Magnetic susceptibility as a proxy for pollution in Triveni-Bandel area, Hooghly district, West Bengal, India

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This study aims at tracing the distribution and concentration of contaminants in fly ash along roads and highways with appreciable traffic by using magnetic proxies. Magnetic susceptibility is used for pollution mapping in the field. The distribution of susceptibility values represents polluted areas strongly influenced by traffic frequency, roadside topography, meteorological conditions (e.g. wind direction) and other factors. A magnetic phase was found to be responsible for the enhancement of magnetic signal in roadside ash. Magnetic methods provide effective tools for delineation of industrial pollution such as fly ash. In the area studied, magnetic susceptibility proved to be an excellent proxy for analysis of intensity of pollution yielding interesting results.

Keywords: Bandel, fly ash, magnetic proxies, magnetic susceptibility, pollution.

INDUSTRIAL pollution and air pollution due to heavy traffic are serious problems for developing countries, aggravated by fast growing industrialization and poorly-established legislative regulation on environmental issues. Human health is continuously being affected by industrial pollution, which affects soil, water and other natural resources. In this aspect, application of quick and cost-effective methods for detection of environmental pollution of soils, sediments, fly ash and dusts is of particular importance. Pollutants are mostly heavy metals which mainly contain magnetic components. Thus magnetic methods are important tools to assess environmental pollution. Magnetic parameters, especially magnetic susceptibility, which is based on the fact that many anthropogenic impacts on the environment (viz. effluents from power plants, combustion of fossil fuel, metallurgical industries, smelters, road traffic, etc.) are accompanied by significant emissions of strong magnetic particles (viz. magnetite), which increase magnetic susceptibility.

Earlier magnetic studies showed how magnetic susceptibility can be applied to identify areas where the concentration of pollutants is higher than the average values. Among all sources of pollution (viz. cement production, copper pit mining, steel manufacture), emission from vehicles is suggested to be the most important source. Morris *et al.*[1] suggested that a possible correlation exists between the atmospheric contaminants. Particles below 10 μm can significantly affect human health, easily transported into deeper body parts such as the respiratory tract and can also accumulate in alveoli[2]. Magnetic methods provide an inexpensive and quick diagnostic alternative to other techniques for directly analysing pollutants and are extremely sensitive to magnetic particles of the above mentioned grain sizes[3–5]. Sediments and soils serve as natural storage for various types of pollutions. Magnetic proxies serve as powerful means for detecting and monitoring pollutions caused mainly due to heavy metals. Earlier studies in the Hamilton harbour area showed that magnetic measurement of sediments reveals the pollution history of an area[6,7]. Thus, measuring susceptibility from the cores of sedimentary rocks is important in tracing the industrial and settlement history of that area. However, deformational events and other geological factors may have an adverse effect in such proxies. Dekkers and Pietersen[8] suggested that the correlation coefficient between the magnetic susceptibility value and concentration of pollutant is different for different heavy metals, and thus their measure may reveal the actual nature of the heavy metal.

All rock, sediment and soil samples contain some portions of ferromagnetic or ferrimagnetic minerals, which are mainly magnetite, maghemite, Fe-hydroxides, Fe-sulfides, etc. Apart from these, few magnetic contaminants are also added from anthropogenic activities which include Ni, Co, Cr, Ti, Al, Mg, etc. Apart from these, anthropogenic ferromagnetic/ferrimagnetic materials consist of highly magnetic spherules produced and released into the atmosphere during combustion (called fly ash), welding, steel production, smelting and others[9]. In the present study, magnetic susceptibility values and variations resulting from anthropogenic causes are considered. Major pollution is caused by effluents from industries, which are mostly deposited close to their sources, thereby altering the magnetic properties of nearby surface layers. Studies on fly ashes, waste products of cement and metallurgical industries and urban particulate matter generally point to the presence of magnetite, maghemite and iron as major magnetic phases. A second important pollution source is vehicle transport, mainly due to abrasion and exhaust emissions, that predominantly accumulate at the road edges. Magnetic properties vary, depending on composition, grain size and source, which enable the differentiation of magnetic signals caused by natural (lithogenic, pedogenic) and anthropogenic origins. The principal aim of the present study was to verify the applicability of magnetic susceptibility measurement in determining pollution. Further, studies were made to delineate the relative degree of industrial pollution using magnetic methods and to detect and characterize the anthropogenic magnetic particles in road dust from a typical industrial city, Bandel (West Bengal, India) by tracing the distributions and

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concentrations of magnetic contaminations along major locations of the city, and, by pollution mapping (2D and 3D) on the basis of magnetic susceptibility values. Magnetic susceptibility was chosen as proxy for measuring pollution because of high sensitivity of magnetic measurements that detects even a minute variation. Moreover, this process is rapid, cheap, efficient and provides scope for more systematic sampling.

In environmental magnetism, properties of magnetic minerals are used as proxy parameters for solving environmental problems such as climate and environmental changes. More recently, the theory is applied to evaluation and monitoring of environmental pollution. One major reason for which magnetism is selected as a proxy is, the high sensitivities of magnetic measurements. Magnetic techniques have been successfully applied in the last decade for studies on climatic and environmental changes and for other anthropogenic activities. Magnetic measurements are suitable for detecting small quantities of magnetic minerals and they are also efficient in terms of time and monetary factors.

Magnetic material like fly ash is a common byproduct produced during coal combustion. With the advancement of application of magnetic properties in environmental studies, discrimination of various ferri-magnetic components is possible from the analysis of different magnetic parameters.

However, apart from all these advantages there are few problems associated with the method of magnetic proxy, because in many cases, only average values of magnetic parameters are obtained. For example, when the sample collected is a mixture of different grain sizes or a mixture of different magnetic minerals, the magnetic measurements may lead to ambiguous results[3,4]. Soils, sediments and dusts are generally aggregates of various mixtures of grain sizes and minerals due to which magnetic measurements may stand as hazards in case of environmental proxies.

To study the magnetic susceptibility of pollutants, Bandel, a small industrial city in Hoogly district (West Bengal) was selected and the study was confined to main roads, road crossing and a few congested colonies of the city (Figure 1). Bandel has a tropical wet and dry climate. A prolonged hot and humid weather is the main characteristic of its climate. The annual mean temperature is 24.8°C; monthly mean temperature ranges from 19°C to 30°C. Monsoon stays from early June till mid-September. Summers are hot and humid with temperatures often as low as 30°C and during dry spells the maximum temperature often exceeds 40°C, especially during May and June. Winter tends to last for only about two and half months from November to February, with seasonal lows dipping to 12–14°C between December and January. The weather generally remains dry during winter. During early summer, dusty squalls occur followed by spells of thunderstorm and heavy rains flooding the city, bringing relief from the humid heat. This thunderstorm is locally named ‘Kal Baishakhi’.

Bandel Thermal Power Station (BTPS) is situated on the western bank of Hoogly river in Triveni town. Triveni is derived from the confluence of three rivers Hooghly, Kunti and Saraswati. BTPS is situated at 22°59′42.6″N and 88°24′19.9″E. The power plant is operated by West Bengal Power Development Corporation Limited (WBPDCL). The power station has 5-units with a total installed capacity of 450 MW. All the units of this thermal power plant are coal based.

The present study in Bandel was concentrated on the polluting materials on road side and thus the samples collected were mainly from the road sections. It is important to note the two major sources of pollution that affect the road sections. They are emissions from vehicles and the materials used for road construction such as asphalt, bitumen, etc. These contaminants further enter the hydrosphere by penetrating through groundwater. Generally magnetic pollutants which have control on the susceptibility of samples are present within A or O horizon of the top soil and necessarily they are in solid state. Common examples of such pollutants are soot particles, fly ash particles and sometimes rust and paint particles also act as pollutants.

Within the studied area, relatively large part of about 260 sq. km was mapped in detail. In order to demonstrate the precise susceptibility variation, the whole mapping was carried out between the 22.945°–23.029°N and 88.383°–88.424°E. Data represented in the present study is from areas in and around BTPS. For systematic sampling, areas with high traffic circulations and areas with weak industrial drainage system were targeted.

A ‘walk through survey’ in and around Bandel and Triveni was carried out. On the basis of traffic density, amount of visible auto exhaust fumes and roadside dust, 25 busy road crossings were selected for collection of dust samples. Dust samples were collected from crossings and the middle of street junctions (near the traffic police booth) by using nylon brush, scarpers and plastic containers as tools in order to avoid external contamination and were put in pocket-sized sealable plastic bags. The locations where samples were collected were plotted on the regional map using latitude and longitude data.

The collected samples were further dried in the laboratory at room temperature and the samples from each site were put into six standard pre-weighed identical plastic cubical boxes with volume of 8.69 cm^3. These boxes are designed for susceptibility measurement of loose materials and they exactly fit with the adapter of the susceptibility measuring instrument. These boxes were again weighed with samples using a weighing machine. All the samples were then subjected to mass and volume susceptibility measurements under low frequency using Bartington Susceptibility Meter (MS-2), housed in the Geophysics Laboratory, Department of Geological Sciences, Jadavpur

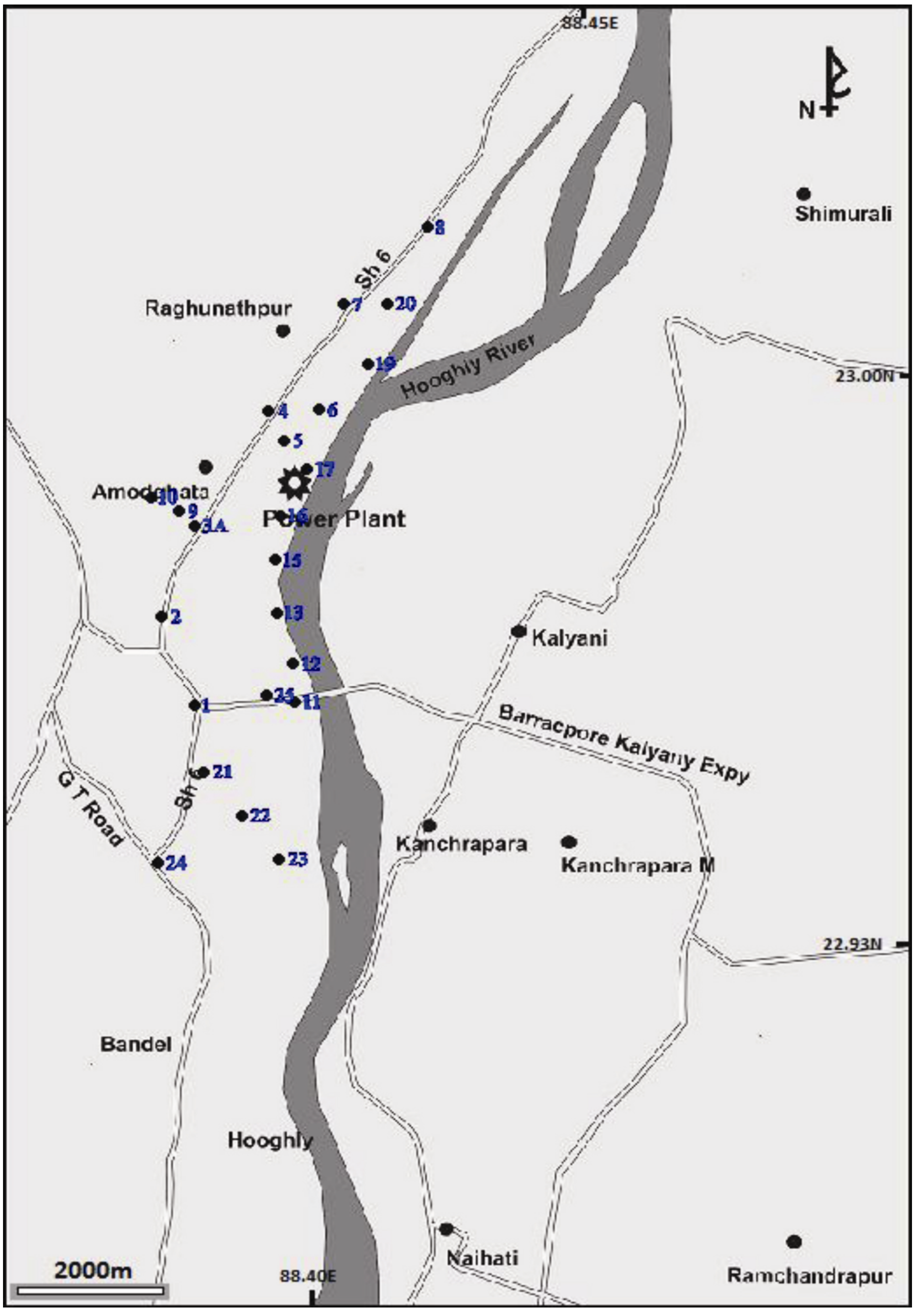

Figure 1. Regional map of the studied area (around Tribeni Bandel Thermal Power Station). Sampling sites are represented by black dots.

University, Kolkata. The susceptibilities were calculated in CGS unit. As susceptibility is a unit-less quantity, it detects the value in the order of 10^{-6} CGS unit. Values were further converted to SI units using the conversion factor.

A single profile was measured in order to qualitatively determine the degree of magnetic pollution around BTPS. As discussed earlier, the measure of magnetic susceptibility is used here as a proxy for measurement of air pollution in the area studied. Measurement of the susceptibility of the collected samples provided important results which are discussed below.

Both the mass and volume susceptibility were calculated for the collected samples (Table 1). In the case of mass susceptibility, the highest value was 85.286×10^{-8} m^3/kg, observed at location-19, near Hanseswari temple of Bansberia and the lowest value was recorded at location-23, which was about 4.291×10^{-8} m^3/kg. The average value of mass susceptibility was 44.288×10^{-8} m^3/kg. The volume susceptibility ranged from a maximum value of 1050.83×10^{-8} m^3/kg at location-19 to a minimum of 50.75×10^{-8} m^3/kg at location-23 with an average susceptibility of 284.514×10^{-8} m^3/kg.

Table 1. Magnetic susceptibility values (mass susceptibility and volume susceptibility) for corresponding sampling sites

Location	Latitude (degrees)	Longitude (degrees)	Mass in SI ($m \times 10^{-3}$)	Density in SI ($d \times 10^{3}$)	Volume susceptibility in SI ($k \times 10^{-6}$)	Mass specific susceptibility in SI ($X \times 10^{-8}$)
1	22.966	88.389	12.023	1.3849	280.750	20.27
2	22.978	88.385	10.495	1.1627	371.900	31.98
3A	22.990	88.390	10.816	1.2411	729.000	58.737
3B	22.990	88.390	7.143	0.8195	271.250	33.098
4	23.005	88.401	8.995	1.0360	358.667	34.618
5	23.001	88.403	8.067	0.9292	257.250	27.685
5 soil	23.001	88.403	5.699	0.6539	230.833	35.301
6	23.005	88.408	9.034	1.0405	129.083	12.406
7	23.019	88.412	9.905	1.1371	423.166	37.215
8	23.029	88.424	8.641	0.9945	109.080	10.968
9	22.992	88.388	10.615	1.2226	196.833	16.099
10	22.994	88.384	8.998	1.0364	77.583	7.485
11	22.966	88.403	11.673	1.3445	210.000	15.619
12	22.971	88.403	12.304	1.4172	227.920	16.082
13	22.978	88.401	10.745	1.2384	89.420	7.220
15	22.985	88.401	10.195	1.1742	178.667	15.216
16	22.991	88.402	7.551	0.8677	105.580	12.168
17	22.997	88.406	12.403	1.4235	162.000	11.381
19	23.011	88.415	10.717	1.2321	1050.833	85.286
20	23.019	88.418	10.071	1.1599	443.080	38.198
21	22.957	88.390	9.575	1.0985	263.916	24.025
22	22.951	88.395	11.483	1.3178	152.333	11.559
23	22.945	88.400	10.267	1.1826	50.750	4.291
24	22.945	88.383	11.879	1.3633	410.800	30.132
25	22.967	88.399	13.229	1.5182	332.167	21.879

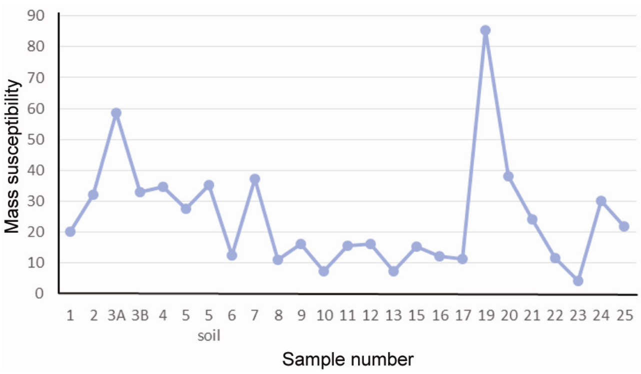

Figure 2. Frequency polygon showing the variations in mass susceptibility values of all locations.

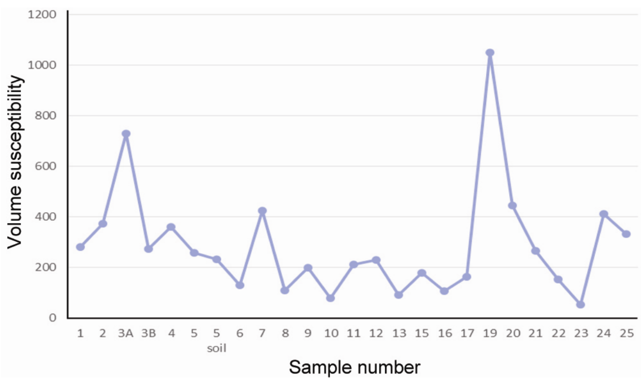

Figure 3. Frequency polygon showing the variations in volume susceptibility values of all locations.

The frequency polygons for both the mass and volume susceptibilities show exactly similar trends (Figures 2 and 3), from which we can decipher that the mass and volume susceptibility can mimic each other. However, there are some marked exceptions. Both the graphs remarkably show four peaks at same locations 3A, 7, 19 and 24 respectively. The values for susceptibilities from location-8 to location-16 show very low values compared to other locations. For the samples collected from location-5, it was observed that the mass susceptibility of the dust sample is lesser than the susceptibility of the soil sample (Figure 2). In contrast, the volume susceptibilities of dust and soil samples in location-5 are almost the same (Figure 3). The scenario is quite different in location-3. Here the trend of both mass and volume susceptibility values is similar. The value of susceptibility (both mass and volume) in case of location-17 is very low, though it is situated extremely near the Bandel Thermal Power Station.

Spatial variations of the mass and volume susceptibility are represented by 2D and 3D contour diagrams (Figures 4 and 5). In this type of diagram, on a particular contour the value of susceptibility will be the same. Henceforth, for the sake of convenience in discussion, contours of equal susceptibility will be termed as 'isosusceps'. On the 2D susceptibility map, regions with very high density of contour lines mark the locations with high susceptibility and those with low values of susceptibility are present within the areas of largely spaced contours. The two peaks within the frequency polygons of

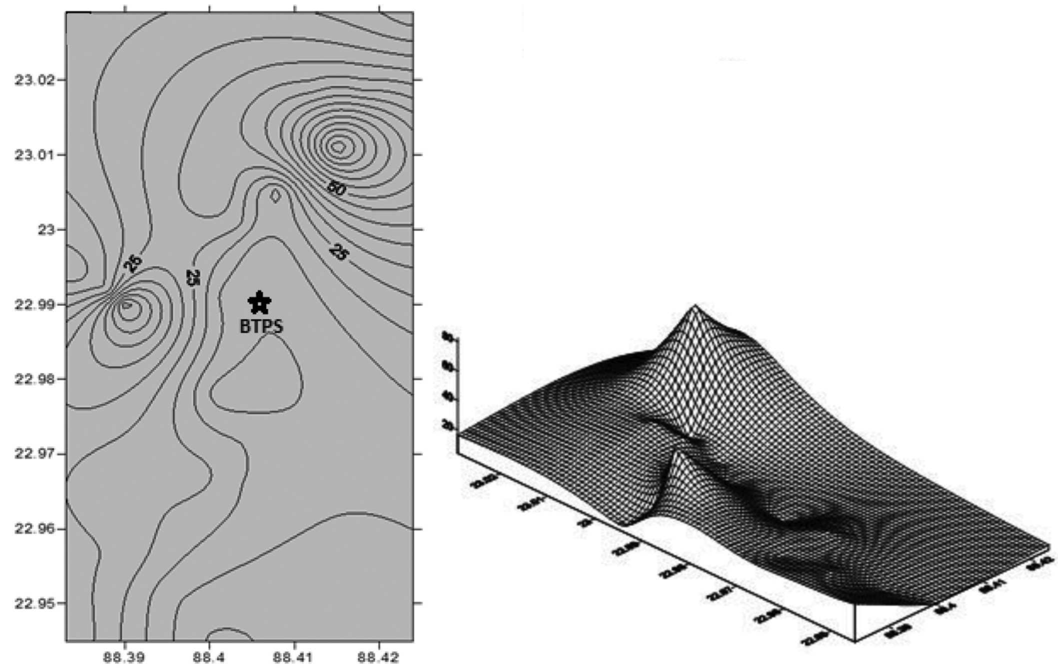

Figure 4. Mapping of volume susceptibility in the studied area through contour diagram both in 2D and 3D.

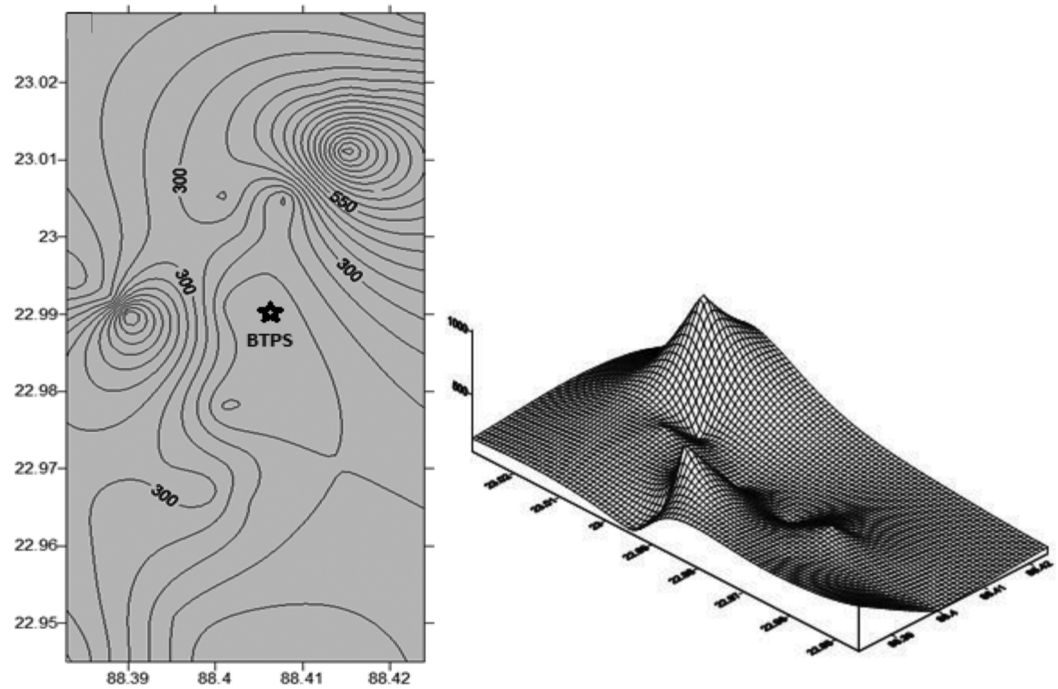

Figure 5. Mapping of volume susceptibility in the studied area through contour diagram both in 2D and 3D.

susceptibilities at locations 3A and 19 are represented by two high densities of contours at the north eastern and the western part of the area represented. Similarly, in the 3D susceptibility contour maps, locations with higher susceptibilities are represented by isolated peaks on the map in otherwise flat susceptibility topography. Both samples from location-5 (dust and soil) have equal values of volume susceptibility but the mass susceptibilities are quite different.

The point at extreme north (location-19) has the highest value (85.286×10^{-8} m^3/kg) and the one at southern end (location-23) has the lowest value (4.291×10^{-8} m^3/kg).

The field work was carried out during summer (mid-March), when wind blows from south towards north, leading to deposition of pollutants (including magnetic pollutants) towards the northern part of the study area. This further caused high susceptibility in that area. Analogously, the southern part of the study area received minimum amount of pollutants leading to lower values of susceptibilities in that particular area. These fluctuations in values of susceptibilities are also recorded in 2D and 3D contour maps (Figures 4 and 5) with highest and lowest susceptibility value areas being represented by highest and lowest peaks respectively. Low values of susceptibilities are also recorded in locations-8–16, which can also be explained in terms of wind direction in that particular season. Thus, during summer months, as the wind blows from south to north, the pollutants are carried towards north leading to low values of susceptibilities in the areas located south of the thermal power station. Among the locations towards south, i.e. those with low values of susceptibilities, some of the locations had relatively higher values compared to others, viz. locations-11, 12 and 24. The reason for their higher values may be pointed towards the fact that these locations were exactly by the sides of the road with more pollutants emitted from motor vehicles. In contrast, the locations towards the north of the thermal power station also had higher values of susceptibility, which was evident both in 2D and 3D susceptibility contour diagrams (Figures 4 and 5). The zig-zag pattern observed within the graph is due to the location of sampling sites alternatively on and off the SH-6, with the samples near SH-6 having higher values of susceptibilities. In location-5, a pair of sample was collected, one from soil and one from dust. The mass susceptibility of the soil sample was greater because of the higher mass of soil than the dust. However as equal volumes of samples were used for measurement (volume of the measuring cubical box is same for all samples) there is no effect of the nature of sample on volume susceptibility. The sample collected from location-24 and location-2 was located towards south and south-west directions respectively, but they showed high susceptibility values, i.e. the concentration of the magnetic pollutants was higher there. This is because location-24 is situated just at the junction of SH-6 and G.T Road and thus experience heavy traffic, releasing magnetic pollutants. The susceptibility of the sample from location-17 was low despite being located near BTPS which may be due to the fact that as the point was very close to the power plant, fly ash and other magnetic pollutants remained in suspension only and were not deposited in that place.

However, the abnormally high value of susceptibility in location-19 needs attention. Field evidences suggest that location-19 is situated near Keshara Rayon Company, whose basement was filled with fly ash. Thus, it can be inferred that the extremely high susceptibility value is not a natural one, but is artificially driven.

The study thus showed that the areas along the roads and highways which are contaminated by traffic emissions can be easily mapped using magnetic susceptibility. Areas which are not affected by anthropogenic input are characterized by low and stable susceptibility values. Also, it is ensured that abrasion products from asphalt and from vehicle brake systems are the dominating sources of magnetic pollution. The most important outcome of this study is that the available data demonstrate the potential of magnetic susceptibility mapping in the study of environmental pollution. Thus, it is recommended that magnetic susceptibility mapping should be done for determining environmental pollution and tracing its sources. A scope for more systematic sampling is provided if a prior magnetic susceptibility mapping is done.

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