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MAGNETIC SUSCEPTIBILITY OF ROAD DUST FROM KOLKATA-IN RELATIONSHIP TO ROAD TRAFFIC

SUCHETA DAS, SUPRIYA MONDAL, DIPANKAR BURAGOHAIN & UTSHA DASGUPTA

Department of Geological Sciences, Jadavpur University, Kolkata, West Bengal, India

ABSTRACT

For the assessment of pollution levels prevalent in relation to the ever increasing roadside automobile traffic, this study has been conducted in and around the metro city, Kolkata. This study was carried out to assess the roadside dust and auto exhaust gaseous levels at 40 busy road-crossings of Kolkata. Magnetic susceptibility is used as a proxy for heavy metal pollution in the road - dust. The studied samples are collected as road-dust during winter season starting from December 2010 to June 2011. The highest susceptibility value (904.5833 X 10^{-6} CGS) as measured is evident from Ultadanga, and the lowest value (133.25 X 10^{-6} CGS) is evident from Vivekananda-Bidhan Sarani crossing. Remarkably a NE-SW ridge of high susceptibility value is found in the susceptibility map made by susceptibility value. It is evident from this study, that the narrow roads, with high traffic frequently played a prime role behind high susceptibility values, whereas wide roads, or open space around even busy road are capable to disperse the magnetic particles. Apart from these highest and lowest susceptibility values we have got such kind of result where traffic is low, but pollution is high due to the nearby constructional site. But generally pollution value is proportional to the traffic.

KEYWORDS: Environmental Magnetism, Magnetic Proxies, Magnetic Screening, Pollution of Roadside Soils, Emissions of Vehicles

1. INTRODUCTION

Industrial pollution and heavy traffic are especially serious problems for developing countries with fast growing industrialization and poorly-established legislative regulation on environmental issues. In this aspect, the application of fast and cost-effective methods for detection of environmental pollution of soils, sediments and dusts is of particular importance. One such proxy method is the use of magnetic susceptibility, which can be measured easily. It is based on the fact that many anthropogenic impacts on the environment (effluents from power plants, combustion of fossil fuel, metallurgical industries, smelters, road traffic, etc.) are accompanied by significant emissions of strongly magnetic particles (e.g., containing magnetite), which cause an increase of the magnetic susceptibility (for a comprehensive review see Petrovsky and Elwood, 1999).

Roadsides in urban area are commonly polluted by particulate matter (PM) derived mostly from traffic: motor vehicle emissions, abrasion of tiers, brake linings as well as road surface, cycling of dust in suspension due to vehicular movement, dispersion of construction material, etc. (Petrovsky and Elwood, 1999; Gautam et al., 2004b).

Land vehicles emitted chemical pollutants such as Carbon monoxide (CO), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and Total suspended particles (TSP). Gaseous chemicals emit from the vehicles of varying physical and chemical properties mix together to form smoke. When we inhaled this smoke, it causes damage to our airways and the lungs.

The results of this study suggested that long-term exposure to air pollution may contribute to the pathogenesis of airway disease, and that the urban levels of air pollution have adverse effects on the respiratory tract.

Magnetic particles are found almost invariably amongst atmospheric particulate pollutants (e.g. Flanders, 1994; Hunt et al., 1984). Iron often occurs as an impurity in fossil fuels – During industrial, domestic or vehicle combustion, carbon and organic material are lost by oxidation whilst the iron forms a non-volatile residue, often comprising magnetic particles (due to melting). These spherules are magnetic, with magnetizations easily measurable using cryogenic magnetometers (Matzka et al, 1999). Depending on the fuel type and temperature of combustion, the spherules contain varying amounts and grain sizes of magnetite (Fe_3O_4) and/or hematite (αFe_2O_3). It has been shown that combustion processes simultaneously release hazardous substances and magnetic particles into the atmosphere. Morris et al., (1995) for example, found a strong correlation between sample mutagenicity and magnetic susceptibility for urban dust samples. In addition to these combustion-related particles, non-spherical magnetite particles can be generated by vehicles, via exhaust emissions and abrasion or corrosion of engine or vehicle body material (Olson and Skogerboe, 1975). Hoffmann et al., (1999) measured profiles of magnetic susceptibility of the soil surface along roads and highways in SW part of Germany, Baden-Württemberg. Maximum values were found to be localized within 2–5 m of the road and reflected the prevailing wind direction.

Gautam et al. (2005), Fialova et al. (2006) found that lithology has the prime effect on soil magnetic properties, and any significant anthropogenic contribution can be clearly recognized using magnetic susceptibility as proxy. Usually there is a good relationship between heavy metals and magnetic materials such as Fe-oxides due to the fact that they are good adsorbents. In several studies, significant correlation between magnetic susceptibility and heavy metal content in soils was found (e.g., Heller et al., 1998; Hoffman et al., 1999; Dearing et al., 2001; Lecoanet et al., 2001; Hanesch et al., 2003; Jordan ova et al., 2003; Schmidt et al., 2005; Magiera et al., 2006). Therefore, this method represents an inexpensive and indirect approach in detecting heavy metal contaminations.

Here the results of our investigations focussed on pollution screening by using magnetic susceptibility on roadsides. The main objective of this study is to test the applicability of the magnetic susceptibility mapping method in this context and to infer the pollution of the 50 busy traffic locations by using Magnetic Susceptibility as a proxy method.

2. ENVIRONMENTAL MAGNETISM

2.1 Overview

A description of the method of environmental magnetism, including a few results demonstrating the capabilities of this technique is presented below (more detailed reviews are found, e.g., in (Oldfield, 1991; King and Chanell, 1991; Strzyszcz, 1993; Dearing, 1994; Heller and Evans, 1995; Vero sub and Roberts, 1995; Reynolds and King, 1995; Petrovsky and Elwood, 1999).

In environmental magnetism, magnetic properties of materials such as soils, sediments and dusts are investigated. Such measurements provide powerful tools for approaching environmental problems of concern such as climate and environmental change and, more recently, environmental pollution. The high sensitivity of magnetic measurements allows the detection of very low quantities of magnetic material which often act as proxies for the underlying environmental processes.

Magnetic techniques provide highly sensitive proxies for paleoclimate in different environments. Anthropogenic pollution can also have a strong magnetic signature and magnetic techniques have proven to be capable of discriminating between different sources of pollution. (Hoffmann et al, 1999)

Magnetic techniques have been applied successfully in studies of climate change, soil erosion, analysis of atmospheric pollution (e.g., by detecting highly V. Hoffmann et al. / Journal of Geochemical Exploration 66 (1999) 313–326315 magnetic fly-ash) and pollution produced by historical or active mining and other anthropogenic activities. The sensitivity of magnetic techniques is best suited for rapidly measuring very small quantities of magnetic particles in bulk samples (in general equivalent to ppb in chemical analyses). A large number of studies are possible that simply cannot be performed by other techniques without costly and time-consuming direct analyses. Strongly magnetic spherical particles (fly-ash) are commonly emitted by many combustion processes. Magnetic parameters are capable to differentiate the ferromagnetic component of atmospheric dust that derived from soil-sized particles from different source areas and also fly-ash from different industrial sources (e.g., Hunt et al., 1984; Chester et al., 1984; Oldfield and Robinson, 1985; Hunt, 1986) fuel combustion from traffic. Environmental magnetism can also have an important role in reducing the effects of pollutants. Laboratory studies of soil iron oxides revealed that these particles are highly absorbable of heavy metals (Rose and Bianchi-Mosquera, 1993).

Although magnetic studies are a successful environmental proxy, the fact that many of the environmental magnetic results depends on the bulk techniques means that only average magnetic parameters are obtained from many measurements. During the 1970s and 80s, scientist realized that magnetic properties were useful for describing and classifying all types of environmental materials. The Bartington Instruments MS2 Magnetic Susceptibility System becomes very popular for use in the laboratory and field in universities around the world.

2.2 Magnetic Susceptibility

Magnetic Susceptibility is a parameter which characterizes the nature and intensity of material's response to external magnetic field. The magnetic susceptibility of a material, commonly symbolized by K_m, is equal to the ratio of the magnetization M within the material to the applied magnetic field strength H. This ratio, strictly speaking, is the volume susceptibility, because the magnetization essentially involves a certain measure of magnetism (dipole moment) per unit volume.

$$K_m = M/H$$

$$I = kH$$

I= intensity of magnetization, H = inducing magnetic field, k= magnetic susceptibility.

The magnetic susceptibility is a unit less constant that is determined by the physical properties of the magnetic material. It can take on either positive or negative values. Positive values imply that the induced magnetic field, *I*, is in the same direction as the inducing field, *H*. Negative values indicate that the induced magnetic field is in the opposite direction of inducing field.

Magnetic susceptibility measures the 'magnetisability' of a material. In the environment, the magnetic ability gives us information about the minerals, particularly Fe-bearing minerals that are present in soils, rocks, dusts and sediments. So, this measurement provides information similar to X-ray diffraction or heavy mineral analysis.

According to the book 'Environmental Magnetic Susceptibility' by John A. Dearing the advantages of this measurement can be summarized as follows:

- Measurements can be applied to all materials.
- Measurements are safe, fast and non-destructive.
- Measurements can be made in the laboratory or field with minimal training.
- Measurements complement many other types of environmental analyses.

Large numbers of samples may be measured very cheaply without limiting subsequent analyses. So, this can be an ideal measurement for reconnaissance studies where we need to measure a large number of samples in order to find 'average' or 'typical' samples for other expensive or time consuming analyses. People who work in remote or foreign areas far from laboratory facilities can easily measure the magnetic susceptibility by using this method and can link data to field observations easily. Therefore, this measurement can reduce the cost (man power and time) in comparison with others. Recently, magnetic susceptibility has been used as an environmental analytical technique in conjunction with analyses of chemistry, radioisotopes, and microfossils.

3. MATERIAL AND METHODS

3.1 Properties of Road Dust

Roadsides in urban area are commonly polluted by particulate matter (PM) derived mostly from traffic: motor vehicle emissions, abrasion of tiers, brake linings as well as road surface, cycling of dust in suspension due to vehicular movement, dispersion of construction material, etc. The motor vehicle emissions usually constitute the most significant source of ultra-fine particles in an urban environment. Important chemical pollutants emitted by land vehicles are Carbon monoxide (CO), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and Total suspended particles (TSP).The smoke is a mixture of particles and gaseous chemicals of varying physical and chemical properties. Magnetic particles are one of the most important atmospheric pollutants. During combustion of vehicles, carbon and organic material are lost by oxidation but iron remains there as a non-volatile residue with some other often magnetic particles (due to melting). These spherules are magnetic and their magnetizations can be easily measured oxidation, butgenic magnetometers. The magnetic spherules contain different amounts of magnetite (Fe3O4) and/or hematite (αFe2O3) depending on the varitheyuel type and combustion temperature. Spherical particles of anthropogenic origin containing a magnetite-like phase were found to be responsible for the enhancement of the magnetic signal (Flanders, 1994). Emissions of vehicles are an important source of inorganic (soot particles in exhaust fumes from diesel engines, heavy metals) and organic (PAH, BTX etc.) contaminants which strongly reduce air and soil quality in the areas of nearby roads.

3.2 STUDY AREA

3.2.1 Sources of Roadside Dust

The most responsible emission components for the roadside environmental contamination: **(1)** vehicles and **(2)** materials used for the road construction (asphalt, bitumen being most important). A large variety of solid, gaseous and fluid contaminants (inorganic and organic chemicals) are emitted into the environment. These pollutants clusters in the topsoil (O=A-horizon), then move through the water system (also penetrate to ground-water), and thus taken up by plants or microorganisms. Only solid particles such as soot particles, metallic or fly-ash particles which were mainly produced by abrasion of a brake system, tyres or asphalt etc. and rust or paint particles etc, are responsible for the enhancement of the magnetic signal in the top soil. Sometimes for asphalt production, highly polluted slag and filter dusts (from coal and refuse combustion) are used as ingredients.

3.2.2 Area of Sampling

The present study concerns the main roads of Kolkata city which is located in the eastern part of India. The city covers approximately 185 km^2 (71 sq mi).with 5.2 million residents and is the third most populous metropolitan area in India and the 13th most populous urban area in the world. The city is also classified as the eighth largest urban agglomeration in the world. The number of registered vehicles increases day by day. More or less 44% increase within 7 years, according to 2002 data. Compared to the other city road space (such as 23% in Delhi and 17% in Mumbai) Kolkata has only 6% road space which create major traffic problems and pollution.

Kolkata has a tropical wet-and-dry climate. The annual mean temperature is 26.8 °C (80.2 °F); monthly mean temperatures range from 19 °C (66.2 °F) to 30 °C (86.0 °F). Summers are hot and humid with temperatures in the low 30's and during dry spells the maximum temperatures often exceed 40 °C (104 °F) during May and June. Winter tends to last for only about two and a half months, with seasonal lows dipping to 9 °C – 11 °C (54 °F – 57 °F) between December and January. The highest recorded temperature is 43.9 °C (111.0 °F) and the lowest is 5 °C (41.0 °F). On an average, May is the hottest month with daily temperatures ranging from a low of 27 °C (80.6 °F) to a maximum of 37 °C (98.6 °F), while January the coldest month has temperatures varying from a low of 12 °C (53.6 °F) to a maximum of 23 °C (73.4 °F). In the month of July and August the city is blessed with seasonal rainfall. In the early summer thunderstorm popularly known as **Kal Baisakhi** disturbs the city life.

As the samples were collected during winter times (i.e., December), the study area is usually characterized by higher temperatures (around 36 ^{0}C), high humidity, and no rainfall with mild winds & often disturbed by thunderstorms.

4. SAMPLING AND LABORATORY PROCEDURES

4.1 Sampling

A ‘walk through survey’ of different areas of Kolkata was carried out and on the basis of assessment of traffic density (vehicle count) and the amount of visible auto exhaust fumes/smoke and roadside dust 50 busy road crossings of Kolkata were selected for pollution analysis.

Samples of road dust were collected from the crossings at the rim of the road using a nylon brush, plastic scrapers, plastic container and tools in order to avoid contamination and were put in pocket-sized sealable plastic bags. Totally 50 sample points and 6 samples from each point were collected. Large particles like stones, brick pieces and other detrital material and organic matter were removed from the collected samples.

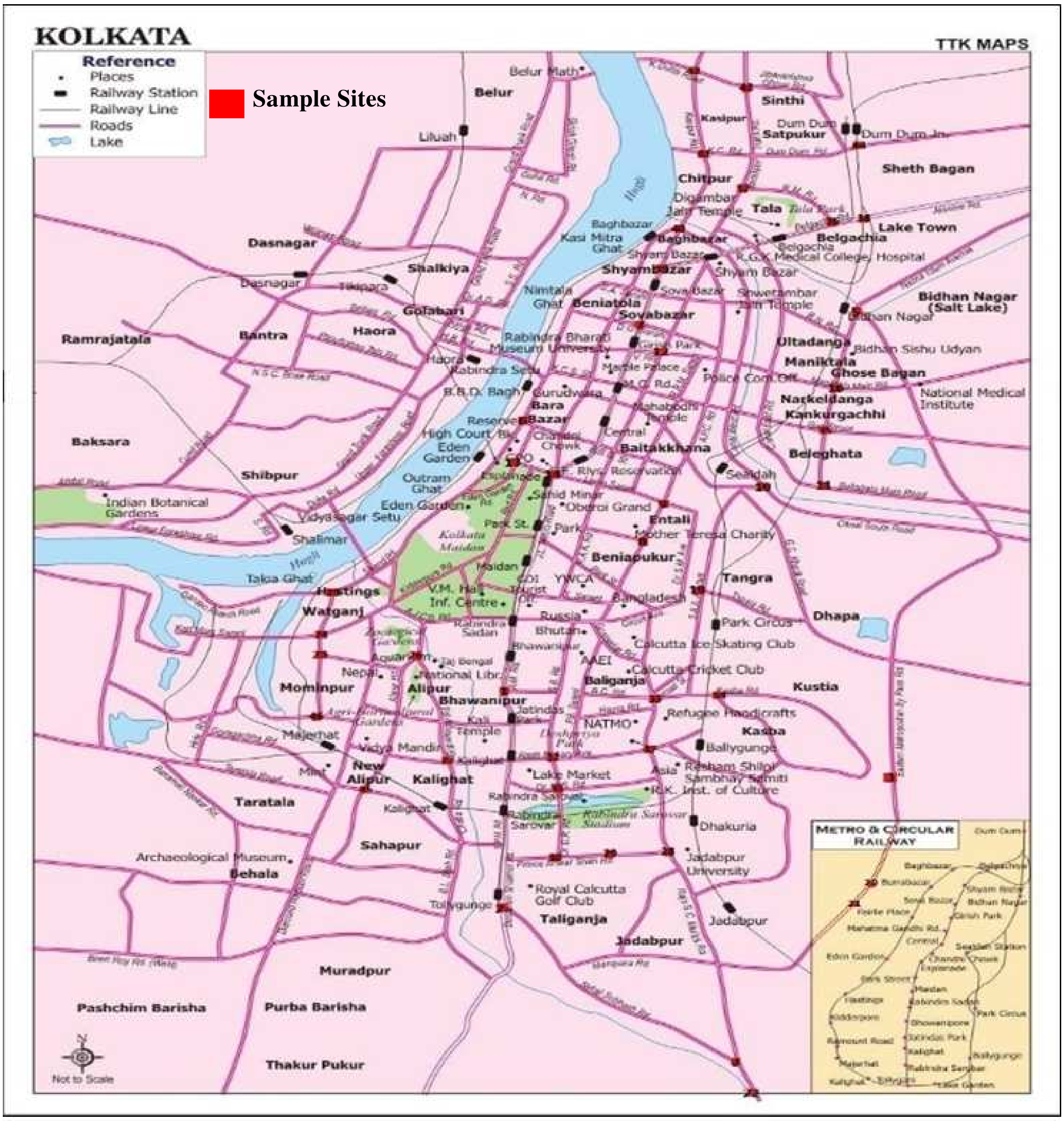

Figure 1: Kolkata, West Bengal. The Location of 50 Sampling Sites Around Metropolitan Areas

Figure 1 shows a location of the sampled point together with a schematic map of the highroad. In addition, samples, exactly from the middle of the street junction, mainly from near the traffic police booth was taken. At this time, I also talk to the nearest on duty traffic officer to know the approximate rate of traffic at that junction.

In the laboratory, samples were dried at room temperature and samples from each sampling point were put into 6 standard plastic cubical sample boxes for magnetic analysis. Then, all the samples were subjected to measurement of low-field magnetic susceptibility using a Bartington MS2 (Figure 2). We use the same 6 boxes in each sample. These boxes were pre-weighted and with known volume content.

Figure 2: Bartington Susceptibility Meter

In case of measuring at first the samples were dried first and then the sample are poured into a clean, dry pre- weighted six cubical glass boxes, and tamp it down with the flat end of a glass cover. Now these boxes are weighted by sample. After this they are put into the dual frequency (0.48 and 4.8 kHz) susceptibility meter MS2C (Bartington) which was used for susceptibility (k) measurements. The meter is now set on CGS unit. As susceptibility has no unit it will detect the value in “X 10^{-6} CGS unit”. Put the boxes, then into the meter. This meter is connected with two dual frequency sensor (470 and 4700 Hz) sensors. They are MS2D (for fieldwork) or MS2B (for laboratory work). A control for the results a dummy sample was measured along with the sample set.

5. RESULTS

5.1 Magnetic Susceptibility Data

A single test profile was measured in order to qualitatively determine the degree of magnetic pollution along a road with high-traffic frequency. Magnetic parameters can be used as a proxy for environmental pollution, when the anthropogenic dust falls, has different and distinguishable magnetic properties. A brief summary on ***k*** of all dust samples according to study point is given in (**Figure 3**). The highest and lowest ***k*** values obtained are 904583.3 m^3 / kg (No. 05) and 13325 m^3 / kg (No. 12). The median in situ susceptibility along the profile varies between 133.25 X 10^{-6} CGS unit and 904.5833 X 10^{-6} CGS unit. Most value lay within 243.6667 X 10^{-6} CGS unit and879. 3333 X 10^{-6} CGS unit. We chose the 40 highest traffic junctions along with 10 normal traffic junctions.

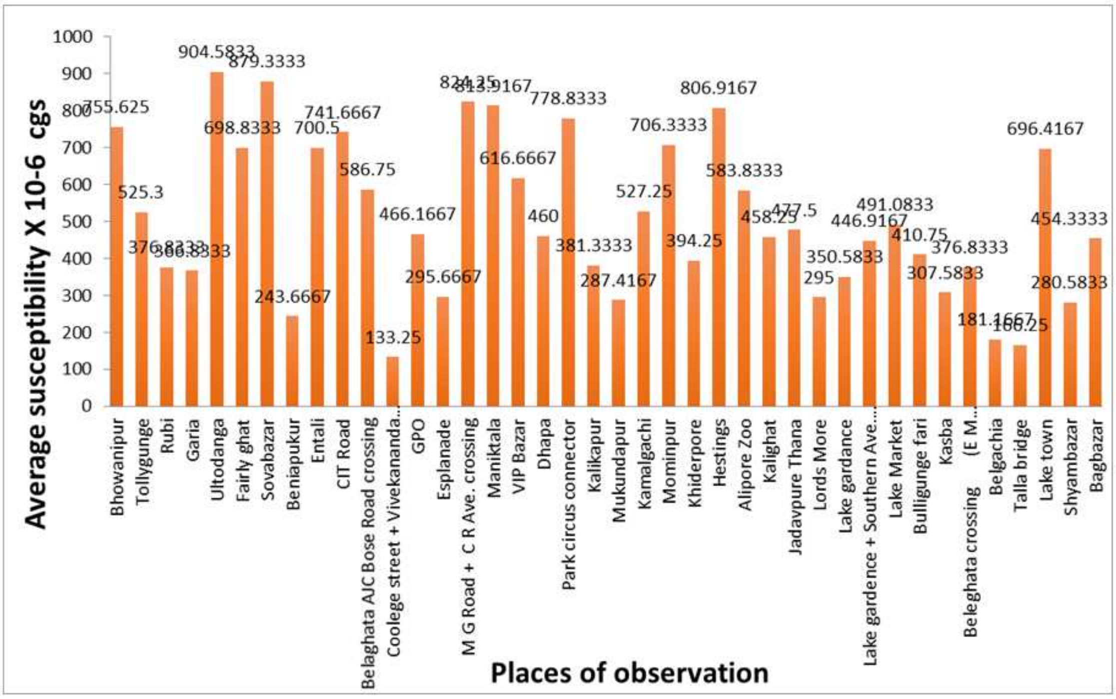

Figure 3

5.2 Mapping

Within the studied area, relatively large areas, of 185 km^2 (71 sq mi) were mapped in detail. In order to demonstrate the in-situ susceptibility variation, I present data from the main road of the urban area with heavy traffic. High-resolution susceptibility mapping was carried out on the original site using a 20 X 20 cm vector diagram **(Figure 4)**. The original data (without filtering) are shown in **Figure 6**. The highest (isolated) peaks may be due to high concentration of magnetically sensitive particles. In general, the maximum susceptibility values are located directly along with the river side. In order to highlight the trend of susceptibility vs. position of the road junctions, all 50 profiles measured for the high-resolution mapping are plotted in **Figure 5**.

6. DISCUSSIONS

The magnetic susceptibility of the road dust collected from all the important road junctions in and around Kolkata Metro city have been measured in the laboratory by high precision Bartington susceptibility MS-2 meter and thereafter mapped in 2D and 3D frame using Surfer software. The diagrams as developments are shown in **Figure 4** and **Figure 6**.

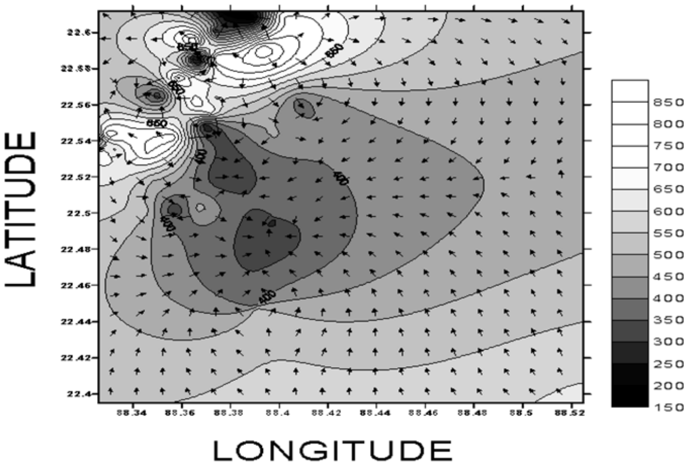

Figure 4: Results of Detailed Magnetic Susceptibility Mapping. High-resolution 2D-Mapping of the Magnetic Susceptibility along the 20 X 20 Cm Net the Original Data Set Is Shown

The highest susceptibility value (904.5833 X 10^{-6} CGS) as measured is found from Ultadanga, and the lowest value (133.25 X 10^{-6} CGS) from Vivekananda-Bidhan Sarani crossing. Remarkably a NE-SW ridge of high susceptibility value is found in the susceptibility map made of the susceptibility value of road dust. The significant peak value starts in the north from LakeTown area, crossing over to Ultadanga, Maniktala, and extending far towards central, to west and south Kolkata along Hastings, Bhowanipur, Khidirpur and Mominpur area. On the contrary, two extended troughs in susceptibility value are found which trend perpendicular to the above mentioned high susceptibility value ridge. The first trough is concentrated over the North Kolkata areas near Belgachia, Shyambazar, Talla and Bagbazar Zone, whereas the second trough, more elongated in dimension starts in Central Kolkata from Entally area, extending to Beniapukur, Dhapa, VIP Bazar, Kalikapur, Mukundupur, Safuipara, and Jadavpur Thana.

Interestingly, the high susceptibility ridge demarcates a zone where Kolkata gets the input in traffic along narrow roads. Along the Jessore road, and also in the northern part of Kolkata there is high traffic congestion, especially comprising the heavily loaded trucks, and long route buses. Moreover, in these areas old autos still play in a huge number result a sharp increase in the magnetic particles containing magnetite in the atmosphere, which settles ultimately to road dust. Narrow roads delimiting air to disperse the traffic exhaust may be another important cause behind this high value ridge.

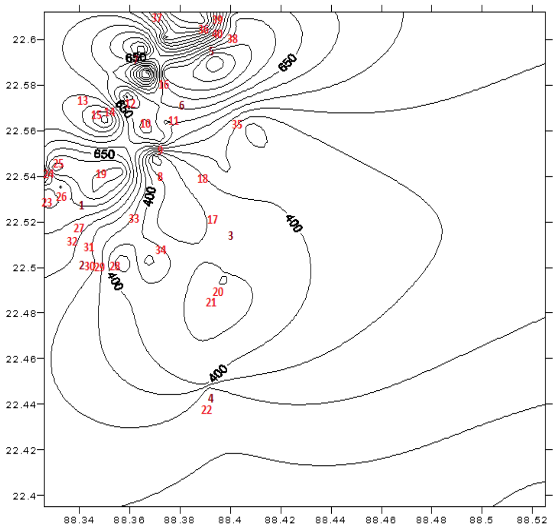

Figure 5: Results of Detailed Magnetic Susceptibility Mapping. Contour Map of Susceptibility

On the southern fringe, Kolkata gets it's a remarkably high traffic input along 2nd Hooghly Bridge resulting a sharp rise in susceptibility values in the adjoining areas like Khiderpore, Mominpur, Bhowanipur and Alipore. Another thing which is revealed out from this study is that the road crossing where, 3 or more roads meet shows a sharp rise in susceptibility values. Ultadanga road crossing with 3 major roads and Park Circus crossing comes under this segment.

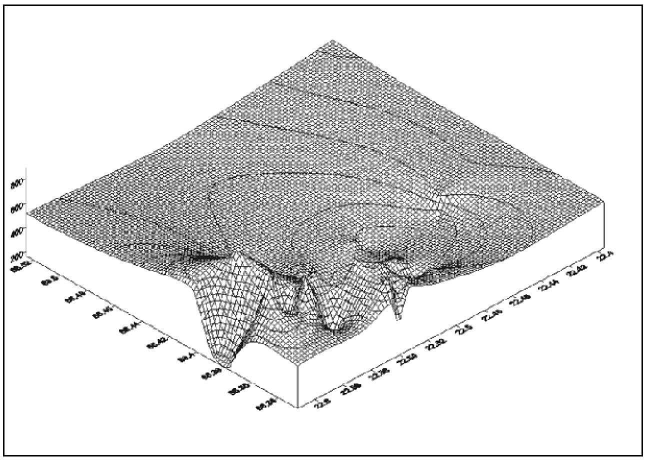

Figure 6: 3-D Mapping of Original Data Shows High and Low Peak

Among the two troughs, the extended trough in Central and East Kolkata mainly centres along Bypass area. From the 90s, this major road has become one of the main traffic arteries in Kolkata. Nowadays, traffic volume has increased to a marked degree along this road. So it is expected that magnetic susceptibility values should also reflect that. However, the trough observed in the area contradicts the assumption. Here, it seems that wide areas on the two sides of the bypass road must have played a role behind the dispersal of the traffic exhaust and thereby came under low value contours.

An almost similar logic can be applied in the case of a north Kolkata trough, where an existence of Tally Canal, proximity of the Ganges River, and wide areas near Chitpur Railway Station must have helped air movement to disperse the magnetic particles to show such a sudden low trough.

From the above observation, it can be concluded that narrow roads, with high traffic volume are creating a role behind high susceptibility values, whereas wide roads, or open space around even busy road is capable to disperse the magnetic particles.

CONCLUSIONS

Magnetic Susceptibility Mapping was used in the field in order to trace potentially contaminated areas nearby the congested traffic in Kolkata Metro City highways. Clearly enhanced value of the magnetic susceptibility up to 800–900 (X 10^{-6} CGS) and even more were found on the roadsides. These values are influenced by traffic emissions. The width of the area on the roadside with clearly enhanced susceptibility values are determined by the traffic density (about 34,000-40,000 vehicles per day). The main question is, whether certain magnetic parameters like magnetic susceptibility can be used as proxies for detecting contaminants like heavy metals or organic matter (e.g., PAHs). In this respect, only a few positive results have been reported in the literature (e. g. Dekkers and Pietersen, 1992; Morris et al., 1994; Versteeg et al., 1995, 1996; Georgeaud et al., 1997; Kapicka et al., 1997). The relation between susceptibility (or other magnetic) parameters and (in) organic pollutants are still in question.

Thus, for isolated sources of pollution which is related to traffic density of any Metro City like Kolkata, magnetic mapping was demonstrated to provide a rapid, cheap, efficient and highly sensitive alternative method for investigating potentially contaminated areas. A new way of environmental monitoring is possible as indicated by repeated measurements in the field. Magnetic mapping can reduce the costs (time and manpower) in comparison with direct analyses of pollutants. So, with respect to my research work I can could that magnetic screening can be used as a first step in determining environmental pollution and the tracing of its potential sources. For a more systematic sampling magnetometer can be used as a proper base in order to reduce time-consuming and expensive laboratory analyses to a reasonable level.

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