Imprints of vehicular pollution in roadside dust from Kolkata, India: insights from magnetic susceptibility, geo-statistical and SEM studies

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The present study aimed to determine the magnetic susceptibility of roadside dust collected from different parts of Kolkata city, West Bengal, India. The average value of susceptibility was 4.96×10^{-6} m^3/kg, the highest being 19.6×10^{-6} m^3/kg and the lowest being 1.2×10^{-6} m^3/kg. The frequency-dependent susceptibility value (average = 2.19) indicated the dominance of stable-single domain grains with a low concentration of superparamagnetic grains at a few locations. SEM analysis showed morphological diversity of road dust – irregular, aggregate, angular and cloudy. Energy dispersive X-ray spectroscopy analysis of the dust particles revealed that Ca-rich, Na-rich and Fe-rich particles were abundant. Compositions were variable with the morphology. The mapping of magnetic susceptibility indicated that the susceptibility values were higher in areas with heavy vehicular traffic and other polluting sources. However, some areas with high pollution had open spaces, indicating the dispersion of magnetic pollutants. The study indicated the degradation of the environment due to anthropogenic activities.

Keywords: Anthropogenic activities, magnetic susceptibility, morphological study, roadside dust, vehicular pollution.

INDUSTRIALIZATION coupled with high population density in the Indian subcontinent has led to a contaminated milieu, especially in large cities like Kolkata in West Bengal. This is due to vehicular traffic and industrial emissions associated with fly-ash particles[1–6]. Most of these environmental contaminants of varied sources and origins are magnetic[7]. Also, magnetic grain size and composition are important to identify the precise source of magnetic contaminants[1]. The contribution of anthropogenic contaminants in metropolitan cities due to vehicular traffic globally dominates over natural causes[1–3,6–9].

Environmental magnetism can act as a dependable non-destructive tool for assessing pollution[10–13]. The principle behind the application of magnetic techniques in the study of environmental pollution is to measure the magnetic properties (magnetic susceptibility in the present case) of the samples under consideration. It is well known that magnetite is a common component of roadside dust. Thereby a positive correlation develops between the concentration of magnetite and toxic elements[14,15]. Magnetite in road dust comes from several sources. The emission from automobiles caused by burning fossil fuels is the most prominent of them. Smelting, abrasion of asphalt-top roadways and vehicle brake systems contribute to magnetic contaminants.

Thompson and Oldfield were the pioneers in research on environmental magnetism[16–19]. Subsequently, Kapicka *et al.*[8] and Hoffman *et al.*[2] carried out magnetic susceptibility mapping in the Czech Republic and Tuebingen, Germany respectively. These studies brought out an interesting association between pollutants and magnetic particles. Boyko *et al.*[7] carried out magnetic susceptibility measurements of the topsoil for validating pollution intensity studies over the long term. In India, Goddu *et al.*[1] reported the magnetic characteristics of road dust from Visakhapatnam city in Andhra Pradesh and Mondal *et al.*[20] from the Bandel–Triveni area in West Bengal. In the present study, we demarcate the degree of environmental pollution by mapping the magnetic susceptibility from road dust samples collected in different parts of Kolkata.

Materials and methods

Study area

Kolkata extends in a roughly north–south direction along the eastern bank of the Hooghly River in eastern India[21]. As a part of the Indo-Gangetic Plains, the soil of the study area is of alluvial origin. According to the geologic setting, Kolkata is located in the peri-cratonic Tertiary Bengal Basin[22]. The climate is tropical wet and dry, which can be designated as ‘Aw’ under Koppen climatic classification[23]. Kolkata city, which is under the jurisdiction of the Kolkata Municipal Corporation (KMC), has an area of 185 sq. km. The western boundary is marked by the Hooghly River

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*For correspondence. (e-mail: rimjhimmaity@gmail.com) and the eastern boundary by the Eastern Metropolitan (EM) Bypass.

Vehicular emission is a major problem which is degrading the environmental quality of the city and impacting the health[24] of its people. Studies conducted in 2008 revealed that the average annual concentration of sulphur dioxide and nitrogen dioxide was within the national ambient air quality standards of India, but suspended particulate matter levels were high and recorded an increasing trend for five consecutive years, causing smog and haze[25]. Severe air pollution in the city led to a rise in pollution-related respiratory ailments, including lung cancer[26].

Sampling techniques, measurement and data representation

A collection of road-dust samples was carried out during January and February 2016 in two phases due to the availability of dry samples. Fifty precise locations for sampling within the city were selected based on traffic density, degree of perceptible automobile exhaust fumes and roadside dust (Figure 1). Samples were collected using a nylon brush and scraper as tools. They were dried in the laboratory at room temperature, and even minute moisture contamination was avoided to prevent negative susceptibility and, consequently, a decrease in the susceptibility value. After drying, the samples from each site were put into six identical non-magnetic cubical boxes having a volume of ~8.69 cm^3, which could fit perfectly within the adapter of the Bartington MS-2 magnetic susceptibility meter. The samples were then subjected to a low field (low field magnetic susceptibility; 0.46 kHz) and high field (high frequency magnetic susceptibility; 4.6 kHz) magnetic susceptibility measurements at the Geophysics Laboratory, Department of Geological Sciences, Jadavpur University, Kolkata. A scanning electron microscope (SEM-EVO-18, Zeiss, Germany) was used to study the morphological properties and elemental composition of roadside dust particles[27], for which a portion of the dust sample was sprinkled over a double-sided carbon tape-mounted electron probe stub and coated using carbon film in SPI-module coater. The coated stubs were examined in the SEM chamber using electron high tension and a probe of 20 kV and 1000 μm for backscatter electron (BSE) mode. The SEM images were taken arbitrarily, choosing 3–4 fields of view using a scanning speed of 7 sec for BSE mode. The elemental composition of representative dust was determined by an energy-dispersive spectrometer (EDS) using TEAM software. The elemental composition was determined using 'spot mode' in which the electron beam was focused on a particular area of the sample within the field of view which had been manually selected.

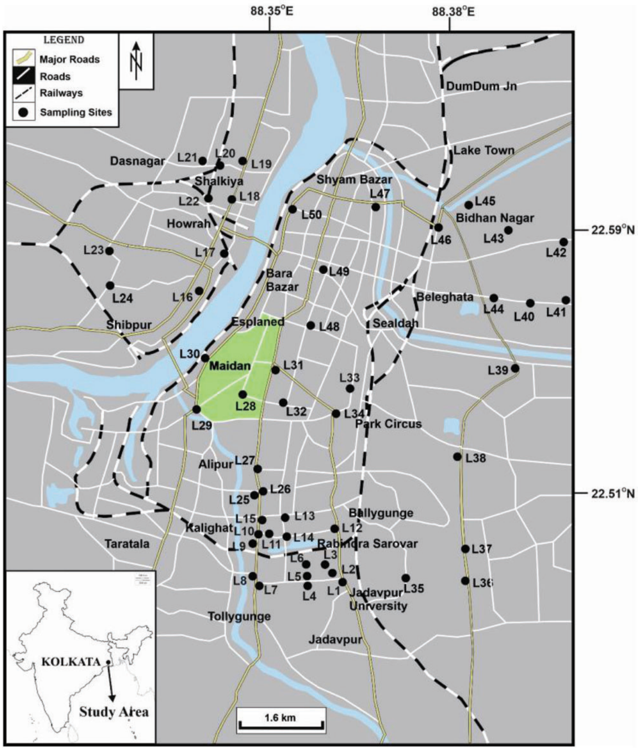

Figure 1. Generalized location map of the study area.

Frequency-dependent susceptibility measurements were carried out to determine the concentration of the super-paramagnetic (SP) minerals and to delineate the threshold value for magnetic susceptibility[28]. The frequency-dependent susceptibility (χ_{fd} %) values are generally represented as a percentage and obtained using the following equation[29]

$$\chi_{\mathrm{fd}}\% = (\chi_{\mathrm{lf}} - \chi_{\mathrm{hf}})/\chi_{\mathrm{lf}}, \tag{1}$$

where χ_{lf} is the low-field mass specific susceptibility and χ_{hf} the high-field mass specific susceptibility.

Results and discussion

Results from magnetic susceptibility studies

Table 1 summarizes the data obtained from low-field magnetic susceptibility (mass-specific) measurements from all locations. The data provided for each sampling site in the table are the average of all the six sub-samples from each site. The values are highly variable, which indicates the distribution of the susceptibility values throughout the city. The average value of susceptibility was 4.96×10^{-6} m^3/kg. The highest value of χ_{lf} was 19.6×10^{-6} m^3/kg, observed at the Belgachia crossing, while the lowest value was 1.2×10^{-6} m^3/kg at Lindsley Street. The spatial distribution of χ_{lf} was acquired using Arc GIS 10.7.1 software and contoured data were interpolated using kriging interpolation (Figure 2). The UTM projection, zone 14, horizontal datum ellipsoid and the World Geodetic System 84 (WGS84) were employed for the same.

In the southeast in Abhisikta locality near the EM Bypass, χ_{lf} was abnormally low. However, the EM bypass is one of the busiest traffic corridors of the city, making it a zone which should witness high pollution. Also, the east–west metro rail service under construction uses large machinery (viz. diggers, cranes), which emit environmental contaminants on a large scale. The difference in the values of the observed and the measures susceptibility was due to the dispersion of the pollutants in large space available. Considering the road connectivity of the Kolkata Metropolitan Area, Jadavpur PS, Rashbehari and Hazra crossings are important road junctions, each connecting four important locations of the city having a variety of workplaces and business hubs drawing massive crowds. Consequently, the number of vehicles (both public and private) is extremely high at these crossings. Further, due to heavy traffic, the vehicles need to wait for a long time at the signal crossings. During sampling most vehicles were observed not switching off their engines while waiting and continuously releasing emissions. On the other hand, the crossings at Jodhpur Park (location-3), Deshapriya Park (location-14), Sharat Bose Road and Sharat Chatterjee Road had much less traffic because these roads are facilitated by one-way traffic. These areas are also dominantly occupied by residential complexes; thus, the rush of people going to work is less here. Further, the area is near Rabindra Sarobar Lake, where there are several tall trees. The pollutants emitted are more likely to have been deposited on the leaves of these trees. The western and southwestern regions of the studied area include Howrah Railway Terminus (location-17), Vidyasagar Setu (location-29), Mourole Road (location-28), Princep Ghat (location-30), Kona Express Way (location-24), etc. The sharp rise in the susceptibility values of dust from these areas points to the remarkably high traffic input from the Vidyasagar Setu, which connects Kolkata with Howrah and beyond. This segment of Kolkata serves as the pathway for all sorts of industrial and commercial imports from the neighbouring states. According to regional surveys, the route to Kolkata from the Kona Express Way through Vidyasagar Setu witnesses about 100,000 vehicles per day. Similar results were obtained for the northern part of the study area, with the highest peaks represented by the Tikiapara railway crossing, and the crossing between Salkia and G.T. Road. In these localities, the high pollution is due to the combined contribution of the railway crossing, huge traffic and a number of small iron and steel industries.

Table 1. Mass-specific susceptibility and frequency-dependent susceptibility values of samples from all locations

Sample no.	Latitude	Longitude	χ_{lf} (10^{-6} SI)	χ_{fd} %
L1	22.502	88.367	2.1	2.38
L2	22.503	88.363	1.5	2.68
L3	22.506	88.364	2.2	0.91
L4	22.499	88.357	2.1	1.43
L5	22.501	88.357	3.6	2.78
L6	22.501	88.357	4.7	2.13
L7	22.501	88.345	5.2	1.92
L8	22.501	88.344	4.2	2.39
L9	22.509	88.345	3.9	2.56
L10	22.513	88.347	2.7	3.7
L11	22.514	88.357	2.6	2.69
L12	22.514	88.365	1.9	1.56
L13	22.518	88.359	3	3.33
L14	22.518	88.352	3.3	3.03
L15	22.516	88.346	9.5	1.56
L16	22.57	88.326	3.7	2.7
L17	22.582	88.336	4.7	2.13
L18	22.595	88.339	12.5	0.81
L19	22.602	88.342	9.6	3.13
L20	22.603	88.333	9.3	1.08
L21	22.604	88.322	19.6	0.94
L22	22.597	88.322	15.7	0.65
L23	22.577	88.303	7.2	2.78
L24	22.569	88.306	4.7	2.13
L25	22.525	88.344	1.6	3.13
L26	22.525	88.346	3.2	2.5
L27	22.538	88.346	3.2	3.13
L28	22.549	88.338	4.7	2.13
L29	22.545	88.33	9.1	1.1
L30	22.559	88.333	3.4	2.94
L31	22.553	88.352	2.4	3.33
L32	22.544	88.352	2.1	2.38
L33	22.543	88.366	5.1	1.96
L34	22.535	88.365	4.2	0
L35	22.502	88.384	3.1	3.23
L36	22.504	88.399	2.3	2.61
L37	22.515	88.401	2.9	2.41
L38	22.538	88.397	2.7	2.96
L39	22.554	88.41	4.6	2.17
L40	22.573	88.421	2.9	0.688
L41	22.574	88.433	2.1	0.95
L42	22.583	88.433	2.1	2.07
L43	22.588	88.415	2.5	3.6
L44	22.574	88.408	1.2	3.01
L45	22.596	88.408	10.2	0.54
L46	22.593	88.388	4.4	2.27
L47	22.593	88.37	5.9	1.69
L48	22.564	88.359	2.6	2.31
L49	22.574	88.362	4	1.38
L50	22.5931	88.35	2.6	3.85

Data provided are averages of all six boxes.

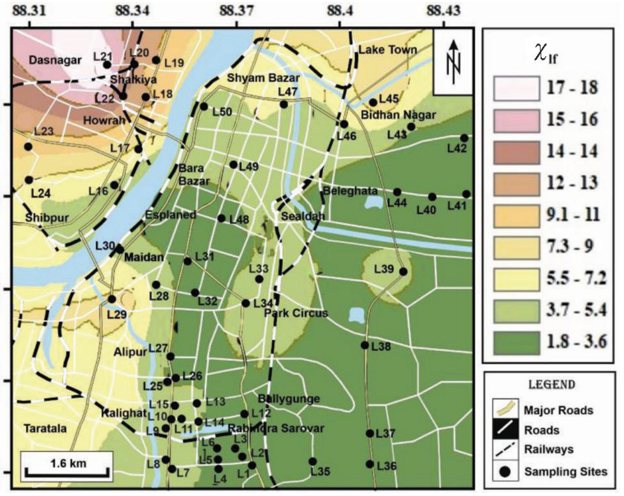

Figure 2. Location-wise variation of magnetic susceptibility throughout the study area.

Also, the northern part of Kolkata still needs to catch up in using eco-friendly technologies, thus causing increased pollution. Important among them are the old auto-rickshaws using petrol instead of compressed natural gas (CNG). Further, the narrow roads in north Kolkata lead to frequent traffic congestion and a low degree of dispersion of road dust.

Results from frequency-dependent susceptibility studies

Frequency-dependent susceptibility (χ_{fd} %) measurements were carried out to determine the presence of SP minerals and to set a threshold value for analysing the intensity of pollution in the study area. Susceptibility measurements in low frequency allow the SP crystals close to the boundary of the stable single domain (SSD) grains to shift the SP/SSD domain boundary. In these conditions, the SP crystals developed are small in size and behave like SSD grains with lower susceptibility values. Thus, the difference in the values of the two measurements (high and low frequencies) can indicate the amount of SP minerals, whose relative amount was calculated from eq. (1).

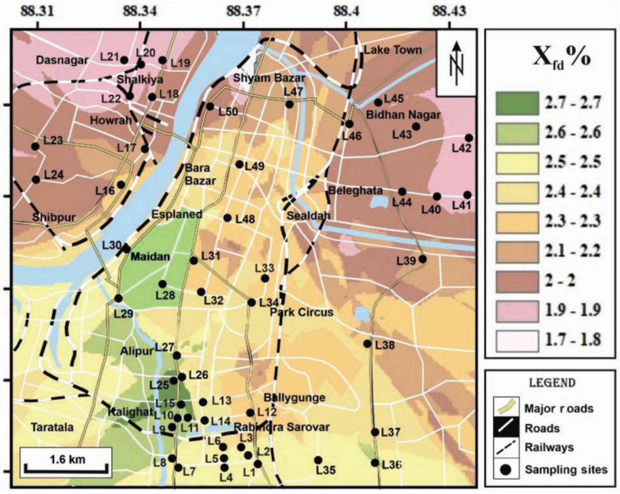

Figure 3. Location-wise variation of frequency-dependent susceptibility throughout the study area.

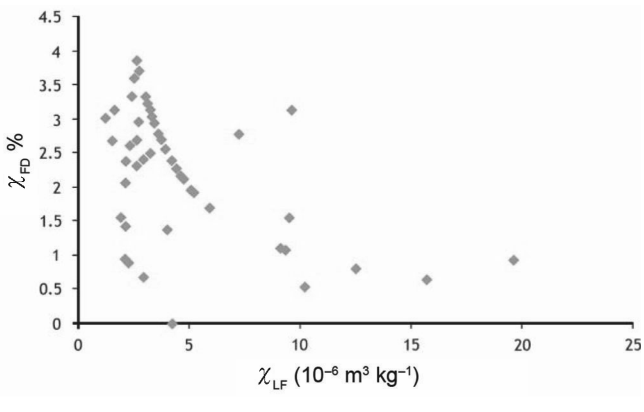

Figure 4. Variation of frequency-dependent susceptibility with change in low-frequency susceptibility.

Figure 3 represents a graph of χ_{fd} %. Values of χ_{fd} % varied between 0% and 3.85%, with an average of 2.19%. These results indicate the contribution from variable concentrations of ultrafine SP particles in the studied samples. The maximum χ_{fd} % value signifies that the concentration of the SP minerals is very low in the studied samples. The studied pollution dust showed a negative correlation between χ_{lf} and χ_{fd} % (Figures 3 and 4). It can be reasonably deduced that if a pollutant is present in the dust, the magnetic susceptibility will increase and the χ_{fd} % will decrease. Spatial distribution of χ_{fd} % was acquired using Arc GIS 10.7.1 and contoured data were interpolated using kriging interpolation.

Results from SEM-EDS studies

SEM-EDS studies were carried out to reveal the surface morphology and elemental composition of representative road dust samples (Figures 5–7). Figure 5 depicts the morphology of bulk road dust samples, whereas Figures 6 and 7 represent both morphologies and elemental compositions of marked dust samples. The particles observed under SEM were mostly angular and heterogeneous with a wide size variation (~1–100 μm). Four different morphologies were identified namely irregular, aggregate, angular and cloudy, with rough surfaces and meld-like structures. Cloudy particles containing Si, Fe and a minor concentration of O and Ca were observed in road dust with high χ_{lf} values; they were mostly of Fe-bearing Ca-feldspar (Figure 6 *a*). Irregular particles were predominant in the road-dust samples with low χ_{lf}. The EDS spectra of these particles showed high O and Si and low concentration of Na, Al and Ca which mostly occurred in feldspar (Figure 6 *b*). Aggregate and angular-shaped particles were observed in road dust with high χ_{lf} values and showed the composition of iron-bearing alumino-silicates. Road dust with low χ_{lf} shows an abundance of irregular particles. However, those with high χ_{lf}, were influenced by cloudy, aggregated and angular particles (Figure 5). Meld-like structure of these particles is due to the high-temperature combustion of fossil fuels. This fact is confirmed by the high abundance of such particles in road dust where vehicular emission is high[2,28,30,31].

SEM-EDS analysis revealed the morphological diversity of road dust and the abundance of iron-rich particles in the studied samples. The analysis indicated that the composition of dust particles was mainly influenced by Ca-rich, Na-rich and Fe-rich silicate particles. Si-rich particles mostly contained Al, Fe, Na and Ca. Irregular particles were composed of calcium and significant amounts of Si, Al and Na (Figure 6 *b*). Ca-bearing particles mainly originated from the erosion of construction materials. Among all iron-rich particles, the most common angular particles were made of Fe, Al, Si

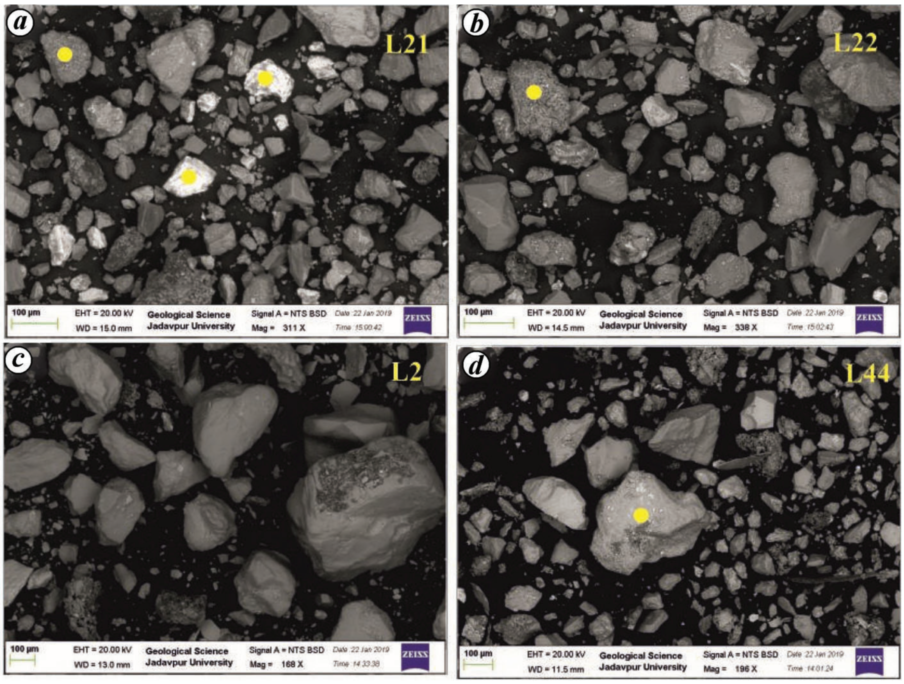

Figure 5. SEM images of bulk road dust samples with low and high χ_{lf} values in the study area. The yellow circles denote the pollutants studied using energy dispersive spectrometer (EDS) analysis.

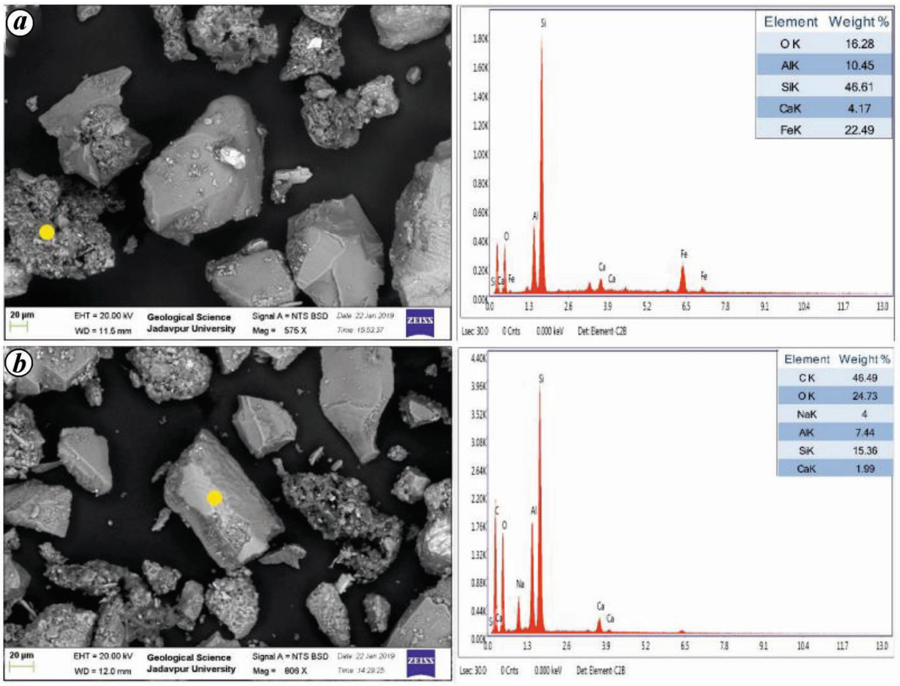

Figure 6. SEM images and elemental spectra for representative samples from (***a***) L22 and (***b***) L2. The yellow circles denote the locations of the beam used in EDS analysis.

and O (Figure 7). These angular iron-rich particles are considered to have been emitted by vehicles having abraded and corroded vehicle parts[2,29–31]. This fact is supported by the observed greater number of iron-rich particles in the magnetic fraction of the industrial areas, in contrast to areas with low traffic density and fewer industries[32–34].

Conclusion

The present study reveals the dominance of magnetic pollutants in roadside dust in Kolkata. The abundance of magnetic pollutants has a direct link with the magnetic susceptibility in urban road-dust samples, and thus magnetic susceptibility

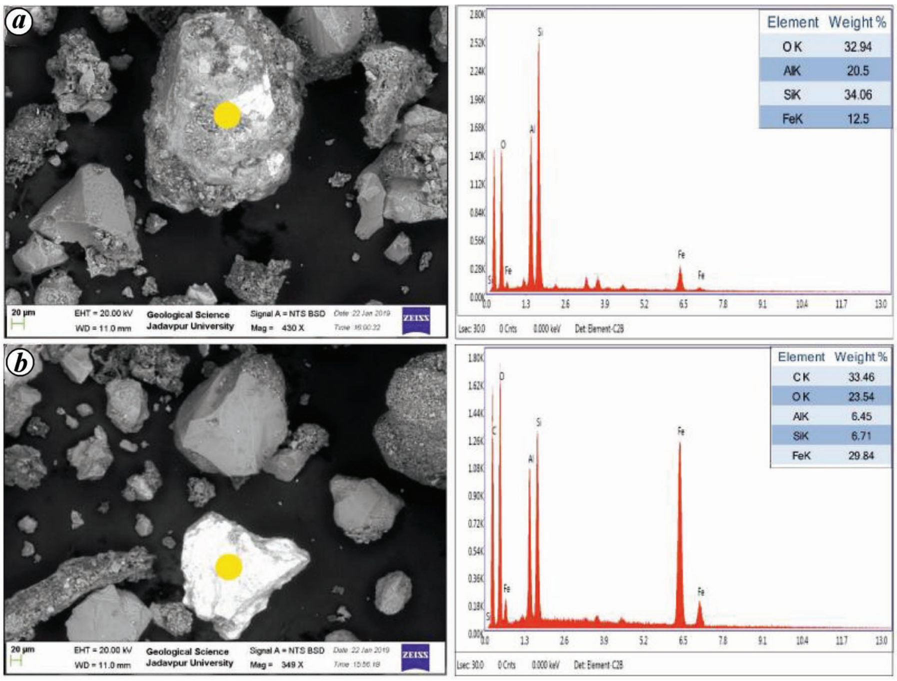

Figure 7. SEM images and elemental spectra for representative sample from L21. The yellow circles denote the location of the beam used in EDS analysis.

mapping can serve as a proxy for environmental contamination. Although magnetic pollutants in urban road dust can originate from various anthropogenic causes, vehicular emissions are the main cause. However, the structure of the magnetic pollutants varies along with their surface morphology and elemental composition due to their origin from varied sources. The magnetic susceptibility studies carried out have proved to be relatively low cost, which can measure pollution in the urban environment. The method adopted in this study is recommended for magnetic susceptibility mapping, which can precede detailed chemical analysis because it can demarcate the regions endangered by environmental contamination. The frequency-dependent magnetic susceptibility provides a threshold value of susceptibility. Thus a series of measurements from any particular area can precisely define the condition of the environment in that area in the long run. This will aid in taking the necessary corrective steps.

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