Chowk might be due to the interference of the stone quarry area nearby which produces a lot of dust particles. Besides, the location is also near to bus stand and railway station. The higher vehicular number plying on the national highway also has an influence on the pollution load. Season wise concentration also shows higher pollution in winter compared to other seasons. Jehangir Chowk with 436.93 µg/m³ in the ambient air shows maximum average concentration of PM₄ in winter, while the lowest average concentration of 180.50 µg/m³ was observed at Shalimar. The overall average concentration for the winter season in Srinagar City was 346.38 µg/m³.

The lowest concentration of PM₄ during spring season might be due to the COVID-19 lockdown. The lowest average concentrations of PM₄ at all locations during April 2020 were Shalimar (44.50 µg/m³), Parimpora (88.0 µg/m³), Pantha Chowk (96.50 µg/m³), Dalgate (97.83 µg/m³) and Jehangir Chowk (106.97 µg/m³), respectively. The maximum average concentration for spring season was recorded at Jehangir Chowk (123.03 µg/m³) and the lowest at Shalimar (53.40 µg/m³). On an average, the city recorded a concentration of 103.28 µg/m³ during the spring season (Fig. 11). In case of PM₄ particle also, the highest annual morning concentration was observed in Pantha Chowk

Fig. 10 Seasonal variation of PM_{2.5} (µg/m³) at different locations in Srinagar City



(281.53 µg/m³) and the lowest at Shalimar (128.37 µg/m³), respectively (Fig. 6). The data on annual average concentration of PM₄ at different locations show that the highest value was recorded in Jehangir Chowk (240.23 µg/m³) followed by Pantha Chowk (228.63 µg/m³), Dalgate (207.10 µg/m³), Parimpora (204.27 µg/m³) and Shalimar (117.30 µg/m³), respectively (Fig. 7).

Monthly, seasonal and annual concentrations of PM₁₀ and TSP in the selected locations

The results regarding PM₁₀ and TSP have been discussed in the same section as the particles are similar in nature due to their larger size compared to the already discussed particle size. The scenario for PM₁₀

and TSP is similar because major portion of these pollutants is comprised of pollutants with smaller size of particulates. Most of the studies conducted on PM₁₀ and TSP showed that 38–77% of the fraction of these two pollutants is comprised by PM_{2.5} particles (Kulshreshtha et al., 2009). These pollutants are larger in size compared to other particulates so they can settle down due to its higher dispersion rate and settling ability compared to other pollutants. But since the sampling was done on a 1-min average basis, the concentration of these pollutants is shown to be higher due to the continuous movement of vehicles at these sites. The movement of vehicles causes constant dispersion of dust from the road surface which stays in the ambient air. The relative humidity

Fig. 11 Concentration of PM₄ (µg/m³) at different locations in Srinagar City on monthly basis

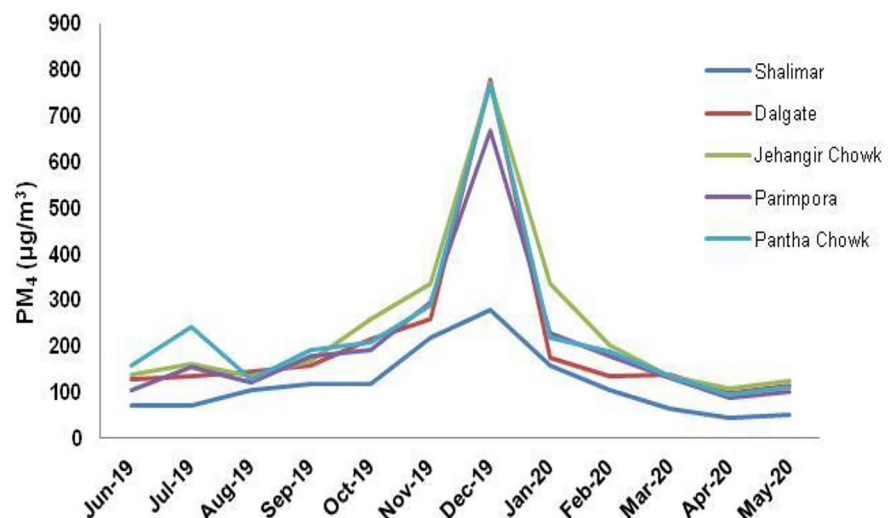
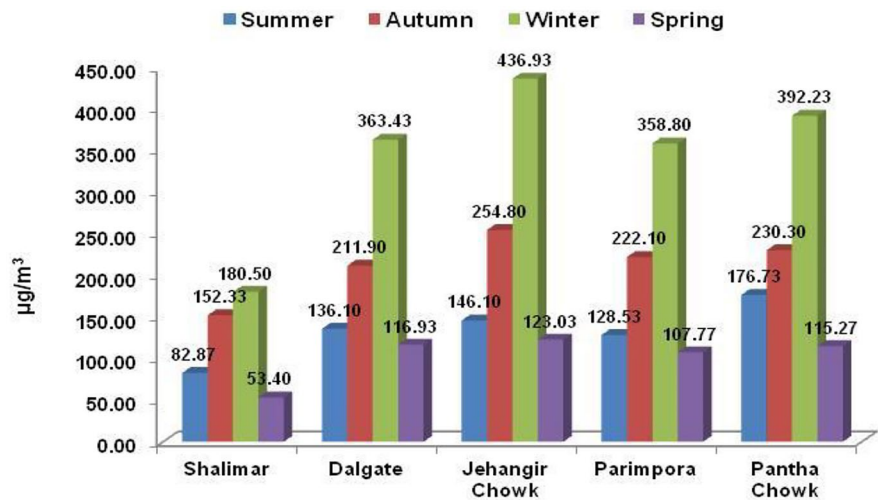


Fig. 12 Seasonal variation of PM₄ (µg/m³) at different locations in Srinagar City



in the air is higher in winter months which cause stagnation of these pollutants in the air. Besides, fog in winter provides these pollutants higher surface area to stay in air. The highest maximum average for PM₁₀ was recorded at Jehangir Chowk (1225.53 µg/m³) followed by Dalgate (1164.07 µg/m³), Pantha Chowk (1104.40 µg/m³) and Parimpora (1062.90 µg/m³) respectively within the city limits. Shalimar (368.53 µg/m³) location recorded very less compared to the other locations (Fig. 12). The maximum average concentration of TSP was observed in Jehangir Chowk (1410.27 µg/m³) during the December month. Other locations like Dalgate, Pantha Chowk, Parimpora and Shalimar showed maximum average values of 1314.10 µg/m³, 1236.73 µg/m³, 1162.20 µg/m³ and

405.87 µg/m³ respectively in the month of December (Fig. 14).

The data also shows that April month recorded a considerable decrease in the PM₁₀ pollutant concentration (Fig. 13). Shalimar recorded 57.13 µg/m³ whereas other locations like Parimpora, Dalgate, Pantha Chowk and Jehangir Chowk recorded 246.33 µg/m³, 254.23 µg/m³, 265.10 µg/m³ and 279.97 µg/m³, respectively (Fig. 12). TSP was recorded low during the month of April and Shalimar recorded the lowest value of 77.77 µg/m³. Other locations also recorded their lowest average during the same month. Parimpora, Dalgate, Pantha Chowk and Jehangir Chowk had their lowest average at 338.73 µg/m³, 348.70 µg/m³, 352.97 µg/m³ and 368.17 µg/m³, respectively.

Fig. 13 Concentration of PM₁₀ (µg/m³) at different locations in Srinagar City on monthly basis

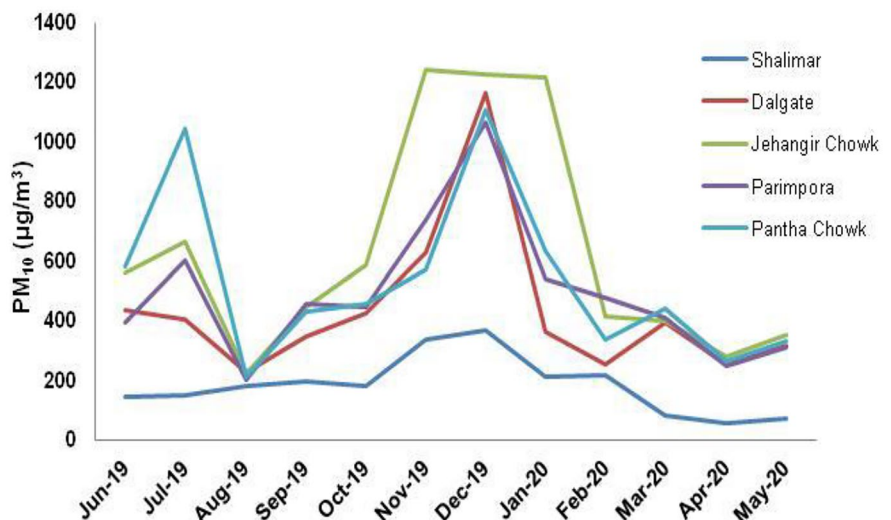
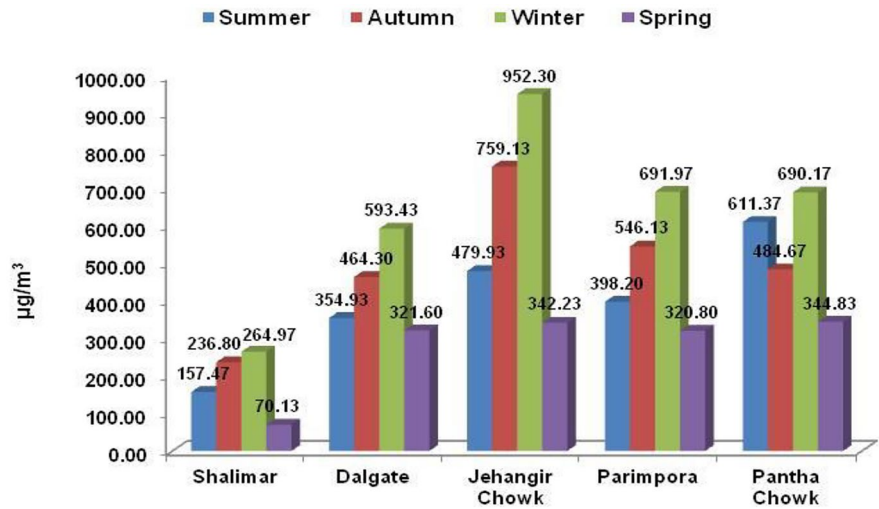


Fig. 14 Seasonal variation of PM₁₀ (µg/m³) at different locations in Srinagar City



The reason for the considerable decrease in April 2020 was especially due to the COVID-19 lockdown which reduced the traffic volume (Fig. 14).

The overall average shows that winter season recorded PM₁₀ concentration of 638.57 µg/m³ and total suspended particulates 768.09 µg/m³ in the city. The overall average shows that 279.92 µg/m³ was the PM₁₀ value recorded in spring season and 366.37 µg/m³ was the TSP value for the same season (Figs. 13 and 15). The reason for higher concentration of TSP and PM₁₀ during winter is due to lower mixing heights of atmosphere which causes the pollutants to remain in the ambient air for longer period. The continuous fog period during the month of December

reduces the dispersion rate of the pollutants in air. On the other hand, during spring season the clear sky and constant sunlight causes faster dispersion of pollutants. Lesser humidity also helps the pollutants to settle down immediately. The highest and lowest annual morning average values of other pollutants like PM₁₀ and TSP showed similar trends with Jehangir Chowk showing the highest and Shalimar showing the lowest values. The highest and lowest averages for PM₁₀ (725.97 µg/m³, 190.23 µg/m³) and TSP (974.50 µg/m³, 217.07 µg/m³) were recorded during morning hours, respectively. The afternoon values were the lowest during the day time at all the sites (Fig. 16). The pollution load during the noon time also showed

Fig. 15 Concentration of TSP (µg/m³) at different locations in Srinagar City on monthly basis

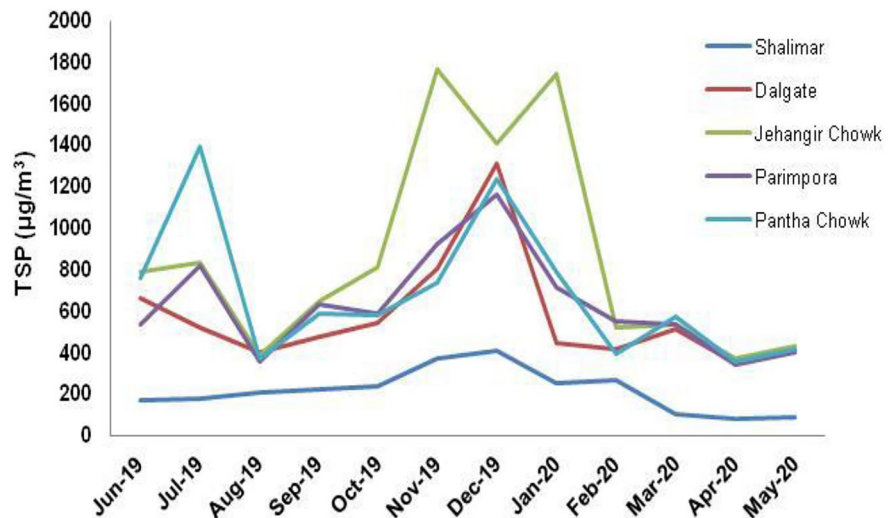
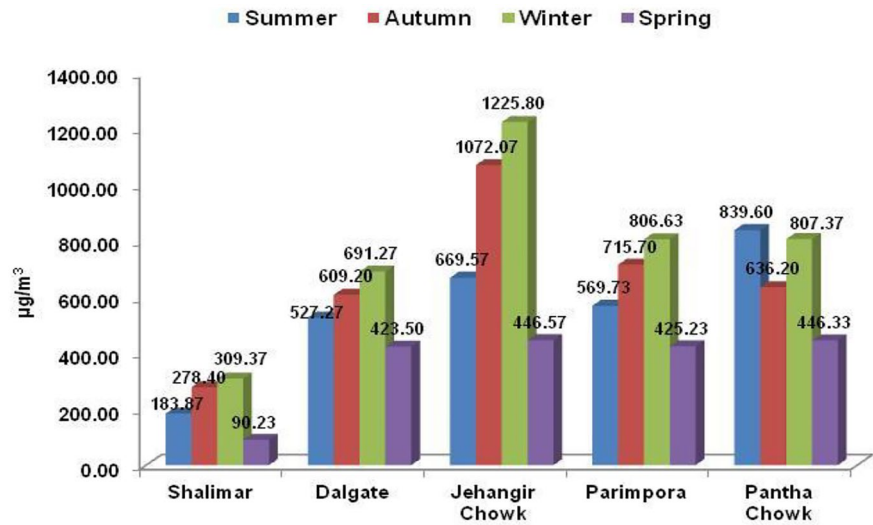


Fig. 16 Seasonal variation of TSP ($\mu\text{g}/\text{m}^3$) at different locations in Srinagar City



similar trend location wise for all the pollutants with Jehangir Chowk recording the maximum and Shalimar recording the lowest values. PM_{10} annual average values stand at $633.40 \mu\text{g}/\text{m}^3$, $532.77 \mu\text{g}/\text{m}^3$, $489.27 \mu\text{g}/\text{m}^3$, $433.57 \mu\text{g}/\text{m}^3$ and $182.33 \mu\text{g}/\text{m}^3$ for Jehangir Chowk, Pantha Chowk, Parimpora, Dalgate and Shalimar, respectively. Data on TSP at all the locations show that average value was recorded at Shalimar ($215.47 \mu\text{g}/\text{m}^3$), Dalgate ($562.80 \mu\text{g}/\text{m}^3$), Jehangir Chowk ($853.50 \mu\text{g}/\text{m}^3$), Parimpora ($629.33 \mu\text{g}/\text{m}^3$) and Pantha Chowk ($682.33 \mu\text{g}/\text{m}^3$), respectively (Fig. 7).

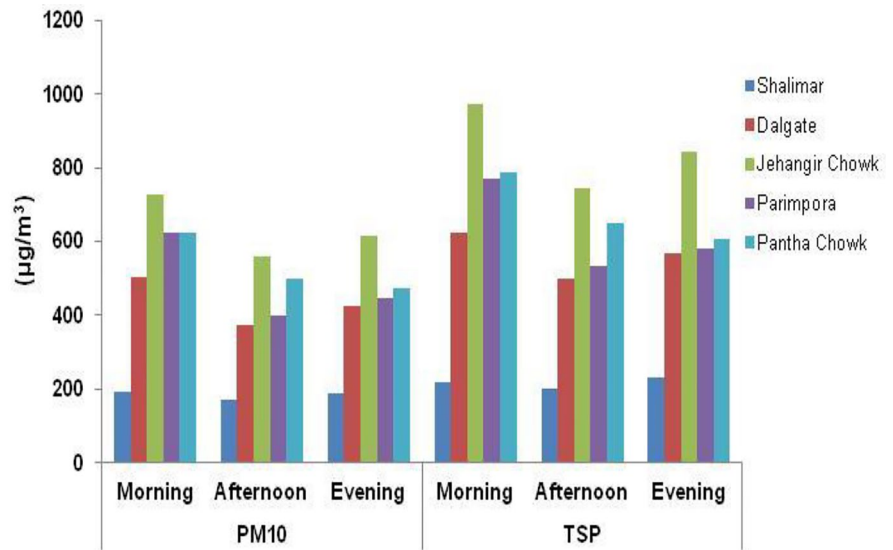
Monthly, seasonal and annual concentrations of CO_2 in the selected locations

Carbon dioxide unlike other pollutants in the air shows gradual increasing trend in the air. Throughout the year from June 2019 to May 2020, CO_2 concentration was seen to be increasing. However, a slight decreasing trend was observed in the months of April 2020 and May 2020. On monthly basis, the maximum average concentration of CO_2 was found during December and Shalimar recorded the highest carbon dioxide value of 637.57 ppm . The recorded maximum average values at other locations were 622.33 ppm , 614.40 ppm , 592.23 ppm and 579.33 ppm at Jehangir Chowk, Dalgate, Parimpora and Pantha Chowk, respectively. The minimum average concentration of CO_2 was recorded at Shalimar during the month of June (355.23 ppm),

whereas Pantha Chowk, Parimpora, Jehangir Chowk and Dalgate recorded minimum average values at 357.10 ppm , 366.40 ppm , 391.20 ppm and 399.23 ppm , respectively (Fig. 17). On the other hand, maximum average concentration in spring reached 626.86 ppm in Jehangir Chowk and the minimum average for the same season was recorded in Shalimar (592.06 ppm). The average value of all the sites during the spring season was 609.29 ppm . The data also shows that the lowest concentration of CO_2 was observed in summer season. The maximum average concentration in summer season was recorded at Dalgate (385.80 ppm) and the lowest average value in the same season was in Shalimar campus at 352.80 ppm (Fig. 18). The average value of CO_2 of different sites in Srinagar City was 369.28 ppm . The highest and lowest annual morning average values of CO_2 showed similar trends with Jehangir Chowk showing the highest and Shalimar showing the lowest values. The highest and lowest averages for CO_2 (560.67 ppm , 520.40 ppm) were recorded during morning hours Jehangir Chowk and Shalimar, respectively (Fig. 19). CO_2 showed an annual average value of above 500 ppm for all the locations with individual values of 506.87 ppm , 529.57 ppm , 533.20 ppm , 511.90 ppm and 506.07 ppm in Shalimar, Dalgate, Jehangir Chowk, Parimpora and Pantha Chowk, respectively (Fig. 7).

The reason for the astute observation in case of carbon dioxide was due to the fact that the decreasing temperature reduces the photosynthetic rate causing the CO_2 to increase in the atmosphere. Besides the temperature recorded in Kashmir for

Fig. 17 Annual average concentrations of PM₁₀ and TSP based on time period of sampling during a day



the period June 2019–May 2020 was lesser in comparison to the previous year, which has led to continuous burning of biomass and wood for heating requirements in domestic households to an extended period till late April 2020. Besides the direct smoke emissions from hotels, dhabas, roadside confectionaries, etc. also add up to the CO₂ emissions. The low sunshine hours during the cold season reduces the mixing volume of the atmosphere and inhibits the dispersion of gases in air. Thus, it increases the CO₂ concentration in air. The lower temperature influences more fossil fuel burning in the automobiles causing increased exhaust emissions (Chen

et al., 2006a, b). Precipitation also has no significant effect on the concentration of CO₂ in air (Chen et al., 2006a, b). These might be the reasons for the increasing CO₂ trend in the atmosphere during spring.

Even though the above reasons suggest the high pollution load in Jehangir Chowk, there are interferences from other factors like hotels, high building rise causing lesser air flow, frequent power breaks introducing diesel generators, congested roads and longer traffic jam hours. The emission of gases and particulates from the vehicle exhaust increases steadily with decrease in speed of the vehicles

Fig. 18 Concentration of CO₂ (ppm) at different locations in Srinagar City on monthly basis

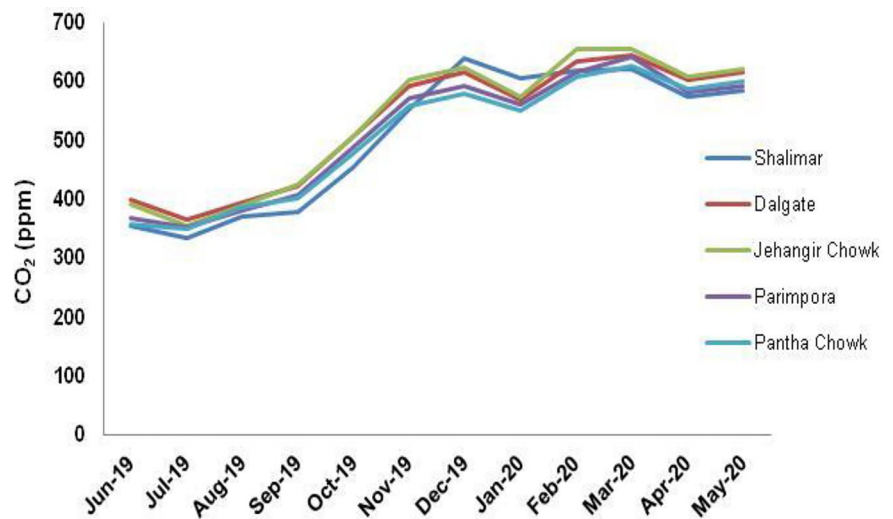
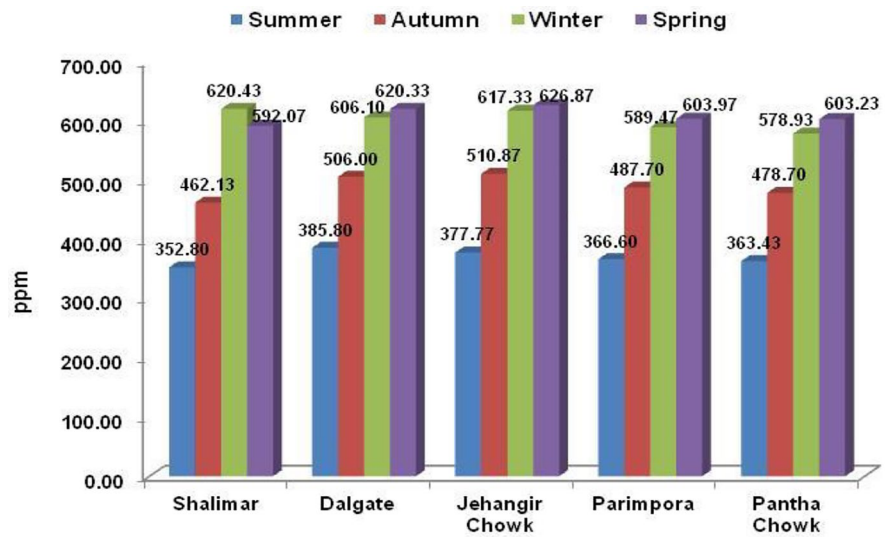


Fig. 19 Seasonal variation of CO₂ (ppm) at different locations in Srinagar City



remain more stagnant at a place the pollutant load build up at a place increasing its concentration at a particular space (Mathew, 2012). Although the traffic movement for locations like Dalgate, Parimpora and Pantha Chowk is high, the wide open area and smooth traffic flow help in dispersal of pollutants faster as compared to Jehangir Chowk (Fig. 20).

Correlation of the studied pollutants with the weather parameters

Correlation analyses of the data have been carried out using Pearson correlation coefficient from the commercial package SPSS. The correlation of

temperature and rainfall with the various pollutants was done during the course of the study (Table 1). The results showed that temperature (both maximum and minimum) had significant effects on the pollutant concentrations. There was a significant negative correlation of temperature with all the pollutants which indicates that the decrease in temperature increased the pollution level. The reason for this is, during colder month fuel consumption by vehicle engine is high which causes increased emissions. Besides, colder region amounts for various biomass burning activities for heating requirements. In comparison to the other seasons, studies reveal that average particulate matter concentrations

Fig. 20 Annual average concentrations of CO₂ based on time period of sampling during a day

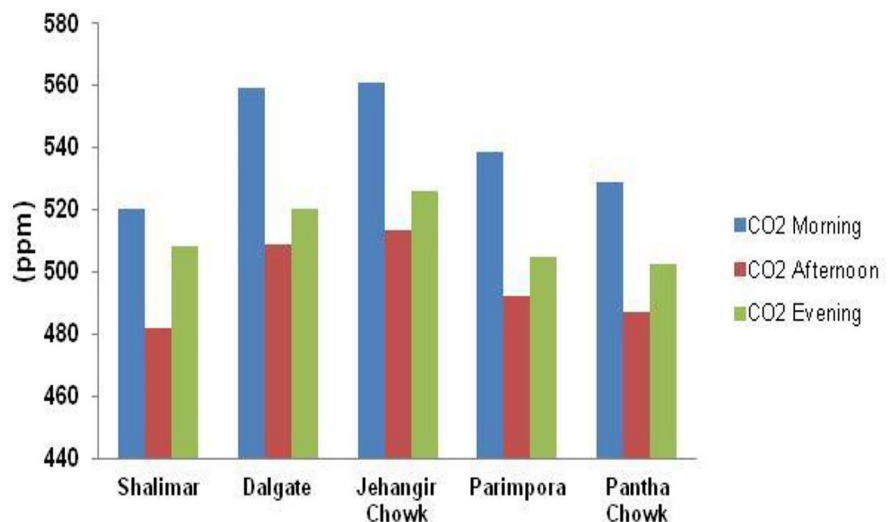


Table 1 Correlation of all the studied pollutants with temperature and rainfall

Weather	Pollutant					
	PM ₁	PM _{2.5}	PM ₄	PM ₁₀	TSP	CO ₂
T _{max}	-0.634**	-0.519**	-0.51**	-0.43**	-0.372**	-0.728**
T _{min}	-0.598**	-0.502**	-0.473**	-0.332**	-0.257**	-0.778**
Rainfall	0.077 ^{NS}	0.021 ^{NS}	0.058 ^{NS}	-0.203**	-0.244**	0.059 ^{NS}

T_{max} maximum temperature, T_{min} minimum temperature

**Significant correlation

^{NS}non-significant correlation

were higher in winter, the season with the lowest ventilation capabilities. This is reinforced by the fact that lower temperatures, high relative humidity, accessible organics produced from automobiles and decreased air mixing height promote particle production (Somuri, 2011). The winter season has foggy weather during most part of the day which provides more surface area for stagnation of particulates in the air. The cloudy weather, low wind speed, high humidity and lower average mixing height of the atmosphere during winter reduce the dispersion and diffusion of pollutants in air (Kulshreshtha et al., 2009). Lower daily temperature would inhibit the photosynthesis rate as well as the carbon cycle of the atmosphere. Therefore, we have the lowest CO₂ levels during hotter periods and the highest during winter (Chen et al., 2006a, b; Sakirko et al., 2008). Recent researches also show that some organic matter releases more CO₂ when exposed to higher air temperature. Besides, extended colder periods in Kashmir induced biomass burning in households which might be a reason for increased CO₂ concentration.

Rainfall had no significant impact on the concentration of pollutants except for small significant negative correlation with PM₁₀ and TSP. This might be due to large size of particles which gets influenced by even smaller rains. During the whole study period, the rainfall was scattered and very low due to which there was only an immediate effect on the concentration of the pollutants. The concentration of pollutants was seen to rise immediately after the rain due to cloudy weather causing low dispersion of particles in air. There is no observable change on CO₂ level when there is small rain with rainfall less than 3 mm (Ying, 2010). The correlation factor is just an indicative of how these parameters show relationship

with the pollutant concentration with their gradual changes, the probable reasons for which have been given above. However, these significant results show that winter season has pronounced effect on the particulate matter concentrations in air.

Conclusion

In light of the study carried out to monitor the ambient air pollutant concentrations, it was seen that the lowest concentrations of particulate matter (PM₁, PM_{2.5}, PM₄, PM₁₀ and TSP) and CO₂ were found in Shalimar campus of SKUAST-K and the highest was found in Jehangir Chowk. However, all the air quality parameters (PM matter) exhibited very low concentration during April 2020 due COVID-19 lockdown. The low pollution load in the Shalimar area was due to lower vehicular number movement in this area. However, the concentration of the pollutants was higher than the prescribed standards of both Central Pollution Control Board (CPCB) and National Ambient Air Quality Standards (NAAQS). The relevance of the study remains on the fact that an easy and quick ambient air quality can be established for the location so that necessary and timely actions can be taken for the mitigation of the pollution in the area. Furthermore, the accuracy of the AEROCET 831 (aerosol mass monitor) and CO₂ analyser makes it easy to carry out the analysis as and when needed. The easy portability and transport of the instruments makes random assessment of the air pollution status less troublesome. Even though the lack of proper vehicular count data due to sensitivity of the location and the COVID protocol restrictions have limited the data in providing the source apportionment of the pollutant load, it does not deprive from the fact that

the major source of pollution in all these locations are basically due to vehicular movement (Kageson, 2005). Large-scale expansion of the study to various other locations can establish a proper ambient air pollutant concentration maps which in future can help different authorities to manage the pollution on the roads due to vehicles and also take into account for proper infrastructure management.

Data availability Data will be made available on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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