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Some observations on the characteristics of aerosols at traffic junctions in Pune city

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Vehicular emissions are one of the potential sources of air pollution, especially in the urban regions. Pune, one of the rapidly growing cities of India, faces a severe threat from this problem. Observations of Total Suspended Particulates (TSP) and Aitken Nuclei (AN) were conducted at four traffic junctions in the city during summer (May 2000) and winter (Jan-Feb 2001). Concentrations of TSP were very high at all the traffic junctions and also the number density of AN was very high. Concentrations of all the measured constituents were more, except NH_4 and Cu, at traffic junctions than those reported at Pashan, a semi-rural location, comparatively away from vehicular effects.

Keywords: Air pollution, Traffic junctions, Vehicular emissions, TSP, Aitken nuclei

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1 Introduction

Due to the rapid rise in rate of urbanization, emissions from mobile sources have become a cause of great concern. With the continuously increasing number of two/three-wheelers, this problem is growing bigger in size everyday. Vehicular emissions have adverse effects on respiratory and immune system of human being and also have potential for carcinogenicity[1]. Not only the occupationally exposed people like traffic policemen, drivers, conductors and near-the-road shopkeepers, but also the common residents and pedestrians in big cities are exposed to high levels of pollutants[2,3]. Aerosols, especially, submicron size particles are one of the major products of vehicular emissions.

The impact of traffic emissions differs from that of industries. Traffic emissions are more harmful as they are released into the atmosphere at low heights and also they do not get sufficient scope to disperse due to surrounding density of high buildings. In Delhi, the annual lead (Pb) levels in the air have been decreased by about 79% at different traffic intersections[4] during 1999 as compared to those in 1995. Also, the levels of CO, SO_2, NO_2 and suspended particulate matter (SPM) have been reduced by about 20, 20, 7 and 6%, respectively in 1998 as compared[4] to those in 1995. These reductions are mainly attributed to the introduction of unleaded petrol and low sulphur diesel, replacement of fuel from petrol/diesel to compressed natural gas (CNG), phasing out of old vehicles, etc. Studies related to air pollution levels at the traffic junctions in India are limited, whereas many such studies have been reported in other countries[5-8].

Pune, being the seventh largest city in India and the second largest in Maharashtra has the dubious distinction of having very high number of two-wheelers in the country. As on 2002, total number of vehicles is about 9.95 lakh, out of which, nearly 7.28 lakh are two-wheelers and every year, about 90,000 vehicles are adding to this figure[9]. About 78% of the total air pollution comes from two-wheelers. There are four national and two state highways running through/around the city. Apart from narrow and poorly managed roads, the bad conditions of many private as well as public transport vehicles aggravate the problem of air pollution.

A study conducted by Patil *et al.*[10] have shown very high levels of toxic trace elements, especially Pb in aerosols at 36 different locations in Pune city. While reporting the results on heat islands in Pune city, Deosthali[11,12] has observed the relation between rising trend of discomfort levels with that of the moisture levels in the urban atmosphere of Pune. This has been attributed to emissions of water vapour by industries and transportation as one of the major factors. More moist areas have been related with more traffic density. Oke[13] has also suggested that the combustion of fossil fuels in vehicular traffic is responsible for the local sources of water vapour and hygroscopic particles less than 0.1 μm radius, i.e. Aitken nuclei (AN).

Even though, some observations regarding gaseous and particulate pollutants have been carried out, so far studies related to the chemical composition of total suspended particulates (TSP) have not been reported for the traffic junctions in the Pune city. In the present study, an attempt is made to fill this gap to some extent. Observations relating to TSP and AN were carried out at four traffic junctions in Pune city during summer (1-5 May 2000) and winter (29 Jan-3 Feb 2001), for a duration of 12 h (0800 AM-0800 PM) at each traffic junction. Though these observations cannot represent the entire season, they can give some idea about the extent of pollutant levels at traffic junctions in the city.

2 Methods of sampling and analysis

TSP samples were collected using a high volume air sampler (Andersen Inc., USA, Model 2200). Two samples, each of about 4 h duration were collected in the morning and afternoon/evening. Whatman-41 filter papers of size 8″ × 10″ were used for the collection of TSP. The average flow rate of air suction was around 1.2 m^3 min^{-1}, after the temperature and pressure corrections. These samples, after gravimetric analysis, were further extracted for water- and acid-soluble components of TSP. Chemical analysis was carried out for various ionic components such as Cl, SO_4, NO_3, NH_4, Na, K, Ca, Mg, Cu, Zn, Mn, Fe, Ni and Al. Details regarding sampling and analysis techniques have been described elsewhere[14]. Hourly observations were carried out for AN using Gardner Counter (Gardner Assoc., Germany). Since their mass is negligible, the concentration of AN is measured in number per cubic centimeter. The Gardner counter measures AN in the concentration range of 2×10^2 cm^{-3} to $1 \times 10^7 cm^{-3}$. Also, at each traffic junction, the total number of vehicles (two, three and four-wheelers, inclusive of road transport buses and heavy-duty trucks, etc.) passing through the junction, during every 30 min interval was counted.

3 Site description

Observations were undertaken at four busy traffic junctions, namely, University Gate (at Chaturshrungi Police Chowky, near Pune University entrance), Simla Office (at Shivajinagar Police Chowky, in front of India Meteorological Department), Swargate (at Nehru Stadium Police Chowky) and Yerwada (at Parnakuti Police Chowky, near Holkar Bridge). Except at Yerwada, the other three sites are surrounded by buildings. Especially, the sites at Swargate and Simla Office are in the close vicinity of commercial and/or government buildings on all four sites. There are four roads converging at these two sites. However, at University Gate, about six roads converge near the sampling site and also, the traffic intensity of two-wheelers is generally high at this site (Table 1). The sampling site at Yerwada is comparatively more open with three roads converging near it and also a river (Mula) flows adjacent to the site on one side. As shown in the map (Fig. 1), sites at University Gate and Simla Office are to the north-west of city center whereas, that at Swargate to the south, and site at Yerwada to the north-east of city center.

Table 1—Traffic density (Average number of vehicles passing per half an hour) at different traffic junctions in the Pune city, India

Location	Traffic Density	
	Summer	Winter
Pune University Gate	1400	3205
Swargate	1176	2088
Simla Office	1786	2708
Yerwada	970	2917

4 Results and discussion

4.1 Aitken nuclei (AN) and total suspended particulates (TSP)

Pollution due to aerosols have an acute effect on human health[15,16]. The concentrations of TSP and AN at the four traffic junctions in both summer as well as winter seasons are shown in Fig. 2. As seen from Fig. 2, among the four traffic junctions, Swargate showed maximum concentration of TSP in both the summer (average 1071 μg m^{-3}) and winter (810 μg m^{-3}) seasons. In fact, concentration was almost double at Swargate than the average concentration (593 μg m^{-3} in summer and 445 μg m^{-3} in winter) at all the four traffic junctions. This could be attributed to the location of the sampling site, where traffic congestion is high due to slow movement of heavy vehicles like state and municipal transport buses and trucks as there is a depot for state transport buses near the sampling site.

Concentrations of TSP are generally in the range of 150-550 μg m^{-3} in the urban regions of India. Whereas, those in West European and North American countries[17] are less than 100 μg m^{-3}. Significantly

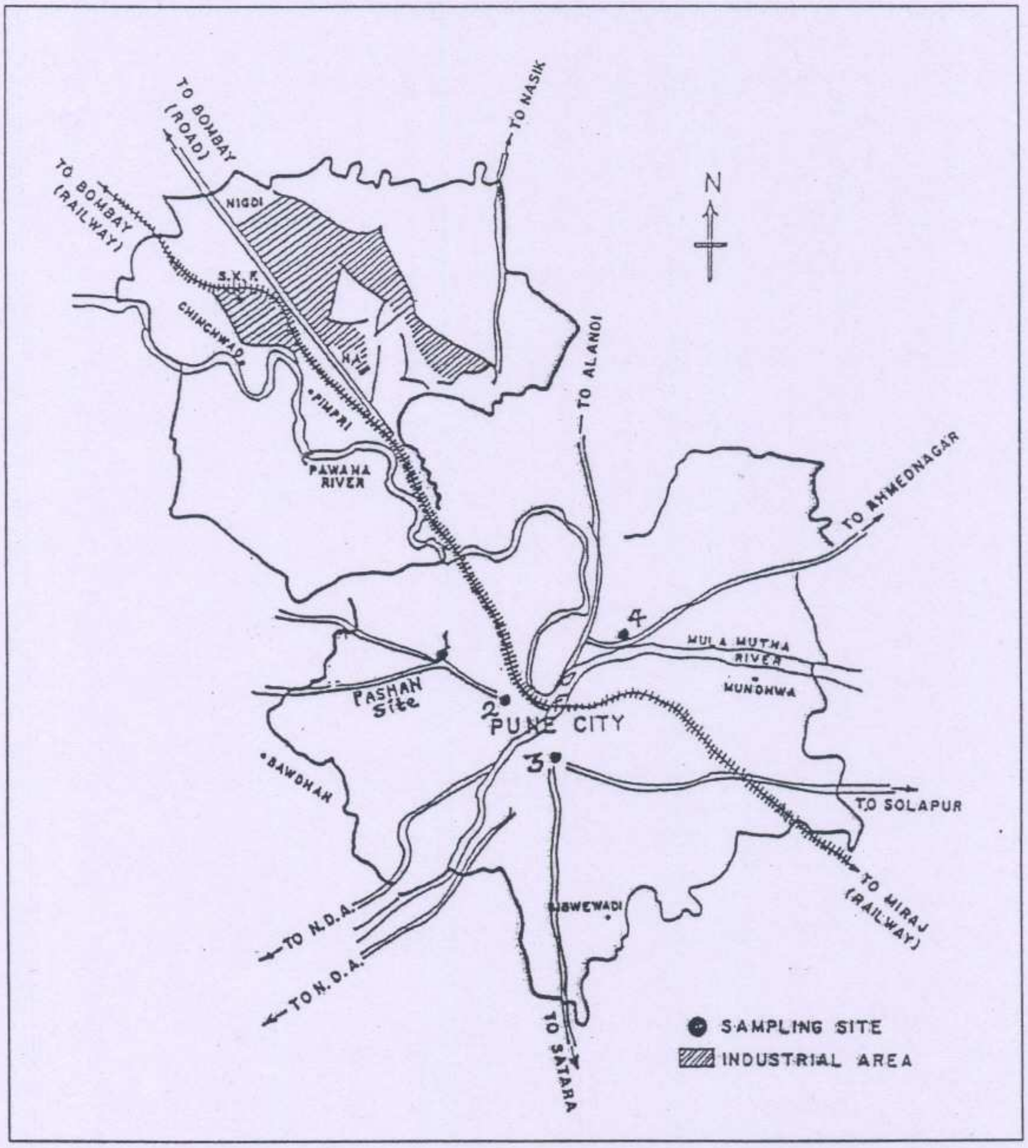

Fig. 1—Locations of sampling sites (1-University Gate, 2- Simla Office, 3- Swargate, 4- Yerwada), at Pune, India

much higher concentrations of TSP are observed near roadways and traffic intersections in cities. Pandey *et al.*[18] have reported a maximum concentration of about 3400 $\mu g\ m^{-3}$ at a commercial-cum-residential center in Lucknow city (Uttar Pradesh), where traffic movement was slow due to encroachments on roads. Krishna Mohan and Muthukrishnan[19] have reported SPM concentrations at a traffic junction in Anna Nagar in Chennai, for 8-10 h duration during daytime. They have reported a maximum concentration of about 1835 $\mu g\ m^{-3}$, which is attributed to the increased volume of traffic. Joshi[20] has reported an average observed value of TSP (2874 $\mu g\ m^{-3}$) and the average equated 24-hourly mean value (703 $\mu g\ m^{-3}$) for 14 locations along the roadside in Indore city (Madhya Pradesh), for the sampling durations, varying from < 1 h to about 4 h. Vinod Kumar and Patil[21] have also observed very high concentrations of SPM at two traffic junctions in Mumbai (Maharashtra). A yearly average value of 1132 $\mu g\ m^{-3}$ and 1015 $\mu g\ m^{-3}$ has been reported at Sakinaka and Gandhinagar traffic junctions, respectively.

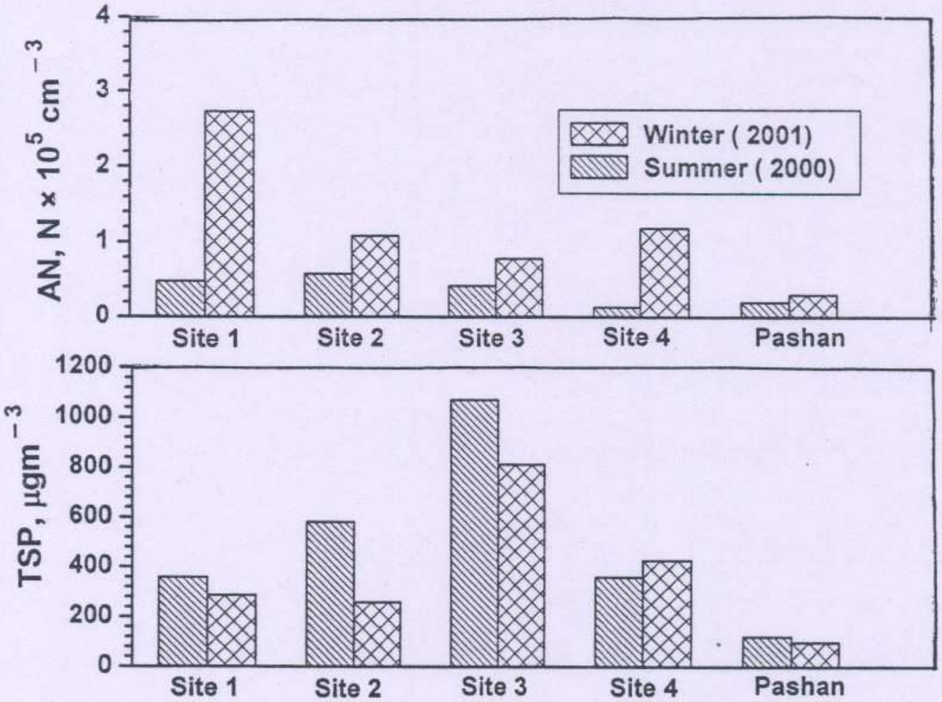

Fig. 2—Concentrations of Aitken nuclei and TSP at different traffic junctions in Pune city compared with those at a semi-urban site, Pashan, Pune, India (Site 1 – Pune University Gate; Site 2 – Simla Office; Site 3 – Swar Gate; Site 4 – Yerawada)

Concentrations of TSP were more in summer than those in winter at all the traffic junctions in Pune city. At Simla Office, they were about 55% more in summer. At University Gate and Swargate they were 20 and 25%, more respectively, in summer than those in winter. Due to more convection and turbulence in summer, the particles get lifted up and also remain suspended for more time. Whereas, in winter, particle load in atmosphere is already less due to the wash-out effect of the preceding monsoon. The concentrations of TSP, though very high at the traffic junctions, are not directly related with the traffic density (Table 1). Traffic density was maximum at the University Gate, where the TSP concentrations were less as compared to those at Swargate and Simla Office. Vinod Kumar and Patil[21] have also observed more SPM concentrations during summer (May) than those during winter (Jan) at traffic junctions in Mumbai, during 8.00 AM to 8.00 PM and have found no relation between SPM and traffic density.

About 65 years back, Sil[22] made some observations of AN at Pune near Simla Office. He has reported an annual average value of 5.84×10^3 cm^{-3} for the period 1935-1937. Afterwards, Mani and Huddar[23] have studied the concentrations of AN at the same location during 1967-1968. They have found about one order increase in the number density of AN (average concentration of 3.49×10^4 cm^{-3}). This increase was attributed to the increase in urbanization, industrialisation and traffic density in the city. Khemani[24] reported the concentrations of AN at this place during 1980-1982, with an average of 2.7×10^4 cm^{-3}. In the present study, an average concentration of 5.8×10^4 cm^{-3} during May 2000 and 10.8×10^4 cm^{-3} during Jan 2001, shows the increasing effect of vehicular emissions on the concentrations of AN.

Unlike TSP, concentrations of AN were more in winter than those in summer. Concentrations of AN were five times more at University Gate site and nine times more at Yerwada, in winter than those in summer. In winter, the prevailing meteorological conditions such as low mixing heights and less ventilation coefficients help in the stagnation of pollutants, especially fine size aerosols. Devara *et al.*[25] have also reported low ventilation coefficients at Pune in winter, which is conducive for more pollution episodes. Similar results have also been reported during winter[22,24]. Significantly good correlation was observed between traffic density and the concentrations of AN at all the four traffic junctions in both summer and

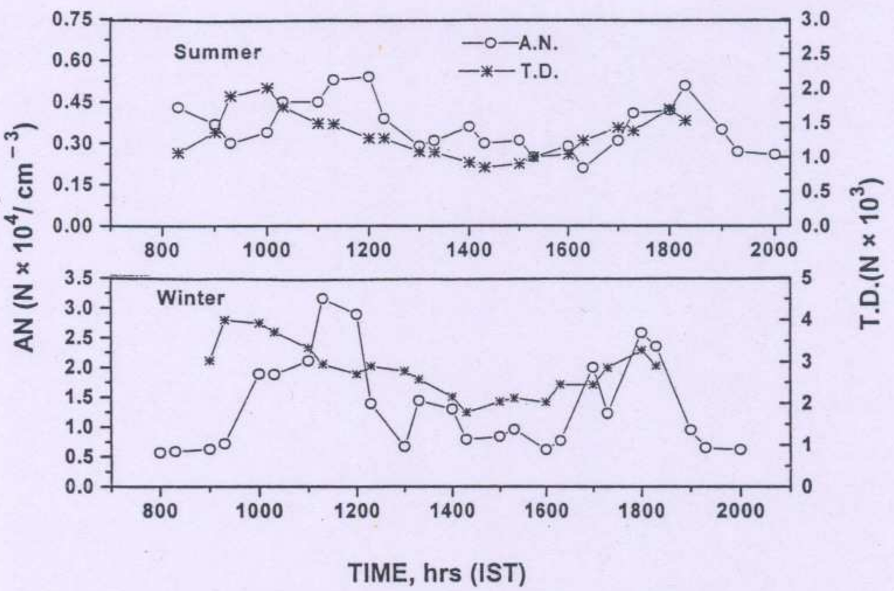

Fig. 3—Variation of Aitken nuclei and traffic density at traffic junctions in Pune city, India.

winter. Raj *et al.*[26] have also reported that the temporal variations in traffic density significantly influence the columnar aerosol optical depth and ozone levels with forenoon and afternoon maxima and noontime minima at Pune. Thus, vehicular emissions are the major source of submicron size aerosols in Pune city. Similar results have been reported elsewhere[27].

Concentrations of TSP and AN in summer and winter seasons have also been shown for a site at Pashan (Fig. 2), about 10 km to the west of the city center. There is comparatively less impact of commercial and industrial activities at this site and also the sampling was carried out at a height of about 12 m above the surface. Even though both TSP and AN showed similar seasonal variations at Pashan, like those at the traffic junctions (more TSP concentrations in summer and more AN concentrations in winter), their magnitudes were far less than those observed at the traffic junctions. Average concentrations of TSP were 122 $\mu g\ m^{-3}$ and 108 $\mu g\ m^{-3}$ in summer and winter, respectively; whereas, concentrations of AN were $19 \times 10^3\ cm^{-3}$ and $21.7 \times 10^3\ cm^{-3}$ in summer and winter respectively, at Pashan site[28,29].

4.2 Variation of AN

Figure 3 shows the variation of average AN concentrations at traffic junctions in the summer and winter seasons along with the variation of average traffic density in the respective seasons. AN variation during 8.00 AM to 8.00 PM period showed two peaks in both the seasons. The first peak was observed just before noon, at about 1130 to 1200 hrs, whereas the second peak was observed at about 1800-1830 hrs in the evening. Both the peaks showed a positive correlation with the peaks of traffic densities. However, there was a time lag of about an hour-and-a-half between the peak of AN and that of traffic density at noon. The traffic density showed first peak at 0930-1000 hrs in the morning. But the evening peaks (at 1800 hrs) for both AN as well as that for traffic density were matching well with each other. As stated earlier, the major source of AN is the gas-to-particle conversion due to photochemical reactions involving certain hydrocarbons, oxides of sulphur and nitrogen, ozone, etc. As the traffic density is high during morning and evening hours, emissions of some of these gases are obviously high during those hours, resulting in the production of AN.

However, the photochemical production of AN does not require only the presence of precursor gases alone, it is temperature dependent also. That is why, in the morning, even though traffic density peaked at 0930-1000 hrs, the concentration of AN continued to increase and was high at 1130-1200 hrs, when the temperature and solar irradiation were favourable for the maximum production of AN. Whereas, in the evening, almost exact co-occurrence of the peaks of AN and traffic density could be linked directly to the vehicular emissions. Even though, the temperatures at

Table 2—Average concentrations of water-soluble constituents of TSP at traffic junctions compared with those reported at Pashan, Pune, India

Season	Location	Concentrations (neq m^{-3})							
		Cl	SO_4	NO_3	NH_4	Na	K	Ca	Mg
Summer	Traffic Junctions	95	144	107	101	66	38	231	38
	Pashan	51	62	47	119	21	11	125	19
Winter	Traffic Junctions	82	146	159	108	34	42	215	38
	Pashan	58	108	78	146	58	21	149	29

Table 3—Average concentrations of acid-soluble constituents of TSP at traffic junctions compared with those reported at Pashan, Pune, India

Season	Location	Concentrations (ng m^{-3})				
		Cu	Zn	Mn	Fe	Al
Summer	Traffic Junctions	60	180	240	8520	11830
	Pashan	230	45	53	3340	2810
Winter	Traffic Junctions	60	260	240	7350	11790
	Pashan	415	76	71	3603	2004

those hours were on decreasing trend, they were sufficient (about 28-32°C during winter and ≥ 33°C in summer) for the production of AN. In fact, the AN production was comparatively faster in the evening hours than that during morning/noon hours, causing no time lag between peaks of AN and traffic density.

The earlier studies during 1980-82, on diurnal variation of AN at Pune have shown a peak in afternoon hours, which had been attributed to the formation of AN due to solar radiation in the presence of certain trace gases[23]. However, the evening peak was not as significant as has been observed in the present study. Thus, the impact of increase in traffic density is directly seen in the prominent peaks of AN in the evening hours. Recently Safai *et al.*[29] have reported diurnal variation of AN at Pashan, Pune in the summer and winter seasons during 1998-99. They have also observed morning/noon and evening peaks, which were attributed to the increased traffic density at the nearby road.

4.3 Chemical composition of TSP

Table 2 shows the concentrations of water-soluble constituents of TSP at traffic junctions (average of five junctions) as compared to those reported at Pashan site[28,30]. It can be seen that the concentrations of seasalt components (Na and Cl) were more in summer than in winter. Na showed about 94% more concentration in summer, whereas Cl showed about 14% more. Concentrations of Ca were also about 7% more in summer. Westerly winds coming from the Arabian Sea might be the reason for more influx of seasalt in summer season. Also, more concentration of Ca in this season can be attributed to its transport from Arabian desert[31]. This also suggests that this source of Ca could be more potential than those situated to the east (in winter, generally easterlies prevail over this region). However, NO_3 showed about 50% more concentrations in winter than in summer. There was not much seasonal variation in the concentrations of SO_4, NH_4, K and Mg. As seen from Table 2, average concentrations of all the ionic constituents were more, except NH_4 at traffic junctions than those reported for Pashan. Especially, K (150%), NO_3 (113%) and SO_4 (71%) showed very high values, followed by those for Ca, Cl and Mg (about 60% more for all) and Na (27%). Only concentrations of NH_4 were about 27% less at traffic junctions than those reported at Pashan, which indicates that the vehicular emissions may not be the major source for NH_4.

Concentrations of acid-soluble constituents of TSP at traffic junctions compared to those reported for Pashan site[28,30] are shown in Table 3. Only the concentrations of Zn were more (about 44%) in winter whereas, the concentration of Fe (16%) was more in summer. No significant change in the concentrations of Cu, Mn and Al was observed in both the seasons. As compared to Pashan, concentrations of all the acid soluble elements were more at traffic junctions, except Cu. Especially, Al (about 400%) and Fe (130%) showed high concentrations, followed by Mn (290%) and Zn (260%). Only the concentrations of Cu were much less at traffic junctions (about 440%) than at Pashan, indicating some strong source of Cu at Pashan site, which could be the emissions from nearby brick kilns.

Thus, the vehicular emissions are the major source for many ionic constituents and elements in aerosols, especially; SO_4, NO_3 and K in water soluble components and Al, Mn and Zn in acid soluble components. Nearly 40% of the total ionic composition was formed by anions (SO_4, NO_3 and Cl) and 60% by cations (Ca, NH_4, Na, K and Mg). Calcium was the major single ion, which contributed $\geq 25\%$ of the total composition. Dominance of Ca in aerosols and precipitation samples, at many locations in western and northern parts of India have been reported by many studies[24,31-33]. Almost all the water and acid soluble components showed more concentrations at Swargate traffic junction, followed by those at Yerwada junction.

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