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Qualitative Assessment of Traffic-Derived Pollution in Urban Topsoil of Chennai, India Using Magnetic Susceptibility and SEM–EDX Analysis

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ABSTRACT

The impact of traffic-related activities on urban topsoil was evaluated by magnetic susceptibility and SEM-EDX analyzes. Low-frequency susceptibility (χLF) varied from 234 × 10^{-6} to 735 × 10^{-6} m^3 kg^{-1}, signifying considerable aggregation of magnetic particles. The frequency-dependent susceptibility (χFd%) was predominantly minimal (<1%), with the exception of the soil sample obtained from Nandanam, which had a value of 4.08%. This indicated the existence of fine-grained superparamagnetic particles linked to contemporary human activities. SEM analysis further confirmed a heterogeneous composition characterized by fibrous and flaky aggregates, suggesting the incorporation of organic material alongside fine mineral particles. EDX analysis indicated a major occurrence of silicate minerals (O, Si, Al), alongside significant iron content and trace amounts of metals such as Ti, Co, Nb, and Mo. The study reveals that automobile emissions, the physical mechanical wear of vehicles, and road dust have a considerable influence on soil composition, highlighting the vulnerability of roadside soils to urban pollutant accumulation.

Keywords Magnetic susceptibility, Ferrimagnetic minerals, Vehicular emissions, Soil pollution, Frequency-dependent susceptibility, SEM-EDX studies.

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INTRODUCTION

Urbanization and increased vehicle activity have made a significant contribution to environmental pollution, especially in urban areas. Along with poor air quality, automotive emissions exacerbate degradation of roadside soils by depositing particulate matter, hydrocarbons, and hazardous metals, which give rise to secondary organic-inorganic aerosols. Their persistence and bioaccumulation affect soil chemistry and pose long-term ecological and public health hazards (Verma *et al.* 2023, De Silva *et al.* 2020).

In India, roadside PM 2.5 and BC levels are markedly elevated in traffic hotspots, underscoring the pressing need to prioritize automotive emissions as a public health concern (Badeenezhad *et al.* 2025, Zhang *et al.* 2025, Lee *et al.* 2025). In the present study, Chennai, a metropolitan city, was chosen as the location for the study of topsoil traffic pollutants. Owing to high vehicle density and congestion, people living and commuting in traffic corridors experience sustained exposure levels above safe limits (De Silva *et al*. 2020).

As a preliminary examination, the soil collected from eight heavy traffic areas of Chennai was tested using magnets to identify magnetic particles; an astonishingly large proportion of the soil was metal particles obtained in a powdered form. Hence, a magnetic susceptibility analysis was chosen to explore the magnetic susceptibility of the topsoil. Because, automobile emissions discharge magnetic particles, including iron oxides from metallic wear debris, and soot-coated minerals, which accumulate adjacent to roadways on the topsoil (Paramasivam *et al.* 2023, Murthuza *et al.* 2023).

After confirming the considerable value of magnetic susceptibility of the soil samples, Scanning Electron Microscopy (SEM) combined with Energy Dispersive X-ray Analysis (EDX) has been used to obtain direct confirmation and magnetic particles present in the soils of the study (Murthuza *et al.* 2021b, Kuklová *et al.* 2022, Alasfar and Isaifan 2021, Kumar 2024).

MATERIALS AND METHODS

Study Area and Sample Collection

Eight high-traffic locations within Chennai were selected based on traffic density, visible roadside dust accumulation, and exposure to vehicular emissions. Sampling sites included Nandanam (S1), Teynampet (S2), Gemini Bridge (S3), Mylapore (S4), Marina Beach(S5), Omandurar (S6), Island Ground (S7), and MRC Nagar (S8). The soil samples were collected in April,2023. A nylon brush and scraper were used to collect soil samples to avoid metal contamination. To minimize negative susceptibility and a decline in the susceptibility value, they were dried in a desiccator at room temperature, taking care to exclude moisture contamination.

Magnetic Susceptibility Measurements

Measurements of magnetic susceptibility were recorded at low (0.465 kHz) and high (4.65 kHz) frequencies using the MS2B dual-frequency susceptibility meter linked to computer-operated Multisus2 software. Low-frequency susceptibility (χLF), high-frequency susceptibility (χHF), and frequency-dependent susceptibility (χFd%) were determined for all the soil samples.

$$\chi Fd\% = \frac{\chi Lf - \chi Hf}{\chi Lf} \times 100$$

SEM–EDX Analysis

Morphological study of the topsoil samples and their elemental composition were analyzed using a high-resolution scanning electron microscope (HRSEM, FEI Quanta 200). SEM images provided information regarding particle texture, aggregation, and morphology, while EDX analysis identified elemental constituents associated with both natural minerals and anthropogenic contamination.

RESULTS AND DISCUSSION

Magnetic Susceptibility of Topsoil Samples from High-Traffic Urban Areas

Magnetic susceptibility analysis was performed to assess the magnetic susceptibility of topsoil samples collected from eight locations (S1 to S8). Magnetic susceptibility measurements revealed clear spatial variability among the eight sampling sites located in heavy traffic corridors (Table 1). Fig. 1 (a) shows the places from where soil samples were collected. In fig. 1 (b), low-frequency susceptibility (χLF) values ranged from 234×10^{-6} m^3 kg^{-1} (S8) to 735×10^{-6} m^3 kg^{-1} (S1). In figure 1 (c), high-frequency values (χHF) followed a similar pattern, spanning from 233×10^{-6} m^3 kg^{-1} at S8 to 705×10^{-6} m^3 kg^{-1} at S1. The highest susceptibilities were consistently observed at

Table 1. Sampling location, Low frequency, High frequency and percent frequency dependent magnetic susceptibility of the soil samples.

Sample ID	Latitude	Longitude	χLF (10^{-6} m^3 kg^{-1})	χHF (10^{-6} m^3 kg^{-1})	χFD%
S1 Nandanam	13.030	80.241	735.00	705.00	4.08
S2 Teynampet	13.039	80.247	493.00	492.00	0.20
S3 Gemini Bridge	13.050	80.251	625.00	622.00	0.48
S4 Mylapore	13.036	80.267	565.00	563.00	0.35
S5 Marina beach	13.058	80.281	440.00	437.00	0.68
S6 Omandurar	13.067	80.274	692.00	688.00	0.57
S7 Island ground	13.074	80.285	691.00	689.00	0.28
S8 MRC Nagar	13.018	80.272	234.00	233.00	0.42

S1, S6, and S7, whereas the lowest was recorded at S8. As per the Figure 1 (d), the frequency-dependent susceptibility (χFd %) ranged between 0.20% (S2) and 4.08% (S1). Except for S1, χFd % values across the sites remained below 1%, suggesting stable ferrimagnetic minerals dominate the magnetic signal. The elevated χFd % at S1, however, indicates the presence of fine-grained superparamagnetic particles, which are commonly associated with recent anthropogenic inputs. Given that all sampling locations are

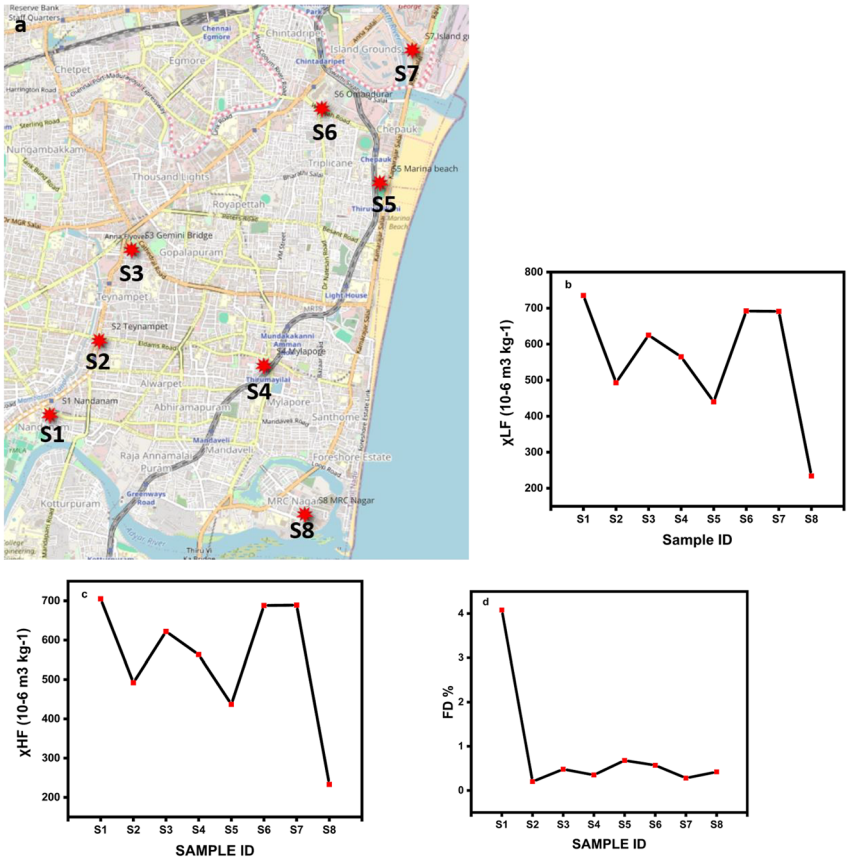


Fig. 1 (a) junctions at which samples were collected in Chennai, **(b)** variation of low frequency magnetic susceptibility with location ID, **(c)** variation of high frequency magnetic susceptibility with location ID, and **(d)** variation of percent frequency-dependent magnetic susceptibility with location ID.

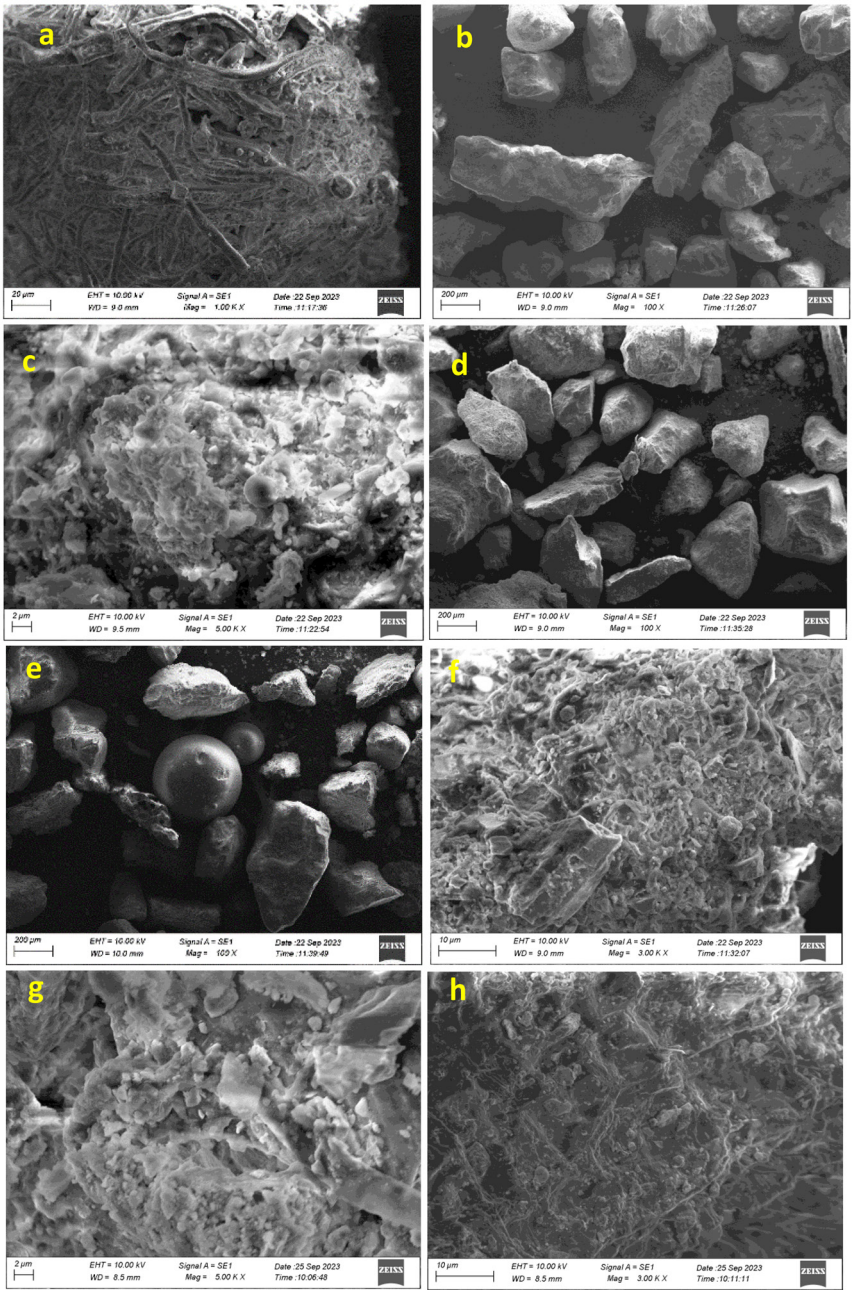


Fig. 2. SEM image of top soil samples from eight traffic areas in Chennai, **(a)** Nandanam **(b)** Teynampet, **(c)** Gemini bridge, **(d)** Mylapore, **(e)** Marina beach, **(f)** Omandurar, **(g)** Island ground, and **(h)** MRC Nagar.

in high-traffic urban environments, the enrichment in χLF, particularly at S1, S6, and S7, strongly suggests contributions from vehicular sources. Exhaust emissions, brake and tyre wear, and resuspended road dust are well-documented sources of ferrimagnetic particles, often rich in magnetite and maghemite. These anthropogenic particulates are likely to have enhanced the bulk susceptibility values observed in this study.

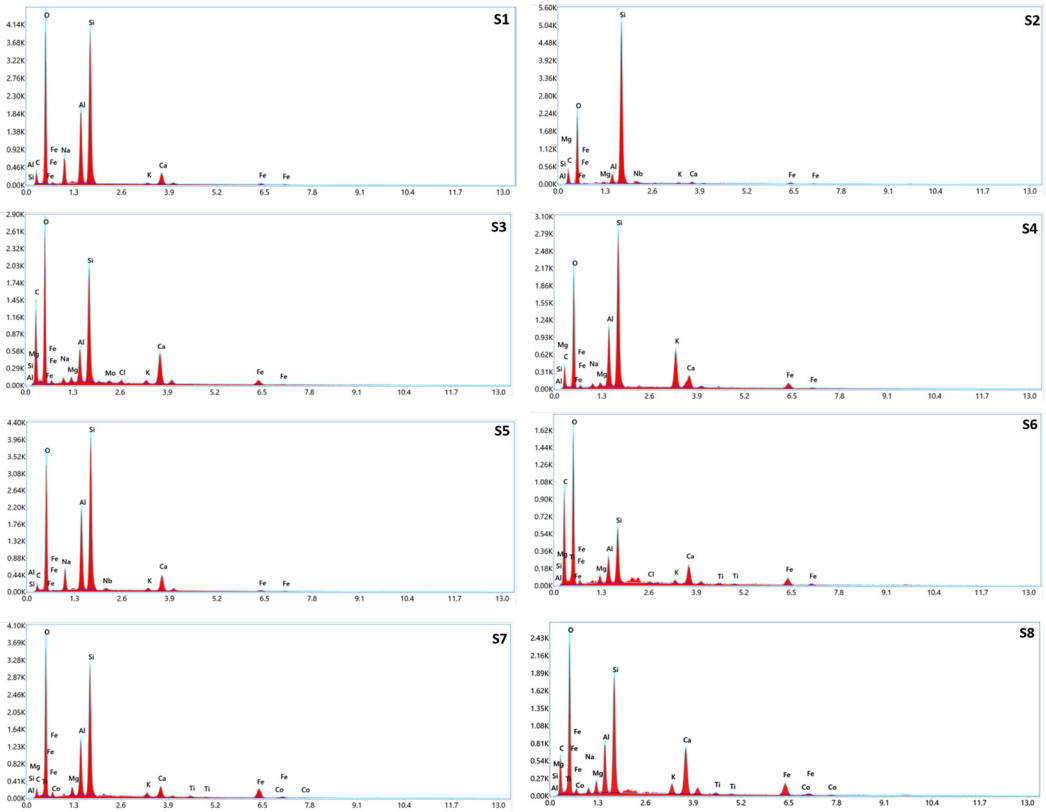


Fig. 3. EDAX spectra shows elemental composition of the top soil samples from eight traffic areas in Chennai, **(S1)** Nandanam, **(S2)** Teynampet, **(S3)** Gemini bridge, **(S4)** Mylapore, **(S5)** Marina beach, **(S6)** Omandurar, **(S7)** Island ground, and **(S8)** MRC Nagar.

Moreover, SEM study was done to confirm this.

Morphology of the soil samples (S1–S8)

The scanning electron microscopy (SEM) images of the eight soil samples reveal significant variations in surface morphology, particle size, and textural characteristics, reflecting both natural soil-forming processes and anthropogenic influences from traffic activity. In Fig. 2(a), sample S1 exhibits a heterogeneous structure with fibrous and flaky aggregates, indicating the presence of organic matter mixed with fine mineral particles. In Fig. 2(b), sample S2, the particles appear angular and irregular with rough surfaces, characteristic of mechanically weathered mineral grains, likely quartz-rich road dust. In fig. 2(c), sample S3 displays highly agglomerated and porous structures, suggesting the accumulation of fine particulates and possible adsorption of pollutants on particle surfaces. In fig. 2(d), sample S4 shows well-defined, angular to sub-angular particles with relatively uniform sizes, indicating a predominantly mineral origin with limited aggregation.

In contrast, in Fig. 2(e) S5 shows a mixture of angular and rounded particles, with some smooth spherical grains, suggesting contributions from high-temperature processes such as vehicular emissions or industrial particulates. In fig. 2(f), sample S6 shows fibrous and intertwined structures with irregular morphology, indicative of organic matter and soot-like deposits, which may be linked to vehicular exhaust emissions. In Fig. 2(g), sample S7 exhibits flaky and layered textures with signs of surface roughness and aggregation, suggesting a combination of clay minerals and deposited particulates. Finally, in Fig. 2(h) sample S8 presents a dense and compact morphology with less distinct particle boundaries,

indicating particle clustering and possible cementation due to prolonged environmental exposure and pollutant deposition.

Overall, the SEM observations demonstrate that while some samples (S2, S4) are dominated by geogenic mineral particles, others (S3, S5, S6, S7, and S8) show clear evidence of anthropogenic influence, including particle agglomeration, surface coatings, and the presence of spherical or fibrous structures. These morphological features support the EDAX findings, confirming that traffic-related activities contribute to changes in soil texture and particle characteristics, potentially affecting pollutant retention, reactivity, and environmental behavior of the soils.

Elemental composition of the soil samples (S1–S8)

In Fig. 3, the EDAX spectra of all eight soil samples (S1–S8) collected from the traffic-influenced area show a consistent dominance of oxygen (O), silicon (Si), and aluminum (Al), indicating that the soils are primarily composed of silicate and aluminosilicate minerals derived from the weathering of parent rock material. The presence of major elements such as iron (Fe), calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg) across all samples further supports the natural geogenic origin of the soil matrix. However, variations in peak intensities and the occurrence of additional elements reflect differences in local environmental conditions and external inputs. Samples S2, S5, and S7 exhibit particularly strong silicon peaks, suggesting enrichment of quartz, likely due to the accumulation of road dust. In contrast, samples S1 and S4 display relatively balanced elemental distributions with fewer trace elements, indicating comparatively lower anthropogenic disturbance and a stronger influence of natural soil-forming processes.

Notably, several samples show clear evidence of anthropogenic contamination associated with traffic activities. Elevated carbon (C) peaks in S3 and S6 indicate the deposition of vehicular exhaust particulates, such as soot and hydrocarbons, marking these locations as zones of direct emission influence. The widespread presence of iron (Fe), with higher intensities in S1, S3, S6, and S7, suggests contributions from both natural iron-bearing minerals and vehicular sources such as brake and engine wear. Additionally, the detection of trace elements, including titanium (Ti), cobalt (Co), niobium (Nb), molybdenum (Mo), and chlorine (Cl) in selected samples further highlights the impact of traffic and urban activities. For instance, Ti and Co in S7 and S8 are indicative of inputs from vehicle components and road dust, while Nb in S2 and S5 and Mo and Cl in S3 and S6 point toward industrial emissions, lubricants, and urban pollutants. Based on these variations, S3, S6, and S7 can be identified as the most affected by anthropogenic inputs, whereas S1 and S4 represent relatively less impacted sites. Overall, the results demonstrate that although the soils share a common silicate-based composition, traffic-related activities significantly modify their elemental characteristics through the introduction of carbonaceous material and trace metals, with potential implications for soil quality and environmental health.

CONCLUSION

The current study shows that traffic-related pollution has a major impact on roadside soils in Chennai. High-traffic areas had higher χLF values according to magnetic susceptibility studies, suggesting a significant buildup of ferrimagnetic particles from vehicle activity. Strong anthropogenic influence was confirmed by SEM observations that revealed a variety of particle morphologies, such as spherical combustion-derived particles, agglomerates, and soot-like deposits. Additionally, enrichment of Fe-bearing particles and trace metals like Ti, Co, Nb, and Mo linked to vehicle emissions, brake wear, tire abrasion, and metallic alloy deterioration was found using EDX analysis.

Traffic-derived pollution in urban soils was successfully identified and characterized by the combined use of magnetic susceptibility and SEM–EDX analysis. These results underline the necessity of ongoing environmental monitoring in highly populated metropolitan areas and highlight the significance of roadside soils as reservoirs of vehicle pollution.

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