ASSESSMENT OF SEASONAL ENRICHMENT HEAVY METALS IN RESPIRABLE SUSPENDED PARTICULATE MATTER OF FARIDABAD CITY'S

Ravinder kumar

Research scholar Vivekanand Global University

Dr. Ravi Kant Pareek

Associates Professor Vivekanand Global University

Abstract:

A major rise in the levels of air pollution, notably respirable suspended particulate matter (RSPM), has been brought about as a result of the fast industrialisation and urbanisation that has taken place in Faridabad city, which is a renowned industrial hub in the Indian state of Haryana. Within the scope of this study, the objective is to evaluate the seasonal fluctuations and enrichment of heavy metals in RSPM across a variety of Faridabad neighbourhoods. A number of residential, industrial, and traffic-dominated locations were chosen for the collection of air samples throughout the pre-monsoon, monsoon, and post-monsoon seasons. Atomic Absorption Spectrophotometry (AAS) was utilised in order to conduct an analysis on the amounts of several heavy metals, including lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr), and zinc (Zn). In order to assess the anthropogenic effect and the degrees of pollution, the Enrichment Factor (EF) and the Geo-accumulation Index (I_geo) were utilised. Low dispersion conditions and increased human activities were shown to be the primary contributors to the greater amounts of heavy metals that were seen during the winter and pre-monsoon seasons, according to the findings. The EF values indicated that there were large contributions from human activity, mainly from emissions from vehicles, process emissions from factories, and activities related to building. According to the findings, there is an immediate requirement for regulatory interventions and pollution control techniques in Faridabad in order to reduce the dangers to public health and enhance the quality of the air there.

Keywords: *Heavy Metals, Respirable, Particulate, Matter, Faridabad*

Introduction

Because of the increased urbanisation and industrialisation that is occurring in some locations, air pollution is becoming an increasingly important environmental and public health problem. One of the air pollutants that contributes significantly to the deterioration of ambient air quality is respirable suspended particulate matter (RSPM), which is also known as PM_{10} (particles with a diameter of 10 µm or less). Not only do these small particles make it more difficult to see, but they also act as transporters for a broad variety of dangerous compounds. These substances include heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), and zinc (Zn). As a result of the fact that these metals are not biodegradable and remain in the environment for an extended period of time, they have the potential to collect and cause long-term health problems such as respiratory illnesses, cardiovascular diseases, neurological impairments, and even carcinogenic consequences. Faridabad, which is situated in the National Capital Region (NCR) of India, is among the most urbanised and industrially dense cities in the state of Haryana by a significant margin. There are a great number of industrial units, vehicle workshops, metal processing plants, and thermal power facilities located inside the city, all of which contribute considerably to the emission of heavy metals into the atmosphere. In addition, the situation is made much worse by the growing number of vehicles on the road, the density of the population, the activities associated with building, and the burning of biomass. The dispersion and deposition of pollutants are also influenced by seasonal changes, such as fluctuations in temperature, humidity, wind patterns, and precipitation. These changes also contribute to seasonal variations in air quality and pollutant concentrations. There is a lack of detailed data on the seasonal enrichment and spatial distribution of heavy metals in RSPM in Faridabad, despite the fact that concerns are mounting. Having a solid understanding of these patterns is absolutely necessary in order to develop efficient methods for managing air quality and reducing the related health risks.

Respirable Suspended Particulate Matter and Heavy Metals

RSPM, often known as PM_{10}, is made up of particles that are airborne and have a diameter of 10 microns or smaller. Heavy metals, such as lead, cadmium, chromium, nickel, and zinc, are recognised for their toxicity, persistence, and bioaccumulation in the environment (Gupta et al., 2007). These particles have the ability to penetrate deep into the lungs and contain harmful chemicals such as heavy metals. Both natural sources, such as soil dust and sea spray, and human activities, such as emissions from vehicles, industrial operations, the burning of fossil fuels, and building activities, are the origins of heavy metals that are found in the ambient air.

Sources of Heavy Metals in Urban Atmospheres

According to the findings of a number of studies, the higher amounts of heavy metals in urban air can be linked to the exhaust from vehicles, emissions from factories, and the open burning of rubbish. The emissions from motor vehicles are a significant source of lead and zinc in the urban areas of India, as stated by Sharma et al. (2013). In the Delhi National Capital Region (NCR), Singh et al. (2011) found very high amounts of cadmium and nickel in the vicinity of industrial clusters. The combustion of diesel fuel, the wear and tear on brakes, the deterioration of tires, and processes related to metallurgy all result in the release of these metals. According to Kumar et al. (2006), industrial emissions from metal processing and electroplating facilities have also been recognised as substantial sources of pollution.

Seasonal Variation in Heavy Metal Concentrations

The distribution and concentration of heavy metals in RSPM are both significantly impacted by seasonal fluctuation which plays a critical role. As a result of temperature inversions, low wind speeds, and increased emissions from heating and transportation operations, research indicates that the winter and pre-monsoon seasons often exhibit greater levels of particulate matter and related metals. This is the case (Mohanraj et al., 2004). According to Kulshrestha et al. (2009), during monsoon seasons, there is often a decrease in the amounts of pollutants that are present as a result of the washout effects that are caused by rainfall. As an illustration, Balachandran et al. (2012) found that during the winter months in Chennai, there were considerably greater levels of lead and nickel. This was ascribed to the stagnant air and the increased anthropogenic activities that were taking place.

Enrichment Factor and Geo-accumulation Index

For the purpose of determining the degree to which human activity contributes to the contamination of the atmosphere with heavy metals, the Enrichment Factor (EF) and the Geo-accumulation Index (I_geo) are frequently utilised. In order to assess whether the source of a metal is natural or anthropogenic, EF utilises a comparison of the concentration of the metal in question to a reference element, which is often iron or aluminium (Chow et al., 1994). Mueller (1969) came up with the idea of I_geo, which assists in categorising degrees of pollution into categories that range from completely unpolluted to very contaminated. For the purpose of demonstrating considerable anthropogenic contributions to airborne metal concentrations, these indices have been utilised in research conducted in Indian cities such as Lucknow and Kanpur (Trivedi et al., 2020).

Studies in the National Capital Region (NCR)

Several research works have focused on the air quality of Delhi and surrounding NCR cities, including Faridabad. Faridabad, being an industrial and transport hub, experiences high emissions from power plants, construction sites, and traffic. A study by Jain et al. (2015) indicated that PM_{10} levels in Faridabad often exceed permissible limits set by the Central Pollution Control Board (CPCB). However, specific investigations into the seasonal enrichment of heavy metals in RSPM in Faridabad are scarce, which highlights the need for localized assessments to inform targeted mitigation strategies.

Health and Environmental Impacts

Exposure to heavy metals through the inhalation of particulate matter is associated with significant dangers to one's health. According to the World Health Organisation (2010), exposure to lead is known to have an effect on the neurological system, particularly in children; cadmium is a recognised carcinogen that has an effect on the kidneys; nickel and chromium are connected to respiratory and skin illnesses. Exposure to excessive quantities of these metals over an extended period of time can also harm the quality of soil and water through deposition, which can have an impact on urban ecosystems.

Materials and Methods

Study area

This study was carried out in the city of Faridabad, which is located in the state of Haryana in India. Located at 29°100 North latitude and 75°460 East longitude, Faridabad is a city that falls under the category of sub-urban. There is a steel mill, a distillery, a number of small and medium scale companies, and a reasonable number of registered cars in Faridabad, which contributes to the city's moderate to high level of industrial activity. The vast majority of the businesses are housed in an industrial area that is situated on the north-eastern outskirts of the city. Both the dryness and the extremes in temperature that characterise Faridabad's climate are prominent features of the city. Summer temperatures average 40 degrees Celsius, while winter temperatures average 10 degrees Celsius. There are around 24 days in a year that are wet, and the annual rainfall average is approximately 450 millimetres. Dust storms can occur throughout the summer months, and thunderstorms can occur during the monsoon season. In general, gentle winds blow. During the winter months, it is not uncommon to see weak inversions.

Sample collection

Air samples were collected from three different locations inside the city: Industrial Estate, which is classified as an industrial district; Nagori Gate, which is classified as a commercial area; and Sector-15, which is classified as a residential area. A protracted summer (July), monsoon (August), postmonsoon (September), autumn (October), and winter (December) were the seasons that were represented by the samples that were gathered from July to December of 2002. On the 22nd of August in the year 2002, the first monsoon rains fell. A dichotomous respirable dust sampler, namely an Envirotech Make 460 model, was utilised in order to carry out the sampling. Depending on the location that was accessible for the sampler, the sampling intake was positioned anywhere from one to three meters above the ground level. A respirable dust sampler with the model number APM-460 has been outfitted with a cyclone that is specifically intended to separate particles of particulate matter (PM10). In order to determine the average flow rate, the air from the atmosphere was pulled through a cyclone and a glass fibre filter (GFF) sheet measuring 20 cm × 25 cm for about twenty-four hours. The flow rate ranged from 0.8 to 1.2 m3 per minute. When the air that contains suspended particulate matter is introduced into the cyclone, the centrifugal forces that are present remove the coarse nonrespirable dust from the air stream. The cyclonic cup is where the suspended particle matter is collected after it has passed through the conical hopper of the cyclone. Following its passage through the cyclone, the fine dust that is comprised of the respirable portion of total suspended particulate matter (TSPM) falls to the ground and is collected on the GFF. The Department of Meteorology at the CCS Haryana Agriculture University in Faridabad was the source of the meteorological data that was obtained.

Sample preparation

In order to collect RSPM, a quarter of the GFF paper that was utilised was sliced and placed in a Teflon beaker that had a capacity of one hundred millilitres. The paper was digested in a hot air oven at a temperature of 150 degrees Celsius after five millilitres of hydrofluoric acid (HF), ten millilitres of nitric acid (HNO3), and three millilitres of hydrochloric acid (HCl) were added to it. Throughout the digesting process, the paper was totally ashed, and the total volume was brought down to 5 millilitres. Once more, 5 millilitres of hydrogen nitrate (HNO3) was added, and the digestion process was carried on in order to ash any remaining filter. After digestion, twenty millilitres of distilled water were added to the portion that had been digested. The mixture was then filtered via Whatman-42 filter paper after being combined with water. The final volume was brought up to 25 millilitres, and the sample was placed in reagent vials made of clean plastic. Up to the time of the analysis, the samples were kept in the refrigerator.

Analysis of samples

A GBC-932 plus variant of the Atomic Absorption Spectrophotometer, manufactured by GBC Scientific Equipment Pty Ltd in Melbourne, Australia, was utilised for the purpose of conducting the examination of trace elements on an air-acetylene flame. Obtaining the standard solutions of the heavy metals from Merck, KGaA, Germany was the source of assistance. The preparation of solutions with varying concentrations was accomplished by diluting the standard solutions beforehand. Following is the formula that was utilised in order to ascertain the concentrations of the elements.

$$\text{Concentration}(\text{mg/gm}) = \frac{(\text{mg metal})/\text{ml} \times (25\ \text{ml/strip}) \times (4\ \text{strips/filter})}{\text{Weight of RSPM}(\text{gm})}$$

The difference in weight between the GFF paper and the cyclonic cup before and after sampling was used to compute the respirable suspended particulate matter (RSPM) and the non-respirable suspended particulate matter (NRSPM).

Enrichment factor

Rahn (1971) presented the idea of enrichment factor as a practical method for establishing if a certain element was discovered in higher abundance than what one might anticipate from crustal sources. This was done in order to determine whether or not the element was indeed there. A comparison is made between the ratio of the concentration of an element in air in a sample and the concentration of a selected reference element, such as iron (Baeyens & Dedurwaerder, 1991; Al-Momani et al., 2005), which is almost entirely crustal in origin, and the corresponding ratio in the average composition of the earth's crust, which is denoted by the term "enrichment factor."

EF=

$$\frac{\text{Concentration of element 'x' in sample/ concentration of reference element in sample}}{\text{Concentration of element 'x' in earth's crust/ concentration of reference element in earth's crust}}$$

Results and Discussion

Site-specific variation

Based on the activities associated with the distinct location, studies were carried out to examine site-specific alterations. Residential areas had the lowest relative standard particle mass (RSPM), with readings ranging from 28 µg/m3 in August to 324 µg/m3 in December. The industrial sector had the greatest concentration of RSPM, ranging from 145 to 330 µg/m3. A range of 115-316 µg/m3 was observed in the commercial area that followed. There was a significant concentration of RSPM in commercial and industrial locations in July, which might be due to the re-suspension of dust by automobiles and winds. In July (105.29 mg/gm) and August (319.88 mg/gm), industrial areas had the highest total heavy metal concentrations (136.19 mg/gm) and December (32.63 mg/gm), while commercial areas had the highest total heavy metal concentrations (56.88 mg/gm) in October, according to this study. Heavy metal concentrations were high overall, even though RSPM concentrations were low in industrial regions in July and August. This was probably because these metals ended up in the environment from places where industries were located. In the other areas, the concentration of respirable dust was positively correlated with the content of heavy metals. Even after the use of unleaded fuel was widespread, lead was found in significant proportions. Lead concentrations in residential areas varied between 1.2 and 15.3 mg/gm, whereas in commercial sectors they ranged between 1.17 and 3.99 mg/gm. A high concentration of lead in the soil along the roadside may be the consequence of decades of lead emissions and the continued use of lead gasoline, which may have contributed to this problem. Dust containing lead is resuspended in the air as a result of vehicle motion. There may be a higher concentration of lead in commercial areas due to this and other sources, such as lead in paints, alloys, plastics, and rubber. The concentration was shown to be an extremely high 15.3 mg/gm in a residential neighbourhood in August. During this time frame, it was also noted that the content of several other metals rose. The probable event that caused the value of all the metals to spike at the same time could not be identified. In 2005, the World Health Organisation reported that high levels of lead in the air might induce a variety of diseases, including chronic nephritis, cerebrovascular sickness, neurodevelopmental abnormalities, behavioural disorders, and haematological disorders. There was arsenic found everywhere, although the amounts were greatest in the residential area in July (15.95 mg/gm), August (67.6 mg/gm), and October (12.51 mg/gm). In September, the industrial zone had a higher concentration (43.51 mg/gm) than the commercial area (4.68 mg/gm) in December. There was the lowest average concentration in the residential area (2.26-67.6 mg/gm), the greatest concentration in the industrial area (3.0-43.71 mg/gm), and the lowest concentration in the commercial area (4.68-13.53 mg/gm). Pacyna (1984), the SubCommittee on Nickel (1975), and Salmon, Atkins, Fisher, Healy, and Law (1978) all agree that nickel in the air comes from the process of smelting and burning fossil fuels, especially oil. Industrial regions had Ni concentrations ranging from 4.15 to 27.26 mg/gm, residential areas from 4.93 to 61.91 mg/gm, and commercial areas from 3.98 to 11.88 mg/gm. The average concentration of Ni was higher in residential areas. The concentration was quite consistent across all of the samples. An exceptionally high concentration (61.91 mg/gm) was detected in a residential area in August, as was the case with other metals. Copper concentrations in industrial areas were found to be higher than in other places, ranging from 0.57 to 16.05 mg/gm. Like other metals, copper had its lowest concentration in residential areas between 0.43 to 18.86 mg/gm, with the exception of August, when it reached its greatest concentration of 18.86 mg/gm. Manganese is mostly responsible for the element's mobility within the atmosphere. It has been spotted in every single one of those places. Compared to lower values, residential regions and industrial areas had significantly higher concentrations (1.81-44.48 mg/gm).

the region (3.84–19.99 mg/gm). A business sector had the lowest concentration, which ranged from 2.43 to 14.96 mg/gm. The manufacturing of stainless steel, which involves the usage of manganese, is likely the source of the emission of manganese as well as the increased concentration of manganese in industrial areas. During the months of July (41.04 mg/gm), August (82.55 mg/gm), and October (11.93 mg/gm), the concentration of iron was found to be greater in residential areas (6.34–82.55 mg/gm). When it was measured in residential areas in September and commercial areas in October, it was found to be below the detection limit of AAS, which is 0.9 ppm for Fe. The commercial region had the lowest concentration (2.03–12.14 mg/gm), followed by the industrial area (0.67–15.98 mg/gm), which had the highest concentration. In the month of December, the concentration was at its lowest point in the industrial sector (15.98 mg/gm). In the months of July (25.53 mg/gm) and August (29.18 mg/gm), magnesium levels were found to be greater in residential areas, whereas in September, magnesium levels were found to be higher in industrial areas (21.0 mg/gm). A concentration ranging from 0.66 to 19.03 mg/gm was found to be highest in the commercial sector. After observing that the residential area had the highest overall average concentration of heavy metals (104.37 mg/gm), the industrial area had the second highest concentration (58.82 mg/gm), and the commercial area had the lowest concentration (47.12 mg/gm). A number of factors, including the exceptionally high concentration of all heavy metals in August, might be responsible for the higher average concentration in residential areas. These factors include the re-suspension of dust, the dispersion of dust from industrial areas, and the activity of vehicles. Figure 2 depicts the overall concentration of heavy metals in a variety of locations across the continent.

Seasonal variation

Studies conducted by Chelani et al. (2001), Ravindra et al. (2003), and Al-Momani et al. (2005) have demonstrated that the concentration of several air contaminants in the ambient air fluctuates with the seasons. As seen in Figure 3, the RSPM showed a significant amount of variation depending on the season. During the summer, the concentration was on average rather high.

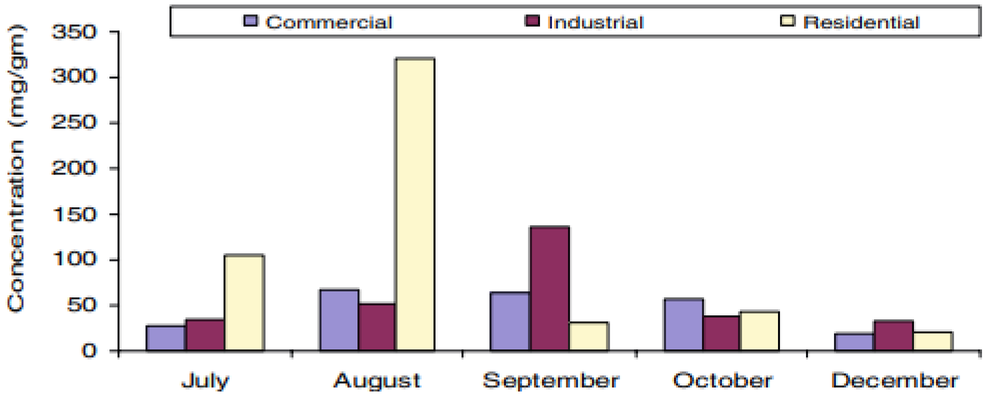

Figure 1 Variations in the overall concentration of heavy metals in the respirable dust of Faridabad city that are particular to certain sites

The soil particles become air-borne more easily during the summer season (Al-Momani et al., 2005), resulting in a concentration of 205 µg/m3. However, during the monsoon season, the concentration drops to a very low level of 96.0 µg/m3 due to the removal of air-borne particles by rain (Ravindra et al., 2003). From the post-monsoon period (152.0 µg/m3) until the fall season (139.0 µg/m3), the concentration was modest. However, it reached its highest point (323.0 µg/m3) during the winter season. According to Thakur et al. (2004), the high concentration that occurs during the winter months can be linked to circumstances such as low wind velocity, low temperature, and generally stable air conditions with a low dispersion rate. It has been discovered that the content of heavy metals is lower during the summer months. The average concentration of iron was higher (17.66 mg/gm) during the summer months, followed by the concentrations of lead (3.07 mg/gm), copper (1.13 mg/gm), magnesium (9.64 mg/gm), manganese (7.55 mg/gm), nickel (6.97 mg/gm), and tin (1.13 mg/gm). A periodic contribution from the winds coming from the Thar Desert in Rajasthan has been responsible for the high content of magnesium, iron, and arsenic. According to Seth and Pandey (1983), the ash that is carried on the wind from the ash-dumping site of the steel production also adds to it since it has a high concentration of these components. According to Al-Momani et al. (2005), the amount of iron was high since it was discovered that the elements that are produced from the crust had a high concentration during the summer. The average concentration was found to be at its highest (146.62 mg/gm) during the monsoon season, despite the fact that RSPM had dropped to a significantly low level. Compared to other elements, the concentrations of Fe, As, Ni, Mn, and Mg were significantly higher, followed by Cu and Pb. These components were likewise found to have a high average concentration during the monsoon season. Despite the fact that the rain had washed away the dust that was hanging in the air, the high wind speed and the direction of the wind most likely resulted in a high concentration of the elements. This was due to the dust, ash, and other pollutants that were transported from the industrial area and the dumping site. The overall average concentration, which was 77.21 mg/gm, decreased in the fall and during the monsoon season, when it was 42.94 mg/gm. During the winter, it was at its lowest (24.57 mg/gm). In addition, it was observed that the high concentration of pollutants was caused by a lack of rainfall, turbulent circumstances, and the dispersion of pollutants from other regions. When looking at the concentration across time, the seasonal tendency was as follows: monsoon > summer > post-monsoon > autumn > winter.

Effect of meteorological conditions

Within the realm of the transformation and transport of pollutants, meteorology is an extremely essential factor. Both the RSPM and the concentration of heavy metals were found to be at their highest levels throughout the summer months. According to Kubilay and Saydam (1995) and Al-Momani, Aygun, and Tuncel (1998), the resuspension of dust and other pollutants was caused by the high temperature as well as the high wind speed. During the summer and monsoon seasons, the direction of the wind was also important for the transport of pollutants from industrial areas to residential areas. As a consequence of the high relative humidity and the high wind speed, the monsoon's concentration of trace elements was significantly greater. During the post-monsoon and fall seasons, lower concentrations were preferred due to the drop in temperature, wind speed, and relative humidity. On the other hand, during the winter season, the stable circumstances and low dispersion rates supported the increase in fine respirable dust particles to be present. Low temperatures and high relative humidity caused a high rate of dust fall, along with precipitation, during the nighttime hours of winter. This resulted in the scavenging off of pollutants. However, at the same time, increased fuel-wood burning for space heating during wintertime resulted in an increase in the level of air pollutants associated with the fine particles. Al-Momani et al., (2005) had observations that were quite similar to those that were reported. On account of the sluggish dispersion rates that occurred throughout the winter, there was an accumulation of pollutants in and around the location where the source was situated. Despite the fact that the steady circumstances were favourable for high concentrations, the turbulent conditions that prevailed throughout the summer caused a slower rate of dust fall and increased re-suspension, both of which contributed to the high concentration that was seen during the summer. In Table I, the weather conditions that prevailed during the sample process are detailed.

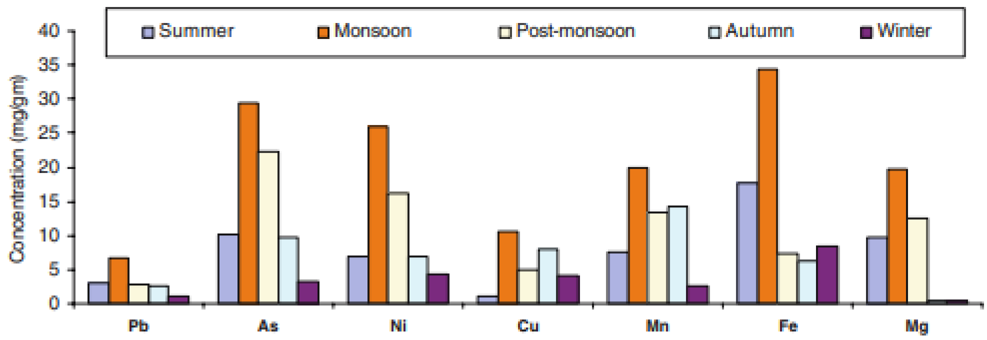

Figure 2 Seasonal variations in average concentrations of heavy metals in respirable dust of Faridabad city

Table I Over the course of many months, the meteorological factors and concentration of heavy metals in the respirable dust of Faridabad city were analysed.

Date	Mean temp. (°C)		Wind speed (Km/hr)	Wind direction	Relative humidity (%)		Rainfall (mm)	Location[a]	Concentration (mg/gm)									
	Max	Min			Morning	Evening			RSPM (μg/m^3)	NRSPM (μg/m^3)	Pb	As	Ni	Cu	Mn	Fe	Mg	Total
July, 18, 2002	41.4	28.5	6.7	NE	64	39	0	C	298	352	3.99	5.81	5.37	1.68	4.87	3.86	1.85	27.43
								I	227	476	1.94	8.87	4.99	0.57	8.83	8.08	1.55	34.83
								R	91	219	3.30	15.95	10.56	BDL[b]	8.91	41.04	25.53	105.29
Aug., 23, 2002	31.5	26.5	8.4	ESE	90	49	0	C	115	380	3.23	13.18	9.95	5.15	5.24	12.14	19.03	67.92
								I	145	292	1.86	7.36	5.92	7.70	10.18	8.53	10.53	52.08
								R	28	219	15.30	67.60	61.91	18.86	44.48	82.55	29.18	319.88
Sept., 28, 2002	35.6	20	3.3	NNE	86	32	0	C	140	350	3.86	13.53	11.88	3.01	14.96	3.65	12.88	63.77
								I	198	500	2.22	43.51	27.26	11.31	19.99	10.9	21.00	136.19
								R	118	204	2.55	10.05	9.20	0.43	5.45	BDL	4.00	31.68
Oct., 23, 2002	29.6	12.5	3.3	NNW	83	33	0	C	153	231	1.96	8.42	6.33	7.45	32.00	BDL	0.72	56.88
								I	163	240	2.32	8.27	6.98	16.05	3.92	0.67	0.18	38.39
								R	103	186	3.42	12.51	7.58	0.59	6.84	11.93	0.68	43.55
Dec., 05, 2002	24.6	5.4	0.9	E	91	34	0	C	316	258	1.17	4.68	3.98	3.66	2.43	3.03	0.66	19.61
								I	330	464	1.15	3.00	4.15	4.12	3.84	15.98	0.39	32.63
								R	324	162	1.20	2.26	4.93	4.69	1.81	6.34	0.24	21.47

a C Commercial, I industrial, R residential.

b BDL Below the detection limit (0.01 ppm for Cu and 0.9 ppm for Fe).

Enrichment factor

It was discovered via the examination of the enrichment factor (Table II) that even while the concentration of particular components could be high, it would not necessarily be enriched. According to Balachandran, Meena, and Khillare (2000), it was found that the resuspension of dust by cars led to an increase in lead concentrations in commercial areas throughout the summer and during the rainy season. The presence of a high enrichment factor (EF 52) in the industrial region during the month of October demonstrated that lead emission was also a component of industrial activity. During the winter, the concentration was at its lowest (1.15 to 1.2 mg/g), and the enrichment was at its lowest. However, at the same time, the RSPM was at its highest point, which may have led to an increase in the concentration of lead. It is possible that the cause of the rise in RSPM is the excessive burning of fuel-wood for the purpose of space heating during the winter months. This lends more credence to the theory that the primary source of lead in the surrounding air was the resuspension of dust and dirt from the side of the road. The concentration of arsenic was found to be higher in residential areas, while the enrichment was observed in commercial and industrial areas. This indicates that smelting, the combustion of fossil fuels (Salmon et al., 1978; Pacyna, 1984), the resuspension of coal ash (Popovic, Djordjevic, & Polic, 2001), and industrial operations (Mahadevan, Minakshi, & Mishra, 1985) were probably the primary sources of arsenic in RSPM, in addition to other sources. In the summer, the enrichment of nickel was low, but it rose in succeeding seasons, with the exception of the winter season, when the enrichment decreased.

Table II The Enrichment Factors (EFs) of several heavy metals observed in a variety of months

Date	Location	P b	As	Ni	Cu	M n	Mg
July18,2002	C	16	11	75	25	8	0.5

	I	4	8	33	4	7	0.2
	R	1	3	14	–	1	0.6
Aug.23,2002	C	4	8	44	24	3	1.6
	I	3	7	37	52	7	1.3
	R	3	6	40	13	3	0.4
Sept.28,2002	C	16	28	175	48	25	4.0
	I	3	30	134	60	11	2.0
	R	–	–	–	–	–	–
Oct.23,2002	C	–	–	–	–	–	–
	I	52	93	559	1384	35	0.3
	R	4	8	34	3	4	0.06
Dec.05,2002	C	6	12	71	70	5	0.2
	I	1	1	14	15	1	0.3
	R	3	3	42	43	2	0.4

Table III Heavy metals' correlation coefficients in the respirable dust of Faridabad city with respect to the city

	Pb	As	Ni	Cu	Mn	Fe	Mg
Pb	1.000	0.834[a]	0.914[a]	0.549[b]	0.737[a]	0.872[a]	0.620[b]
As		1.000	0.976[a]	0.649[a]	0.788[a]	0.792[a]	0.768[a]
NiCuMn Fe			1.000	0.677[a] 1.000	0.802[a] 0.599[b] 1.000	0.846[a] 0.444 0.632[b] 1.000	0.726[a] 0.353 0.532[b] 0.738[a]
Mg							1.000

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

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

a little bit. The highest level of enrichment (EF 559) was found in the industrial sector during the month of October. On the basis of the enrichment factor, it was discovered that the majority of nickel emissions came from human activities. The burning of fossil fuels in automobiles, industrial operations, smelting, and resuspension of coal ash were the most likely causes of nickel emissions. After careful observation, it was found that the enrichment of copper was in line with the general trend for its concentration. There was a significant amount of enrichment in commercial and industrial regions. Based on observations, it was found that the primary origin of copper was anthropogenic, with steel plants and coal-ash resuspension being the primary sources. The EF demonstrated that the human activities were the source of the manganese in the commercial and industrial region. The most significant contributors to the emission of manganese into the atmosphere were the manufacturing of stainless steel through the use of manganese in vehicular activity and the re-suspension of ash (Popovic et al., 2001). RSPM was shown to have a crustal origin for both the elements Fe and Mg. The wind, dust storms, and re-suspension caused by automobiles have all contributed to the atmospheric input that they have received. Mg was solely obtained from natural sources, as evidenced by the fact that the enrichment factor was less than seven in every trial. Dust that is blown from the Thar Desert in Rajasthan is the primary source of magnesium and iron during the summer months. During the month of October, high enrichment factors were recorded for all of the elements in the industrial region; however, the enrichment was not seen for magnesium, which is the sole element that originates from the crust. The particular enrichment was linked to some human activity, such as the occasional burning of industrial leftovers or waste from a certain sector, according to the statement. Despite the fact that there is a lack of severe application of laws, the owners of small or medium scale companies clean the premises and burn the garbage outside of the campus. In the study that was conducted by Al-Momani et al. (2005), it was also shown that the content of crustal derived elements, specifically magnesium and iron, was much greater during the summer months. After conducting a correlation study, it was shown that heavy metals obtained from various locations had a positive link with one another. It was noticed that there was a substantial and significant positive association ($P < 0.01$) between the elements As, Ni, Pb, Fe, and Mn. Pb and Mn were shown to have a substantial correlation with copper. Copper was not found to have a link that was statistically significant with either magnesium or iron. Table III gives an overview of the findings from the correlation analysis.

Conclusion

A complete analysis of the seasonal enrichment and distribution of heavy metals in respirable suspended particle matter (RSPM) has been presented by the current study. This analysis was carried out over a number of different sites in the greater Faridabad city area. In light of the findings, it is clear that the concentrations of RSPM and the heavy metals that are linked with them, including lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), and zinc (Zn), are subject to large variations depending on the season. The primary reasons for the elevated levels that were seen during the winter and pre-monsoon seasons were the increased emissions caused by human activity, the decreased atmospheric dispersion, and the increased energy requirements that occurred during the colder months. According to the results of the application of the enrichment factor (EF) and the geo-accumulation index (I_geo), the majority of the heavy metals that were discovered in RSPM were of anthropogenic origin. This was particularly the case for industrial discharges, automobile emissions, and construction activities. The largest pollution loads were found at locations that were located in close proximity to industrial and high-traffic zones, which further provided evidence that localised emission sources are a significant factor. Additionally, this study provides significant baseline data that might be of assistance to politicians, environmental agencies, and urban planners in the process of establishing targeted mitigation programs to enhance the quality of the air that is present in the environment. It is vital to continue monitoring and research in order to follow changes over time, evaluate the effectiveness of interventions that have been adopted, and preserve both public health and the environment in Faridabad and other urban-industrial locations that are comparable.

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