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The Occurrence and Distribution of Organic Compounds with Atmospheric PMs in Nine Cities of Gujarat, India

Riya H. Shah[1*], Nirmal Kumar J. I[1], Rita N Kumar[2], Dipa Lalwani[1], Nirali Goswami[1]

[1]P.G. Department of Environmental Science and Technology (EST), Institute of Science and Technology for Advanced Studies and Research (ISTAR) –A constituent college of CVM University, Vallabh Vidyanagar- 388 120, Gujarat, India
[2]Department of Biological and Environmental Science, NV Patel College- A constituent college of CVM University, Vallabh Vidyanagar- 388 120, Gujarat, India

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Abstract

Since the last decade, organic contaminants linked to the atmospheric particulate matter have been a major source of worry across the country. The ambient air samples were taken from nine cities using a cascade impactor at four separate stages. SEM and an energy dispersive X-ray system (EDAX) were used in Gujarat, India, to examine the morphology and elemental composition of fine and ultrafine particle sizes using a scanning electron microscope (SEM) and an energy dispersive X-ray system (EDAX). Si, C, O, Cl, F, Na, Zn, Al, K, Ca, Mg, and Ti were found to be quite abundant in the EDAX spectra, with traces of Sc, Ni, and Cu. Transition metal elements such as Ti, Zn, Ni, Cu, S, and Fe were discovered, indicating the influence of industry in the abundance of fine and ultrafine particles. In addition, gas chromatography-mass spectrometry (GC–MS) was used to examine the organic chemical contaminants that had stuck to particle matter. At nine different locations, a total of 308 organic chemicals were discovered, including 242 aliphatic and 66 aromatic chemical compounds. Vapi city was dominated by ultrafine particles. Commercial and urban places such as Ahmedabad, Anand, and Surat had more polycyclic aromatic chemicals than industrial sites.

Keywords: Cascade Air sampler, Heavy metals, Organic Chemicals, Atmospheric Particulate Matter, Major cities

1 Introduction

Air pollution is one of the world's most pressing issues today. It is a substantial contributor to a wide range of diseases, malignancies, and early deaths (Marco et al., 2019). Based on World Health Organization (WHO) statistics for 2014, published estimates of air pollution-related mortality were estimated to be more than 3.7 million per year. Air pollution is the primary cause of global disasters such as global warming and climate change (Perera et al., 2019; Sadatshojaie et al., 2020). A considerable part of such pollution is caused by ongoing urbanisation, rapid economic expansion, and an increasing population according to World Bank Annual Report 2013 which includes Organic, inorganic pollutants with particulate matter aerodynamic size 2.5 µm and less than 10 µm

A significant number of organic pollutants are released from point and non-point sources which are present in the atmosphere. These are the substances that are not commonly monitored but potentially enter into the environment (Geissen et al., 2015). Organic compounds are also known as contaminants of emerging concern (CECs), are the chemical that are released in the atmosphere for which no regulations are currently established (Tang et al., 2019). These pollutants may be mobile and persistent in air at low concentrations (Gavrilescu et al., 2015).

The presence and distribution of chemical compounds around the planet are influenced by the atmosphere. Organic chemical compounds make up a significant portion of air particles, and their identification is crucial. The tracers employed to assess ambient air quality are sources as well as molecular fate (Simoneit, 1984). Due to their aerodynamic diameter, the emissions of these Particulate Matter compounds, notably $PM_{2.5}$ and PM1.0, in the urban and industrial environment are known to represent a primary hazard to human health. These Particulate matter with a diameter of 2.5 m and 1.0 m can enter the body through breathing, causing carcinogenic, mutagenic, and teratogenic effects (Meng et al., 2013; Brown et al., 1996; Kawanaka et al., 2004).

Organic material, which has been produced by significant biogenic and anthropogenic activities such as traffic and industrial emissions, coal biomass burning, and agricultural waste, has occupied a large fraction of the atmospheric particulates, accounting for around 40-60% of fine aerosols and contributing significantly to climate change. Emission of these chemical compounds into the atmosphere exposes a wide population to uncontrolled exposure, particularly in industrial and urban areas where chemicals and humans are in close proximity. The main sources of these chemical compounds are vegetative emissions and incomplete fossil fuel combustion (Wang et al., 2006).

It has been proposed that metallurgical enterprises may release a small number of trace elements into the atmosphere, such as Cr, Mn, Zn, and Cu, and that trace elements such as Fe,

Corresponding author: Riya H. Shah, P.G. Department of Environmental Science and Technology (EST), Institute of Science and Technology for Advanced Studies and Research (ISTAR) –A constituent college of CVM University, Vallabh Vidyanagar- 388 120, Gujarat, India, E-mail: shahriya1015@gmail.com

Cu, and Zn may correlate to vehicle emissions (Séguret et al. 2011). The scanning electron microscope with energy dispersive X-ray (SEM-EDAX) is a powerful analytical tool for morphological and elemental identification, as well as an increased understanding of natural and anthropogenic sources of trace elements (Singh et al., 2014; Galvez et al., 2013). Furthermore, alkanes, alkenes, alkanoic acids, and aromatic hydrocarbon compounds are found in the organic matter of aerosol particles and are employed as the source, transit, and receptor tracers for volatile and organic chemical substances (Omar et al., 2006).

According to the World Health Organization (WHO), India has 13 of the top 20 most polluted cities in terms of fine particulate matter. While the study area of Gujarat has a population of 60.4 million people and is home to the world's largest industrial estate, climate and pollution are strongly linked in this region. The goals of this research are to:

1. Describe the morphological structure and elemental composition of Particulate Matter, and correlate them to their potential sources.
2. To investigate qualitative data on the existence and distribution of organic chemical substances linked with Particulate Matter.
3. Establish a link between the morphological structure of PMs and their elemental composition, as well as the organic chemicals they contain.

2 Experimental methods

Gujrat, India's industrial hub, was the focus of our research. All of the Particulate Matter (PM) samples from the atmosphere were taken using a Cascade impactor at a height of 4 meters above ground level in the winter season from the nine major cities of Bhuj (Kutch), Vadodara, Vapi, Ankleshwar, Rajkot, Ahmedabad, Anand, Surat, and Bhavnagar (Figure 1). The particulate matter samples were run for 24 hours at a flow rate of 20 L/min. The aerosol samples were collected using Glass Fibrous Filters (GFF) with a diameter of 25 mm for the first three stages and a diameter of 47 mm for the fourth. To remove organic contaminants, filters were pre-baked at 100°C for 1 hour before exposure (Ge et al., 2017). Before and after sampling, each filter paper was weighed three times, and the net mass was computed. Each PM filter was individually wrapped in alumina foil and stored in a polypropylene (PP) container. To prevent evaporation of the volatile components, all samples were kept in the refrigerator at 4°C until further examination (Pachauri et al., 2013; Lalwani et al., 2021).

2.1 SEM-EDAX analysis

For SEM-EDAX analysis, a 1/4th filter paper size was utilized to quantify the morphological and elemental composition present. At Sophisticated Instrumentation Centre for Applied Research and Testing – SICART, Vallabh Vidyanagar, Anand, the weight percentage of each element present in the spectrum was determined using a TEAM EDS instrument with a Silicon drift Detector that quantifies the element and performs elemental mapping with a maximum energy resolution of 129Ev. Each site underwent an EDAX examination, with the elements being quantified qualitatively and quantitatively.

2.2 GC-MS analysis: Extraction methodology

The filters were allowed to cool to room temperature before being transferred to 15 mL PP tubes for further investigation. The extraction solvent mixture of Methanol and Dichloromethane (DCM) (1:1) was utilized, with certain changes, as reported in earlier investigations (Giri et al., 2013). For the extraction of the target compounds, 2 mL of solvent was introduced to the PP tube, followed by ultrasonication (Sonicator, USA) at 50% frequency for 15 minutes. The sample tubes were then vortex mixed for 1 minute before being centrifuged for 5 minutes to obtain the supernatant, which was then transferred to new PP tubes, and the operation was performed two more times to obtain a total of 6 mL of extract. The extract was evaporated in a hot water bath for up to 1 mL and kept in the refrigerator until the analysis (He and Balasubramanian, 2009). To determine the presence of organic contaminants, the extracts were analysed using a GC 2010 plus coupled with a Shimadzu Mass Spectrometer at the Central Salt & Marine Chemicals Research Institute in Bhavnagar. With a flow rate of 1 mL/min, a cone voltage of 0.3 kV, and an ion source temperature of 300°C, good quality Helium gas was employed as the carrier. It's worth noting that all of the identified aliphatic and aromatic chemical values were calculated using the chromatogram's peak height percent. For each chemical, chromatograms from Library: NIST17.lib m/z and pubChm were used to identify it. The interference was removed by performing a blank during the organic chemistry analysis.

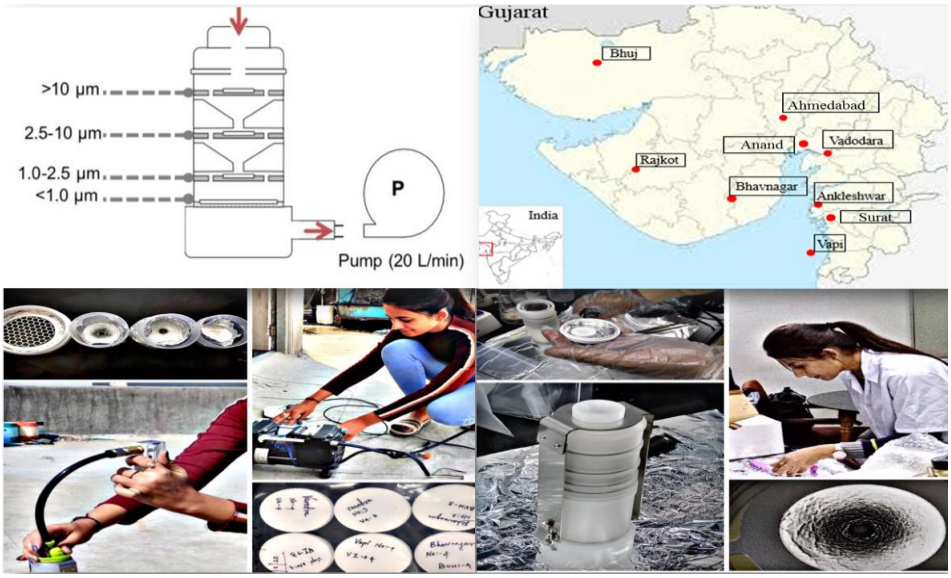


Figure 1*:* Sampling location and methodology

Table 1: Sampling Information

No.	Location	Area type	Sampling Date	Latitude	Longitude	Temp	Humidity
1	Bhuj	GIDC	27-Jan-20	23.2561	69.6969	26°C	53%
2	Vadodara	GIDC	30-Jan-20	22.2519	73.1798	23°C	33%
3	Vapi	GIDC	03-Feb-20	20.3613	72.9265	28°C	37%
4	Rajkot	GIDC	05-Feb-20	22.2847	70.7944	24°C	58%
5	Bhavnagar	GIDC	07-Feb-20	21.7586	72.0958	27°C	58%
6	Ankleshwar	GIDC	01-Feb-20	21.6198	73.0323	28°C	27%
7	Anand	Commercial	02-Feb-19	22.5496	72.9268	24°C	40%
8	Ahmedabad	Commercial	20-Feb-19	22.9983	72.5558	28°C	31%
9	Surat	Residential	08-Jan-19	21.2083	72.7700	26°C	29%

Table 2: Particulate matter mass concentration at the sampling location

No.	Location	PM>10	PM10-2.5	PM 2.5-1	PM<1
1	Bhuj	34.72	138.8	69.44	208.3
2	Vadodara	34.72	208.3	104.1	173.6
3	Vapi	104.1	104.1	138.8	243.0
4	Rajkot	34.72	138.8	69.44	208.3
5	Bhavnagar	34.72	69.44	69.44	321.5
6	Ankleshwar	34.72	69.44	104.1	486.1

*The final and the initial weights of sampling locations Ahmedabad, Anand, and Surat were not determined so the mass concentration is not mentioned.

3 Result and Discussion

3.1 Mass concentration

Mass concentration is the most important criterion for judging air quality. Table.2 shows the greatest PM>10 concentration at Vapi (104.1 g/m3), PM10-2.5 concentration at Vadodara (208.3 g/m3), PM2.5-1 mass at Vapi (138.8 g/m3), and higher PM1 concentration at Ankleshwar (486.1 g/m3). Except at Bhavnagar and Ankleshwar, the daily mass concentration for PM size less than 10 µm or PM10 g/m3 (100g/m3) throughout the measurement period surpassed the 24-hour particle standard at all locations. According to India's National Ambient Air Quality Standard (NAAQS, CPCB 2009), elevated levels of PM less than 2.5m or PM2.5 g/m3 (60g/m3) were recorded. The combined impact of climate processes and anthropogenic outrush from numerous regional sources such as industrial emissions, automotive exhaust, waste incineration, and fossil fuel combustion could explain the elevated amounts of particulate matter at these sampling locations. The cold weather during the winter season encourages ambient particles in the atmosphere to live longer, resulting in a higher concentration of particulate matter.

3.2 Size and Morphology of Various Aerosol Particles

The particles in the study ranged in size from microscopic particles with equivalent diameters of 100nm to coarse particles with equivalent diameters of up to 50 µm. The morphological structures of different groupings of particles differ. The particle morphologies ranged from tubular silica formations to irregular mold of biological particles. It's worth noting that the Carbonaceous group was dominated by different particle morphologies ranging from spherical to patties and subangular to irregular, all of which were dominated by halogens such as chlorine and fluorine. S, k, Fe, and other minor elements were detected in organ silicates and aluminosilicate compounds.

3.3 Major Particle Category

The particles were classified into three categories based on the morphological and elemental composition determined by the SEM-EDAX: Biogenic Aerosols with spherical bacterial spores and organic fragments, Geogenic Aerosols with weathered soil and rock planes, and anthropogenic aerosols resulting from industrial emissions and combustion processes (Table 3).

Biogenic Aerosols: These aerosols are the result of Matthias-Maser and Jaenicke's (1991, 1994) method of determining biological existence. The biological agents contain both dead and alive particles, as well as trace amounts of Na, Mg, K, P, Si, Fe, Cl, Al, and Ca, which are essential plant species markers (Posfai and Buseck, 2010) that distinguish these particles from other particulate matter. This clustering rule was determined using (Coz et al., 2010) (C + O) > 75% and 1% K; Cl 10% are biogenic aerosols. Biogenic particles of a size range of about 10 µm and a spherical spore-like structure were identified at the Vapi site (Figure 2) in the current investigation. These biological particles could comprise the number of living fragments and microorganisms as spores of fungi, bacteria, and viruses. A couple of studies have reported similar particles (Cong *et al.*, 2009; Coz *et al.*, 2010).

Geogenic Particles: Silica/Quartz: SiO_2 particles, commonly known as silica, have a higher content of Si and O (50 percent by weight), and they can come from both natural and manmade sources (Li et al., 2010b). With tubular silica wire, the size of these particles ranged from 100 nm to 10 µm at the Bhuj site, whereas varying shape was seen at Surat, Anand, and Ahmedabad (Figure 3). Silica is a major component of sandstone, clay, gravel, and granite, and it can also come from construction and demolition materials like cement, glass, bricks, and ceramics, as well as the pharmaceutical industry.

Aluminosilicates: According to weight, Alumiono-silicate compounds make up around 72 percent of the earth's crust (Cong et al., 2009). These are mostly formed by geological formations eroding. The dispersion of geological dust results in irregular forms as platty, subangular shapes in aluminosilicates (containing Al, Si, K, Fe, and Ca). Aluminosilicates with significant levels of Al, Si, K, Fe, and Na have been studied in this study, including Fe aluminiuosilicate (Almandine), K-

feldspar (K aluminum silicate), and Na-feldspar (Na aluminum silicate), as well as other mineral dust components (Figure 4) which could be due to crustal emissions, agricultural operations, and fuel-biomass combustion at Bhuj and Vadodara sites, which ranged from 10 µm to 50 µm. Because these particles may quickly spread into the air, they account for the largest amount of world aerosol mass in the atmosphere (Pipal et al 2015).

Anthropogenic emissions: Chlorine Particles: In our current study, we found globular, platy, and irregularly shaped Chlorine particles rich in Si, Na, and S with particle sizes ranging from 5 µm -10 µm (Figure 5) at Bhavnagar and Ankleshwar GIDC locations, indicating the sources of anthropogenic emissions such as coal combustion, salt manufacturing, biomass burning, and stag emissions. In addition, the presence of a considerable amount of Cl could be related to the manufacturing of insecticides and pesticides, whose particles of chloride have also been examined in Delhi aerosols by Shrivastava et al (2009).

Fluorine Particles: At Rajkot, carbon fluoride compounds were observed with variable morphological structure by the increased composition of F and C (≈50% by weight) with a particle size up to 20 µm (Figure 6) It might be originated from the electronic microfabrication process at the site. Carbon Fluoride is a potent greenhouse gas.

Chlorofluoro Particles: The Vapi site was dominated by CFCs, also known as halocarbon compounds, with irregular shapes and F, Cl, and C (50 percent by weight). The presence of these chemicals in aerosols, refrigerants, foam blowing, and solvent cleaners indicates anthropogenic origins. These particles ranged from several nm to 20µm. Long-range transport chemicals are present. (Figure 6).

Table 2: Classification of particle Category used in the data analysis based on selection criteria

Particle Category	Sub Category	Possible Phase/ Minerals	Morphology of particles	Sampling site	Elemental composition of each sub-category (Weight %)
Biogenic Aerosols					
Biological particles	Elevated levels of C and O with minor elements		Variable morphology	Vapi	C (48.63) O (29.79) Cl (6.98) S (4.98) Si (3.06) Na (1.74) Zn (1.22) K (1.07) Al (0.68) Ca (0.63) Fe (0.56) Ti (0.42) Sc (0.13) Mg (0.11)
Geogenic Aerosols					
Silica	$Si-O_2$ With minor Elements	Quartz	Tubular Morphology With Variable Structures	Bhuj	C (21.01) O (44.01) Si (21.4) Na (5.38) Al (2.55) K (2.55) Ti (1.57) Ca (1.48) S (0.82).
				Ahmedabad nr Pirana	O (46.9) C (22.8) Si (28.8) S (0.47) Ca (0.42) K (0.28) Na (0.21).
				Anand	O (40.9) C (34.6) Si (16.9) Ca (1.59) N (1.24) S (1.10) Fe (1.07) Al (1.03) K (0.83) Mg (0.34) Cl (0.30)
				Surat	O (50.6) Si (34.8) C (14.1) S (0.50)
Alumino silicate	K-Al-Si-O with particles of C	K-feldspar	Sub-angular morphology	Vadodara	O (34.59) C (28.64) Si (10.65) k (5.61) Zn (2.90) Fe (2.51) Al (2.24) Ca (2.15) Na (1.13) F (1.78) S (1.26) Ti (1.03) Cl (0.96) Mg (0.36).
	Na-Al-Si-O	Na -feldspar	Platy shaped		O (41.73) Na (10.15) Mg (0.28) Al (3.69) Si (30.61) S (0.13) Cl (0.15) k (3.28) Ca (2.51) Sc (3.15) Ti (2.52) Zn (4.70)
	Fe-Al-Si-O & F particles	Almandine	Irregular morphology	Bhuj	Si (31.4) O (23.85) C (22.47) F (6.91) Al (1.23) Na (1.17) S (0.89) K (0.70) Mg (0.30) Fe (11.09)
Anthropogenic Aerosols					
Industrial emission and Combustion Processes	Chloride particles with particles of C	Chlorosilane	Irregular morphology	Bhavnagar	C (20.95) O (23.05) Si (18.11) Cl (10.14) Zn (4.63) Fe (4.30) Al (4.18) Na (2.94) K (2.44) S (2.13) Mg (1.55) Ti (0.66).
		Sodium chloride	Globular clustered structure		C (21.65) O (20.49) Cl (19.56) Na (13.85) Si (8.82) k (2.81) Ca (2.45) Zn (2.15) Al (2.14) S (1.99) Fe (1.83) Ni (0.66) Mg (0.68) Ti (0.54) Sc (0.2) P (0.09).
		sulphur chloride	Platy shape	Ankleshwar	C (50.23) Cl (20.31) O (13.72) Si (4.28) S (3.94) Zn (1.77) K (1.76) Na (0.97) Fe (0.81) Al (0.75) Ca (0.51) Cu (0.48) Ti (0.47)
	Fluoride particles	carbon fluoride	Variable Morphology	Rajkot	C (33.56) O (15.93) F (41.67) Na (1.15) Al (0.42) Si (1.49) S (1.04) Cl (0.53) K (0.82) Ca (0.50) Ti (0.26) Fe (2.60).
	Chloro-fluoro particles	CFCs	Irregular morphology	Vapi	C (28.13) F (25.79) O (15.56) Cl (9.59) S (4.68) Si (4.37) Fe (2.92) Ca (2.53) Al (2.15) K (1.47) Na (1.41) Mg (0.61) Ti (0.61) Sc (0.18).
	Al-Si-O with Cl-F deposits	Fly ash	Spherical shape	Ankleshwar	C (35.36) Cl (23.21) O (14.62) F (12.59) Ca (2.99) Si (2.86) Al (2.50) S (2.28) Fe (1.14) k (1.09) Cu (0.66) Na (0.62) Mg (0.10).

Al-Si-O with Cl-F depositions: Spherical-shaped fly ash particles were observed at the Ankleshwar site with particle sizes ranging from several nm to 5 µm (Fig 6). Cl and F are deposited in the inorganic form of ash which might be originated from the burning of coal and steam generating plants nearby the site. Previous studies (Pachauri et al., 2013) have also reported similar particles.

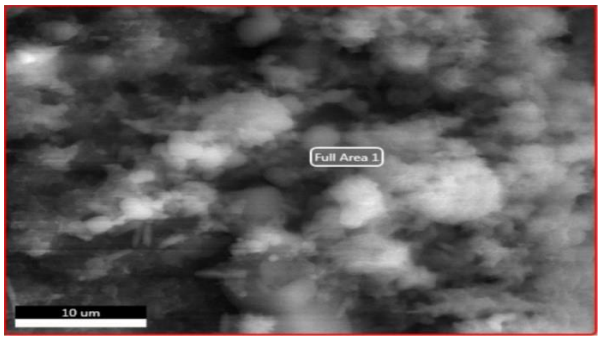


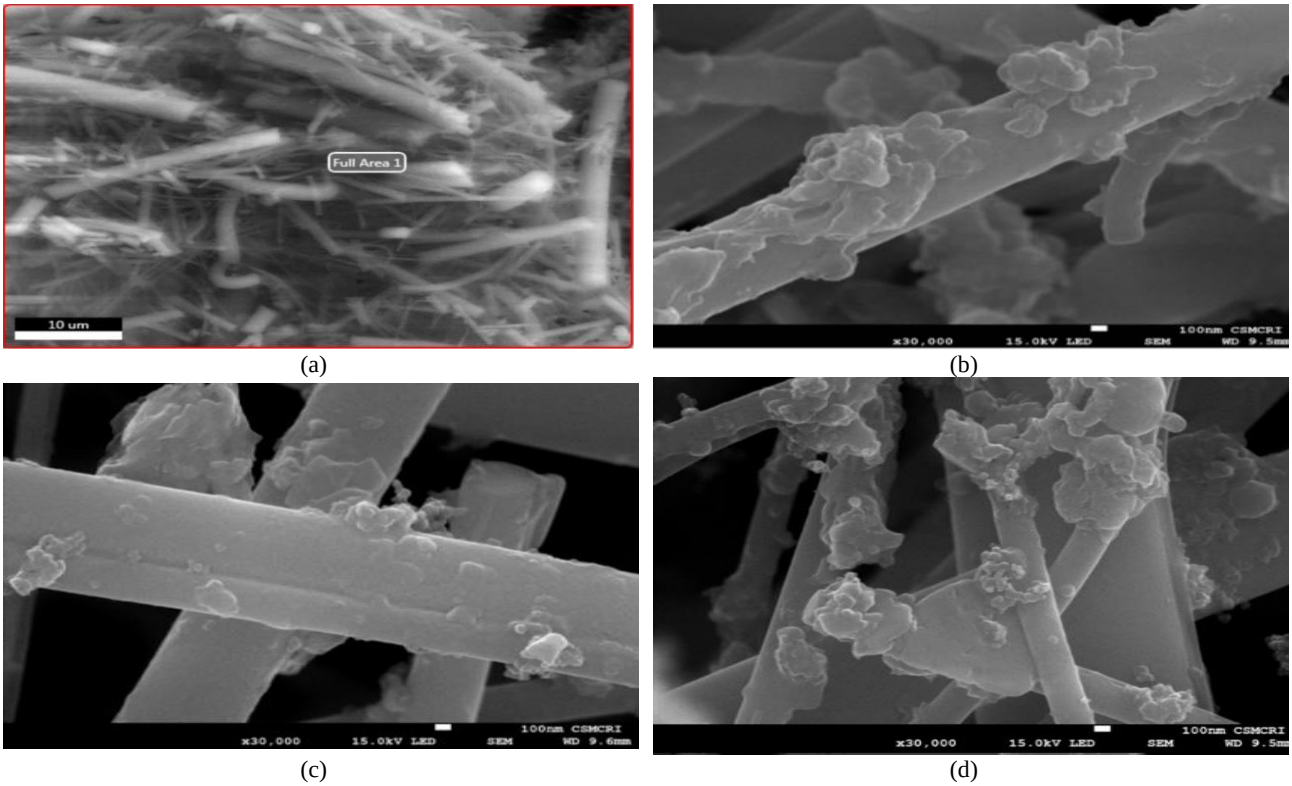
Figure 2: biogenic particles variable morphology and spore-like formation

3.4 Qualitative analysis of Organic chemical compounds

A total of 308 organic chemical compounds were detected in two-particle sizes collected from nine cities in Gujarat, including Bhuj, Ankleshwar, Vadodara, Bhavnagar, Vapi, Rajkot Ahmedabad, Anand, and Surat, of which 242 aliphatic compounds and 66 aromatic compounds were found. Of the 244 aliphatic compounds, 136 alkane compounds and 58 alkanoic acid compounds were found, while the other aliphatic compounds included in Table 2-3 provide a qualitative review of the detected aliphatic and aromatic chemical components related to particulate matter. Because the peak height % of the detected compound was taken into account, the detection of these substances was completely variable and independent of any specific particle size. This should be considered a limitation of the outcome.

3.5 Qualitative analysis of Alkane compounds

Atmospheric alkanes identified in Gujarat's nine cities varied from C6 to C54. Short-chain n-alkanes (Cn C26) are prominent derivatives, with odd-even carbon number dominance at C27–C31. Road crustal emissions are responsible for the increased alkanes. In comparison to other GIDC locations, alkanes are present in larger proportions in Bhuj, Ankleshwar, Vapi, Rajkot, Bhavnagar, and Vadodara. Bhuj and Ankleshwar had the largest concentrations of n-alkane compounds, which could imply a major source of fine particle emission or a difference in chemical character and composition between the two Gujarati cities (Vijay Bhaskar and Mehta, 2010). While alkanes derived from fossil fuels have a lower carbon number and are cantered at C22–C25, they have no carbon preponderance. C5C8, on the other hand, was found in ultrafine particles in Bhuj and was classified as a gasoline-like chemical. Alkanes were shown to be the most abundant in Fine particles in previous studies (Wang et al., 2006). Among alkane compounds Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13, - were predominant at Bhavnagar, Vapi, Vadodra and Rajkot, and Cyclooctasiloxane, hexadecamethyl was predominant at Ankleshwar and Bhuj as shown in table 4 and 5. According to a recent study, incomplete combustion of fossil fuels and petroleum residues, and also wood combustion, ceramic dust might be the important source for n- alkanes in the cold period (Boreddy et al., 2018).



(a) (b)

(c) (d)

Figure. 3: (a) SiO_2 tubular shape- silicon tubes/wires. (b) (c) (d) shows silica particles with variable morphology

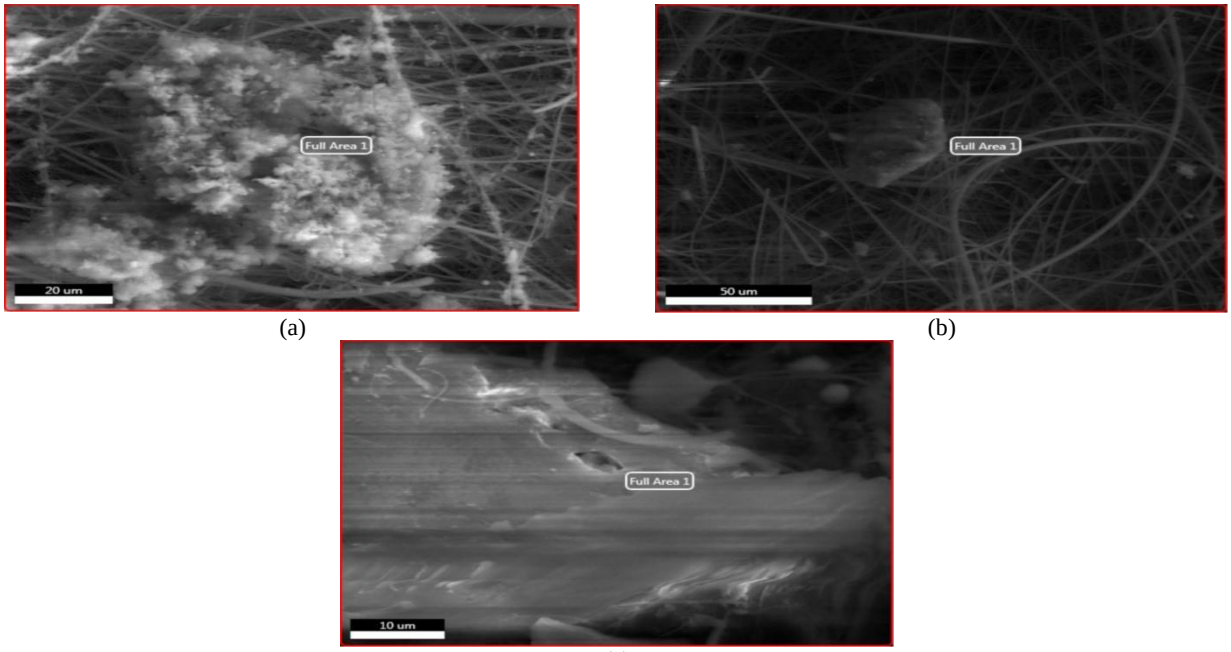


Figure. 4: (a) K-feldspar with subangular morphology (b) Na –feldspar, platy shaped structure (c) Aldamine Fe-Al-Si-O with F particles, irregular morphology

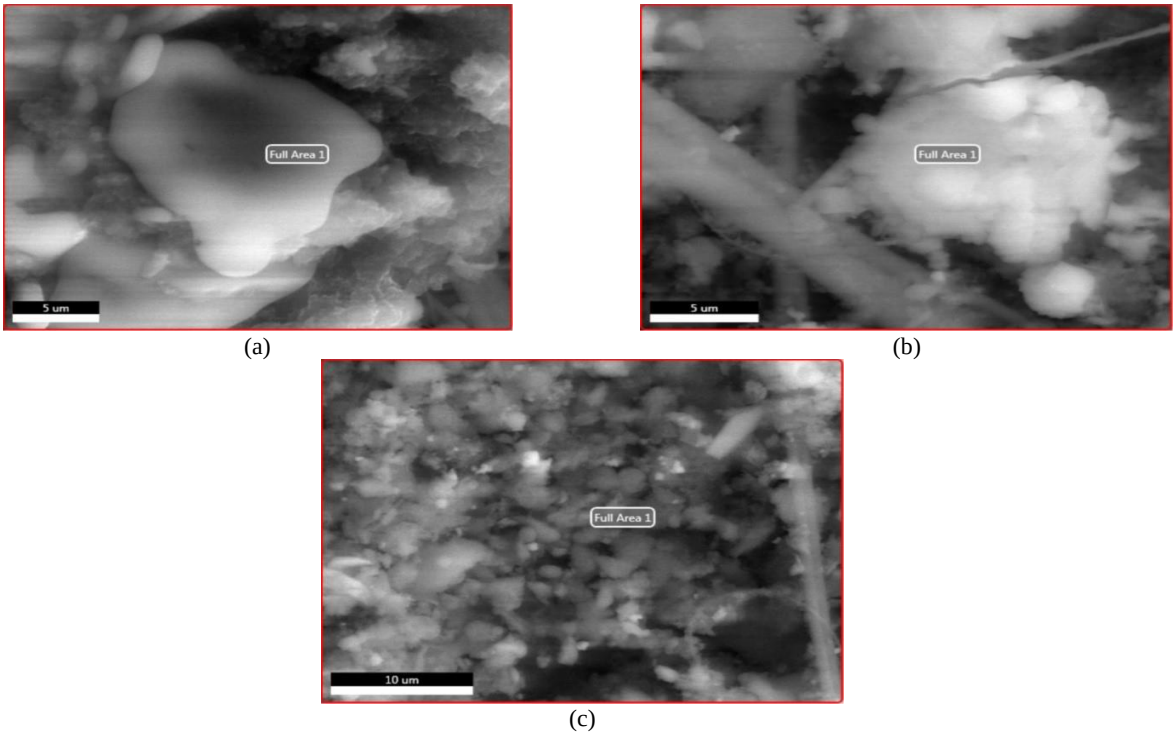


Figure. 5: (a) Sulphur chloride particles with carbonaceous compounds, Platy shaped structure (b) Sodium chloride particles globular clustered structure (c) Chlorosilane irregular shaped particles

3.6 Qualitative analysis of n-alkanoic acid compounds

As indicated in Tables 4 and 5, fine particulate matter detected from 9 cities in Gujarat exhibited dominance with the highest alkanoic acid compounds in Vapi, although significant levels of pentadeconic acid and hexadeconic acid with methyl serate were detected in Surat, Anand, and Ahmedabad. Aliphatic dicarboxylic acids such as pentadeconic acid, hexadecaonic acid, tridecaonic acid, and dodecaonic acid found in particulate matter are important compound classes due to the possibility of their formation by chemical reactions in the atmosphere. In addition, petadecaonic acid and hexadecaonic acid are the major sources of fat in milk. Eicosanoic acids are oxycarboxylic acids (Table 4 and 5) are likely photo-oxidation products from cyclic olefins and unsaturated fatty acids. The most common particulate dicarboxylic acids originating from combustion engines are butenedioic related acids, according to research.

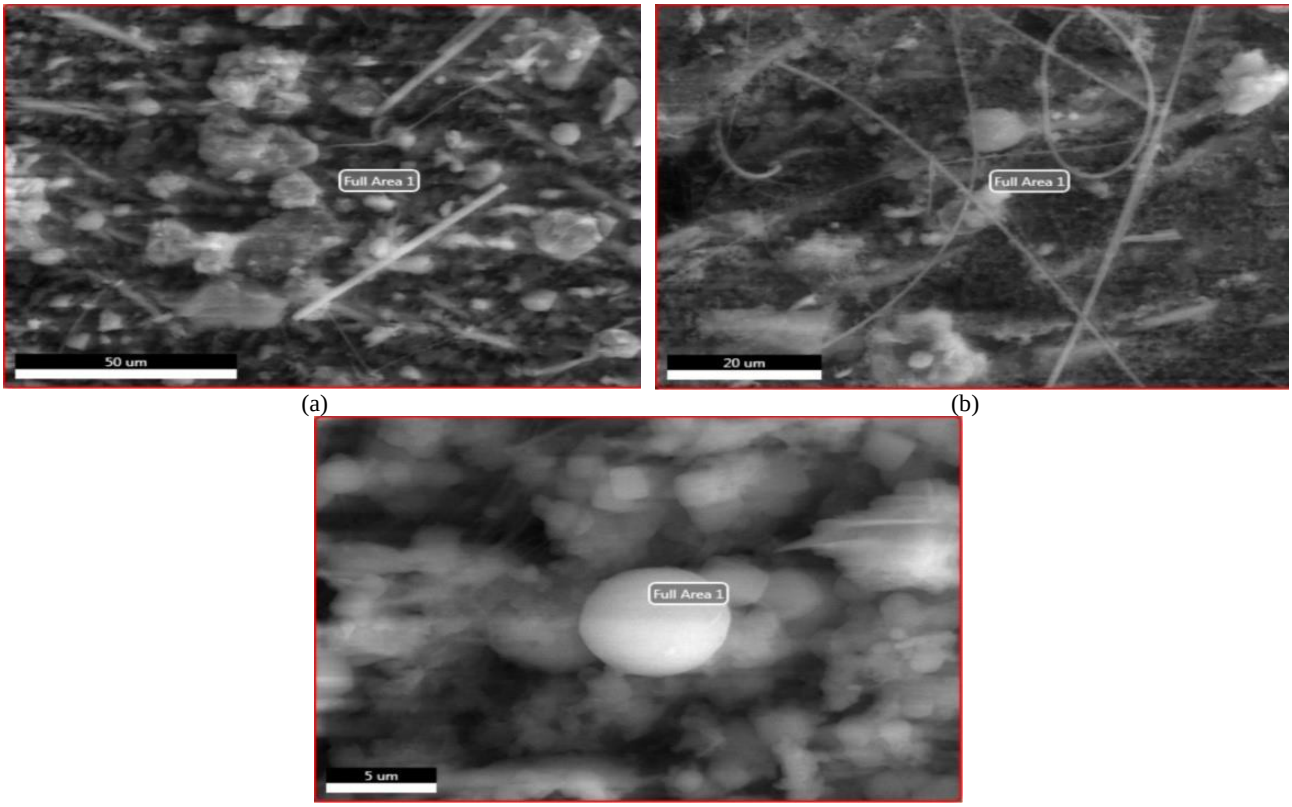


Figure 6: Scanning electron images and energy-dispersive X-ray spectra: (a) chlorofluorocarbons irregular structure (b) Carbon fluoride nearly spherical shaped (c) Fly ash spherical particles with chlorine and fluorine deposition

Pentadecafluorooctanoic acid, dodecyl ester molecules have also been found at the Bhuj site, indicating that PFOA is present in the air as a result of numerous industrial processes such as telomerization.

3.7 Qualitative analysis of Aromatic hydrocarbon compounds

Incomplete combustion of organic materials releases polycyclic aromatic hydrocarbons, with home heating, coal gasification, liquefying plants, coal-tar pitch and asphalt manufacture, and coke aluminium production being the main anthropogenic sources. The concentration of benzene mono and dimethyl benzene is quite low in coal-tar; however, the concentration of naphthalene and pyrene hydrocarbon compounds is very high. Paraben and phthalates are produced during the manufacturing of personal care items, whereas diethyl phthalates tracer's cigarette is also a significant source of PAHs in Table 4. The creostote-derived phenol group-containing hydrocarbons are also formed during burning and benzene degradation in the environment under the effect of UV LIGHT radiation. These aromatic compounds are also employed as an industrial solvent for non-polar chemicals, which are often made from petroleum or coal tar. Naphthalene and fluorene were found in Anand and Ahmedabad, respectively. The only Aromatic chemical found in all cities was 7,9-Di-tert-butyl-1-oxaspiro (4,5) deca-6,9-dien, which could be the product of plastic residue. Because no particular pattern was found, we may conclude that the aromatic chemical detection pattern was unique at all nine sites.

Table 3: shows the indices for the PM 2.5-1.0 fine particulate matter associated organic chemical compounds.

Sr No.	Sampling site	Range (%)	No. of	Dominant compounds from 2.01 onwards	Possible source
1	Bhuj	0.0-2.0	44		
		2.01-4.0	4	Eicosane	Petrochemical compounds
				Cyclononasiloxane, octadecamethyl-	Insecticide / Pesticide
				Heptadecane	Plant oil
				Pentadecane	
		4.01-6.0	-		
		6.0 onwards	-		
2	Ankleshwar	0.0-2.0	46		
		2.01-4.0	2	Tris(2,4-di-tert-butylphenyl) phosphate	Chemical industry
				Dodecane, 1-iodo-	Petrochemical industry
		4.01-6.0	1	Tridecanoic acid, 12-methyl-, methyl ester	Plant oil
		6.0 onwards	-		
3		0.0-2.0	14		

Sr No.	Sampling site	Range (%)	No. of	Dominant compounds from 2.01 onwards	Possible source
	Rajkot	2.01-4.0	3	Tridecanoic acid, methyl ester	Plant oil
				Tridecane, 1-iodo-	Biogenic emission
				Heptacosane	Food processing industry
		4.01-6.0	2	Tris(2,4-di-tert-butylphenyl) phosphate	Automotive industry
				Triacontanoic acid, methyl ester	Atmospheric reaction
		6.0 onwards	1	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,	Preceramic polymer
4	Vadodara	0.0-2.0	5		
		2.01-4.0	5	2,6-Di-tert-butyl-4-methylphenol, O-	Automotive industry
				Hexane, 2,2,3,3-tetramethyl-	Chemical industry
				Eicosane	Petrochemical industry
				Triacontanoic acid, methyl ester	Atmospheric reaction
				Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,	Ceramic dusts
		4.01-6.0	1	2-methyloctacosane	Tobacco smoke
		6.0 onwards	-		
5	Vapi	0.0-2.0	8		
		2.01-4.0	4	Eicosanoic acid, methyl ester	Oil refining
				Tridecane, 1-iodo-	Biogenic emission
				Eicosane, 1-iodo-	Petrochemical compounds
				Aluminum, triethyl-	Plastic industry
		4.01-6.0	1	Triacontanoic acid, methyl ester	Atmospheric reaction
		6.0 onwards	2	Trisiloxane, 1,1,1,5,5,5-hexamethyl-3	Pharmaceutical industry
				Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,	Ceramic polymers
6	Bhavnagar	0.0-2.0	22		
		2.01-4.0	5	Pentadecane	Plant oil
				Octasiloxane,1,1,3,3,5,5,7,7,9,9,11,11,13,13,	
				Hexadecyl isopropyl ether	Chemical industry
				Tridecane, 1-iodo-	Biogenic emission
				Tetracosane	Crustal emission
		4.01-6.0	-		
		6.0 onwards	-		
7	Ahmedabad	0.0-2.0	38		
		2.01-4.0	1	Benzene, 1,3-bis(1,1-dimethylethyl)-	Petrochemical compounds
		4.01-6.0	1	Benzaldehyde, 2-methyl-	Automobile exhaust
		6.0 onwards	3	Benzene, 1-(dimethoxymethyl)-4-methyl	Biogenic emission
				Hexadecanoic acid, methyl ester	Biogenic emission
				Methyl stearate	Textile/ rubber industry
8	Anand	0.0-2.0	35		
		2.01-4.0	5	Benzaldehyde, 2-methyl-	Automobile exhaust
				Benzene, 1,3-bis(1,1-dimethylethyl)-	Petrochemicals compounds
				1,2-Benzenedicarboxylic acid	Cloth dyeing
				Dibutyl phthalate	Plastic industry
				Methyl tetradecanoate	Biogenic emissions
		4.01-6.0	-		
		6.0 onwards	3	Pentadecanoic acid, 14-methyl	Cow's milk
				Methyl stearate	Textile/ rubber industry
				Benzene, 1-(dimethoxymethyl)	Biogenic emission
9	Surat	0.0-2.0	39		
		2.01-4.0	1	Benzene, 1,3-bis(1,1-dimethylethyl)	Biogenic emissions
		4.01-6.0	2	Benzene, 1-(dimethoxymethyl)	Automobile exhust
				Benzaldehyde, 2-methyl-	
		6.0 onwards	2	Methyl stearate	Textile/rubber industry
				Pentadecanoic acid, 14-methyl	Cow's milk

Table 5: shows the scale for the PM <1.0 ultrafine particulate matter associated organic chemical compounds established

Sr. No.	Sampling site	Range (%)	NO. of compound	Dominant compounds from 2.0	Possible Source
1	Bhuj	0.0-0.5	15	Tridecanoic acid, 4,8,12-trimethyl-	Atmospheric reactions
		0.51-1.0	17	Dodecane, 4,6-dimethyl-	
		1.01-2.0	10	2,6-Di-tert-butyl-4-methylphenol, O-trifluoroa	Biogenic emission
		2.0 onwards	5	Heneicosane	Food oil refinery
				Heptadecane	Plant oil
2	Ankleshwar	0.0-0.5	7	1-Docosene	Detergent
		0.51-1.0	10	Eicosane, 1-iodo-	Petrochemical compounds
		1.01-2.0	9	7,9-Di-tert-butyl-1-oxaspiro (4,5) deca-6,9-dien	Petrochm/plastic
		2.0 onwards	7	4-Methyl-2,4-bis(p-hydroxyphenyl) pent-1-ene	cosmetic agents
				Tris(2,4-di-tert-butylphenyl) phosphate	Chemical industry
				Eicosane	Petrochemical
				2,3-Dihydroxypropyl icosanoate, 2TMS deriv	Pharmaceutical
3	Rajkot	0.0-0.5	6	Sulfurous acid, 2-ethylhexyl isohexyl ester	Disinfactant
		0.51-1.0	8	Stearic acid hydrazide	Detergents
		1.01-2.0	10	Eicosane, 2-methyl-	Petrochemical
		2.0 onwards	9	Tridecane, 1-iodo-	Biogenic emission
				Pentadecane	Food products
				Tris(2,4-di-tert-butylphenyl) phosphate	Chemical industry
				Octadecane	Plant oil
				Heptadecane	Food products
				Octadecane, 6-methyl-	Chemical industry
4	Vadodara	0.0-0.5	10	Octadecane, 2-methyl-	Plant oil
		0.51-1.0	13	Undecane, 3,8-dimethyl-	Chemical industry
		1.01-2.0	5	Tridecanoic acid, 12-methyl ester	Atmospheric
		2.0 onwards	6	Triacontanoic acid, methyl ester	Plant oil
				Undecane	Chemical industry
				Bicyclo[2.2.0]hex-2-ene-1-carboxylic acid	Engine combustion
5	Vapi	0.0-0.5	36	Tetrapentacontane	Diesel oil
		0.51-1.0	20	Eicosane	Petrochemical
		1.01-2.0	14	n-Hexadecanoic acid	Plant oil
		2.0 onwards	10	Tetradecanoic acid	Atmospheric reaction
				7,9-Di-tert-butyl-1-oxaspiro (4,5) deca-6,9-dien	Petrochm/plastic
				Heptadecane	Fuel oil
				1,3,5-Trisilacyclohexane	Pre ceramic comounds
				Cyclononasiloxane, octadecamethyl-	Petrochm/plastic
				Tetracosamethyl-cyclododecasiloxane	Fuel oil
				2,4-Di-tert-butylphenol	Chemical industry
6	Bhavnagar	0.0-0.5	3	2,3-Dihydroxypropyl icosanoate, 2TMS	Pharmaceutical industry
		0.51-1.0	13	Heptasiloxane, hexadecamethyl-	Pre ceramic components

Sr. No.	Sampling site	Range (%)	NO. of compound	Dominant compounds from 2.0	Possible Source
		1.01-2.0	9	Tridecanoic acid, 12-methyl-, methyl ester	Atmospheric reaction
		2.0 onwards	5	Eicosane, 7-hexyl-	Petrochemical industry
				Triacontanoic acid, methyl ester	Atmospheric reaction
7	Ahmedabad	0.0-0.5	20	Ethanone, 2,2-dimethoxy-1,2-diphenyl	Pharmaceutical industry
		0.51-1.0	9	Benzaldehyde, 2-methyl-	Automobile exhaust
		1.01-2.0	5	Benzene, 1-(dimethoxymethyl)-4-meth	
		2.0 onwards	4	Methyl stearate	Textile/rubber industry
8	Anand	0.0-0.5	25	Benzene, 1,3-bis(1,1-dimethylethyl)-	Petrochemical compounds
		0.51-1.0	11	Benzaldehyde, 2-methyl-	Automobile exhaust
		1.01-2.0	4	Benzene, 1-(dimethoxymethyl)	
		2.0 onwards	5	Methyl stearate	Textile/rubber industry
				Pentadecanoic acid, 14-methyl-, methy	Cow's milk
9	Surat	0.0-0.5	27	Benzene, 1,3-bis(1,1-dimethylethyl)-	Petrochemical compounds
		0.51-1.0	7	Bis(2-ethylhexyl) phthalate	Cosmetics
		1.01-2.0	4	Benzene, 1-(dimethoxymethyl)-4-meth	Automobile exhaust
		2.0 onwards	6	Benzaldehyde, 2-methyl-	Petrochemical compounds
				Methyl stearate	Textile/rubber industry
				Eicosanoic acid, methyl ester	Food Products

3.8 Distribution of organic chemical compounds

Organic compounds were found at various locations and in various particle sizes. The alkane compounds were found in descending order with decreasing particle size in Bhuj, Ankleshwar, Ahmedabad, and Anand and Surat, and were dominating in fine particles. Similar findings were previously reported (Wang et al., 2006), with n-alkanoic acid being dominating in ultrafine particles except in Anand and very dominant in Vapi. Surprisingly, aromatic hydrocarbons are discovered to be more prevalent in commercial places such as Surat, Anand, and Ahmedabad than in GIDC areas, although these aromatic compounds were detected in increasing order as particle size decreased, as shown in Figure7.

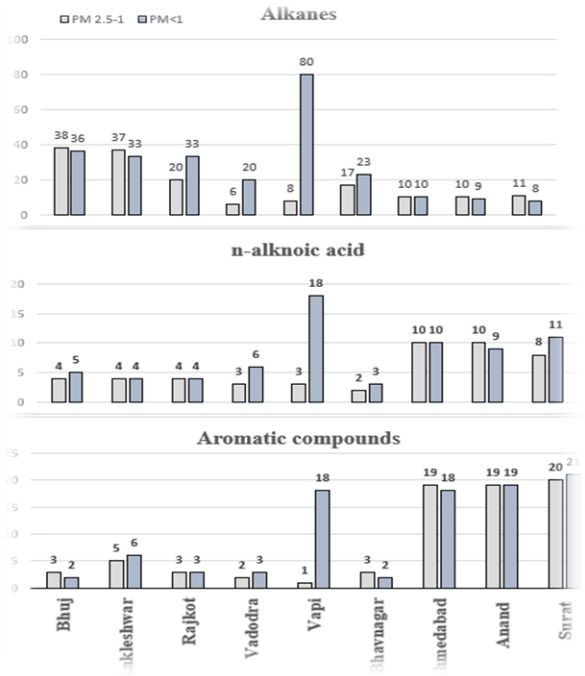


Figure 7: shows the No. of organic compounds at different locations

4 Conclusion

The SEM-EDX device was used to analyze the elemental and morphological content of air particles. The aerosol particles were divided into three categories: biogenic, geogenic, and anthropogenic. The findings demonstrate that these airborne particles were both natural and anthropogenic in origin, with anthropogenic emissions accounting for the majority of the particles. The aluminosilicate particle group was a significant producer of minerlogenic particles. It was discovered particles with equivalent diameters ranging from 100nm to 50µm. The organic chemical analysis was carried out using a GC-MS equipment, and the results were categorised using an indices scale depending on the results.

The organic chemical analysis was done using GC-MS instrument and were grouped by indices scale based on the peak height of the fine and ultrafine particulates and total of 308 compounds were detected and different distribution patterns were observed whereas carbonaceous elements in the particles indicate biomass burning emissions during winter season. This study provides vital information about occurrence and distribution of the ambient air organic pollutants in Nine cities of Gujarat, where methyl serate was found to be dominant at Ahmedabad, Anand, and surat with Hexadecnoic acid, Pentadecanoic acid and eicosane acids whereas Vapi was domineering with Trisiloxane, and 2,4-Di-tert-butylphenol, Pentadecane, and trioctonic acid were dominant at Bhavnagar site, while of 2-methyloctacosane high peak was observed at vadodra with oxasilioxane compounds which were also found to be dominant at Rajkot with hexadecane, also found dominant at Bhuj site, the elevated peak of 2,3-Dihydroxypropyl icosanoate was observed at Ankleshwar which demands further detail study on spatial, temporal variations and its impact on health issues.

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Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language. Also, all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All procedures performed in this study involving animals were following the ethical standards of the institution or practice at which the studies were conducted.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses, and manuscript writing.

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