Multivariate Urban Air Quality Assessment of Indoor and Outdoor Environments at Chennai Metropolis in South India

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Abstract: The present study examines indoor and outdoor environmental particulate matter and gaseous pollutants in order to evaluate the urban air quality, the sources and pathways of pollutants, and its impact on Chennai megacity, South India. A total number of 25 air conditioner filter particulate matter samples collected from residential buildings, schools, colleges, commercial shopping malls, and buildings near urban highways were studied for indoor air quality. Similarly, outdoor air quality assessments have been done in various parts of the Chennai metropolis, including the Manali-Industrial area, the Velachery-Residential site, and the Alandur Bus Depot, as well as collected air quality data sets from the Central Pollution Control Board at continuous ambient air quality monitoring stations. The suspended atmospheric particles where the highest concentration (47%) occurred were mostly located in the roadside environments followed by commercial areas (42%), which indicates the increase in air pollution in the roadside areas. Further, environmental magnetism and ecological risk indices were studied from the collected data set. The study predicts that the air pollutants were predominantly from anthropogenic sources, such as vehicle emissions, effluents from power plants, abrasion of tires, steelworks, burning of fossil fuels and construction materials, etc. As a result, the current study suggests 68% of indoor pollutants were from the anthropogenic input, 18% from the pedogenic origin, and 14% from high heavy metal pollution at the sampling sites. This indicates that raising the ventilation rate via mechanical components significantly enhances the indoor air quality. These findings might be valuable in improving urban air quality, reducing traffic-related pollutants, and improving environmental quality.

Keywords: urban air quality; air conditioning filter samples; mineral magnetism; toxic elements; gaseous emissions; ecological risk

1. Introduction

Suspended particulate matter is a mixture of solid and gaseous particles in the atmosphere, which is an emerging threat in developing countries. It is precipitated by vehicle...
emissions, suspended road dust, industrial hubs, construction materials, biomass combustion, domestic cooking, smoking, pollen, mold spores, household and farming chemicals, deforestation, smoking, and seasonal factors such as storm dust and sea salt [1]. SPM is an atmospheric medium that can indicate the degree of pollution caused by trace elements, polycyclic aromatic hydrocarbons (PAHs), and other biological contaminants [2]. Thus, air pollution is one of the significant problems in the world’s growing urbanization and industrialization [3]. Urban air quality in several countries contains organic and inorganic toxic contaminants, and trace metals in specific have been identified [4–7]. Atmospheric pollutants, or heavy metals, are also the most important contaminants because of their activity and toxicological significance in ecosystems [8]. Toxic metals in SPM are the consequence of both natural and manmade activities, such as urbanization, industrialization, automotive emissions, biomass burning, and construction materials, which have resulted in a significant enrichment of such substances [9–12]. Urban environmental particulate matter is the primary source of atmospheric contamination, which has an emerging impact on human health and ecological risk [13,14]. Humans can directly absorb the toxic elements that enter an organism through the particles via inhalation, ingestion, and dermal contact with the human body [15]. Particulate matter (PM) is one of the primary pollutants responsible for the majority of health issues in Indian cities [16,17]. Suspended particles, which may be re-suspended in the atmosphere due to climatic factors and anthropogenic activities, have the most significant impacts on air environmental quality and human health in metropolitan areas [18,19]. According to recent research, SPM contains ferrimagnetic particles exacerbated by the environmental magnetism of nearby topsoil and rock formations [20,21]. India is the second-most populous country in the world where air quality-based incidence has risen in the last decade. Among the world’s top 20 polluted cities, 13 Indian cities are listed for poor air quality [22,23]. Various monitoring sites in India record high concentrations of PM2.5 that are suggested by the National Ambient Air Quality Standards (NAAQS) limits on the atmospheric concentration of 40 µg/m³. In India, 20–28 million people are affected by respiratory diseases such as asthma, of which 10 to 15% are children [24,25]. These gravitational settling particles usually have a particle size range between 0.5 and 1000 µm. Furthermore, in the metropolitan region, 80–90% of people spend all of their time in this indoor environment, which has a significant impact on human health and working efficiency [26,27].

Usually, outdoor environmental particulate matter samples are collected using high-volume air samplers, or they can be collected from dry vacuum pumps and dust collector machines on the street and roadside. Many regions of the globe utilize air-conditioning systems, and those parts are often affected by severe air pollution due to increased anthropogenic activities. In addition, fossil fuel combustion in households and the discharge of municipal waste release several pollutants, including particulate matter and other gaseous pollutants [28]. The factors affecting indoor and outdoor environments include meteorological parameters, particle pollutants, biological pollutants, and gaseous pollutants [29]. Environmental magnetic methods are mainly using for the determine the source and pathway of contaminants from atmospheric particles and their characteristics [30–35]. Finding the source of air pollution is essential for controlling and preventing ambient emissions, particularly at the source. Nevertheless, in recent decades, many proxies have been approaching and investigating air quality management, but this study applies environmental magnetic techniques to determine the magnetic mineral characteristics of the sources associated with air pollutants in the SPM. Further, this study evaluates indoor and outdoor environmental air quality in urbanized zones and finds the sources of pollutants by assessing the ecological risk. In addition, the multivariate methods assessments of urban air quality, including gaseous pollutants and influences of meteorological parameters, would be used in the Chennai megacity in South India.
2. Materials and Methods

2.1. Location of the Study Area

The Chennai megacity is the fourth largest city in India and the capital of Tamil Nadu state. The study area is approximately 70 square miles and falls within the latitudinal and longitudinal extensions of 12°50′–13°20′ N and 80°10′–80°40′ E, with a mean sea level of 6.7 m (Figure 1). The Chennai metropolis experiences a tropical climate; thus, the weather is typically hot and humid. The study areas fall in three different geological formations: the Archaean crystalline rocks, consolidated Gondwana formation, and Tertiary periods of sediments. Additionally, it presents in the recent alluvium formation. The northern part is primarily an industrial area, comprising petrochemical industries at Manali (Chennai Petrochemical Corporation Limited or CPCL), thermal power plants at Ennore, and other industries at Ambattur. The southern part of Chennai has industrial regions (Guindy Industrial Estate), while the western section, near Sriperumbudur on the Bangalore highway, is growing with new factories. A part of logistics, software services, health care, automobile, and manufacturing industries form the financial base of Chennai city.

Figure 1. Study area with sampling sites of Chennai urban zone, South India.
2.2. Sampling and Laboratory Procedures

A total of 25 air conditioner (AC) filter particulate samples were collected from the Chennai metropolitan area’s indoor environments. The sampling locations were chosen from the city’s various land use zones, which included industrial areas (IA), roadside/traffic areas (R/TA), and residential and commercial centers (RC). The particulate samples were collected (5 samples) from industrial regions surrounded by heavy equipment manufacturers, petrochemical stations, coal-burning power plants, metal processing, and metallurgical industries. Further, (14 samples) the samples collected from roadside locations and the areas nearby the railway, expressway, and high-density traffic roads. The 6 filter particulate samples were collected from residential and business sectors, and these sites have high-density population and commercial areas. Initially, the interior air conditioner filters were cleaned, and SPM samples were collected after one month. The sampling period, pattern, and duration are noted properly. All samples were collected, tagged, and sealed in a sampling box before being transported to the research lab. The aqua regia sample was done by particulate samples (0.1 g) that were digested by using a concentration of nitric acid (Merck, CAS-7697-37-2) and hydrofluoric acid (Merck, CAS-7664-39-3) mixture ratio of $\text{HNO}_3 : \text{HF} = 3:2$ and heated at 150 $^\circ\text{C}$ in using the hot plate open-vessel method [28,29]. The calibration solutions (blank samples) were prepared at the same volume fraction as the samples in the same acid mixture solutions. The mixture was cooled before being properly opened. The individual digested samples were quantitatively transferred to a 50 mL volumetric flask and diluted using ultra-pure water. After proportional dilution with an appropriate calibration standard, these solutions were analyzed using Atomic Absorption Spectrophotometer (Perkin Elmer AAS Analyst 800). Trace element concentrations, such as Fe, Cr, Pb, Cu, Zn, Mn, Ni, and Co, were determined and used for ecological risk assessment in the study domain. Under the same settings, the reference standards materials were ingested.

The indoor and outdoor air quality study adopted sampling materials and methods and are graphically presented in Figure 2. The particle size was analyzed using a laser Malvern Master Sizer 2000 with an analytical size range of 0.1–2000 $\mu\text{m}$. It used a resolution of 0.5 and quantification of SPM to analyze the electronic analytical precision digital balance. The environmental magnetism of atmospheric particulate samples was determined by using Bartington Magnetic Susceptibility Meter (Model MS2B) with dual-frequency mode (Low (0.47 kHz) and High (4.7 kHz) frequency) sensors [31,32].

![Figure 2](image-url)
The characteristic of environmental magnetism, such as mass-specific magnetic susceptibility ($\chi$), low-frequency magnetic susceptibility ($\chi_{\text{lf}}$), and high-frequency magnetic susceptibility ($\chi_{\text{hf}}$), was evaluated in the collected particulate samples. The volume or mass-specific susceptibility divides mass by volume; the calculation of the formula gives it [30]. All MS2B samples were measured in 10 cm$^3$ pots, and each sample mass was,

$$\chi_{\text{lf}} = \frac{X}{\rho}$$

(1)

where the $\chi_{\text{lf}}$ is the low-frequency mass-specific susceptibility (m$^3$ kg$^{-1}$); the volume susceptibility (10 mL) was used and $\rho$ is the sample bulk density (kg m$^{-3}$). Likewise, the high-frequency magnetic susceptibility ($\chi_{\text{hf}}$) was evaluated. Further, the frequency-dependent magnetic susceptibility was calculated following the formula suggested by [31].

$$\chi_{\text{fd}}\% = \left( \frac{\chi_{\text{lf}} - \chi_{\text{hf}}}{\chi_{\text{lf}}} \right) \times 100$$

(2)

The frequency-dependent magnetic susceptibility defines the concentration of ultrafine magnetic grains generated through pedogenesis, superparamagnetic (SP), or single stable domain (SSD) [32]. Environmental magnetism data were used to calculate the concentration of ultrafine (0.03 mm) superparamagnetic, ferrimagnetic minerals found as crystals in soil that are primarily generated by biological activities. Whenever ultrafine minerals are dependent on the concentration, the mass value is somewhat lower when assessed at high frequency; when the particles are absent, the mass value is the same at both frequencies. Blanks with the same procedure but without the particulate samples were generated for quality assurance and quality control, which comprises reagent blanks, analytical duplicates, and standard reference material analysis. The observed magnetic minerals’ concentration was estimated to be 90–100%, and the analytical accuracy of the results was more than ±5% [33].

The outdoor air pollutant data sets were collected from Central Pollution Control Board and measured by Continuous Automatic Air Quality Monitoring Stations (CAAQMS). The ambient air quality parameters included fine particulate matter (PM2.5 (µg/m$^3$)), sulfur dioxide (SO$_2$ (µg/m$^3$)), nitrogen dioxide (NO$_2$ (µg/m$^3$)), nitrogen monoxide or nitric oxide (NO (µg/m$^3$)), nitrogen oxides (NOx (ppb)), carbon monoxide (CO (µg/m$^3$)), ozone (O$_3$), Benzene, Toluene, and O Xylene. The meteorological data sets were wind direction (WD (degree)), wind speed (WS (m/s)), solar radiation (SR (W/m²)), temperature (°C), and relative humidity (RH (%)), collected from the Central Pollution Control Board stations at Manali (industrial zone) and Velachery (residential area) and Alandur Bus Depot (roadside area). Analytical variability was assessed on each sample using repeated measurements. Using SPSS 20 version, a large data set was geo-statistically analyzed to determine the origin of the contaminants (IBM Corp. in Armonk, NY). Magnetic and geochemical data were analyzed using Micro Soft Excel 2016 and GeoDa software, the most typical multivariate statistical analysis approach.

3. Results and Discussion
3.1. Indoor Environmental Suspended Particulate Matter (SPM) Characterization

The urban atmospheric particles contain toxic pollutants such as organic and inorganic compounds and trace elements concentrations. A total of 25 AC filter particulate samples collected from various places were classified as industrial areas (n = 5), roadside/traffic areas (n = 14), and residential/commercial areas (n = 6). The SPM analysis determined how much SPM was accumulating in the samples per day. The maximum SPM concentration of 0.382 g/day was observed at the sampling station Tiruvottiyur industrial sectors, as shown in Figure 3. There is higher concentration of SPM is the presence of industries and highway roads in this area. The minimum SPM concentration of 0.01 g/day was observed at Mugapper west and Keelkatalai, which fall under residential areas. Indoor air
Atmosphere 2022, 13, 1627

pollutants in the closed environment (e.g., office, home) may be derived from the outdoor environment [14]. Since AC filters indoor air, toxins may be stored and accumulated in those filters [6,24]. The impact of exposure to humans depends on indoor air pollutants. It may be observed immediately for sensitive people and after months or years for others. Immediate symptoms like eye irritation, throat pain, vomiting, dizziness, and tiredness can often present after a single exposure or after multiple exposures [23]. A breathing problem such as asthma may arise shortly after exposure to air pollutants in an indoor environment. The rise in the worldwide prevalence of asthma and allergies has prompted work on alternative environmental factors in recent years [26,33].

![Figure 3. The spatial variation of indoor environmental suspended particulate matter (SPM) (g/day) and station-wise concentration (mg/m³) of SPM in the study area.](image)

3.1.1. Particle Size of the Atmospheric Particulate in Indoor Environments

The particle size of the collected AC filter samples plays a major role in the indoor environment. The particulate matter was classified as suspended atmospheric dust (SAD), heavy dust (HD), and settled dust (SD) based on their size. The measured particle size of the samples ranges from 0.5 µm to 1000 µm. The particulate matter with a size range of 0.001 µm to 1 µm is mainly suspended atmospheric dust, 1 µm to 100 µm is accumulated settling dust, and 100 µm to 1000 µm is heavy dust [36]. The spatial variation of the settled and suspended atmospheric particulate, heavy particulate, and overall particle size distribution of the study area is given in Figure 4.

The size of the suspended atmospheric particulate is less than 1 µm, which is the finest particle that causes harmful effects on human health since they are easily inhaled, ingested, or dermally contacted by humans [15]. These suspended atmospheric particulate particles were highest (4.7%) in roadside samples, followed by commercial areas (4.2%), which indicates the increase in air pollution in the roadside areas given in the Supplementary Materials (Figure S1). Very fine particles may pass through the skin and enter the body like soluble particles that dissolve and pass through the. These particulate samples can cause adverse effects on the elderly, children, and people with chronic lung disease and influenza skin [36]. The volume of settled particulate samples with a size range of 1 µm to 100 µm is 60% in all the locations, as shown in the Supplementary Materials (Figure S2). These settled particulate samples can cause various health issues like eye irritation, respiratory problems (asthma), non-malignant respiratory diseases, lung cancer in non-smokers, bronchitis, oxygen deficiency in blood, and decreased lung function [2]. The volume of heavy particulate particles with a size range of 100–1000 µm is 34.5% at Tiruvottiyur, the northern part of the study area that comprises mainly particulate industrial sectors. It shows a higher risk of pollution, as shown in the Supplementary Materials (Figure S3). On
the other hand, with coarse-particle particulate, the human immune system is typically ineffective against such hazardous fine wood particles, allowing them to enter the body essentially undetected. With disastrous results, the fine particulate in respiratory organs can cause diseases, including bronchitis, asthma, and even cancer [12]. Heavy particulate samples cause permanent damage to organs, developmental problems in children, lung cancer, and premature death, and it affects the central nervous system and reproductive system. Fine particulate and suspended particulate are particularly prevalent in metropolitan areas. They occur primarily in burning fuels (e.g., traffic, heating systems) and industrial operations (e.g., manufacturing, power production) and are not observable to the human eye. Because more than 98% of the particles are less than 1 µm in size, this area is the most hazardous [37]. These particles can cluster together to create large, rough surfaces, indicating a solid adsorption characteristic for gases, liquids, and biogenesis compounds like microorganisms [11].

Figure 4. The particle size of particulate samples classified based on size (SAD-0.001 µm to 1 µm; SD-1 µm to 100 µm; HD-100 µm to 1000 µm) in all sampling sites of the study area.
3.1.2. Environmental Magnetism of Indoor AC Filter Particulate

Magnetic properties are suitable proxies to record pollution, as they are highly sensitive, have fast processing in laboratory experiments, and the preparation of samples is relatively easy. Laboratory instruments are relatively small in size and user-friendly with most non-destructive steps [21]. Numerous experiments were done using magnetic properties to determine the air quality of urban environments [16]. The mass frequency-dependent magnetic parameters of air conditioner filter particulate samples are plotted in Figure 5.

Figure 5. Spatial distribution of environmental magnetic parameters, such as the mass-specific magnetic susceptibility (χ), mass-specific low magnetic susceptibility (χ_Lf) and frequency-dependent susceptibility (χ_{fd%}), in the study area with textural and superparamagnetic (SP) grain size characterization.
Magnetic susceptibility, one of the most commonly used magnetic parameters of environmental materials in environmental magnetism, is primarily reflected in the concentration of ferrimagnetic and ferromagnetic concentrations in the environmental samples [31]. The analysis was performed three times, and the average values were taken for further calculation, implemented by [32]. The particulate samples from residential and commercial areas were at low and very low concentrations, given as $\chi_{\text{lf}}$ ($10^5 \times 10^{-8}$ m$^3$ kg$^{-1}$), whereas some parts of commercial area samples exhibited moderate to high $\chi_{\text{lf}}$ values (average = $17,946 \times 10^{-8}$ m$^3$ kg$^{-1}$; and $15,756.467 \times 10^{-8}$ m$^3$ kg$^{-1}$). The high value of $\chi_{\text{lf}}$ indicates the presence of ferrimagnetic grains in the samples. Similarly, according to Dearing 2001, the frequency-dependent magnetic susceptibility ($\chi_{\text{fd}}\%$) is used to determine the presence of superparamagnetic (SP) mineral fractions [35]. The spatial variability of environmental magnetic activity of ferrimagnetic and superparamagnetic grains is shown in Figure 5. The most vulnerability was seen in roadside and commercial zone samples except for a few locales. Minerals with high magnetic responses often have iron (Fe) atoms in their matrix [38]. The high magnetic susceptibility in the above-said zones might be due to the redesignation of urban streets and the development of metro rails. Moderate magnetic susceptibility was seen in the bustling street crossing points and primary transport terminals. The magnetic susceptibility character of the particles relies upon the climatic condition, geomorphology, and vegetation of the examination region. Recent studies indicate that the fluctuations in $\chi_{\text{lf}}$ with crystal size are lower than previously assumed and that a constant mean of 3.1 SI ($\pm 0.4$ SI) corresponds to a $\chi_{\text{lf}}$ value of $\sim 596 \times 10^{-6}$ m$^3$ kg$^{-1}$ ($\pm 77 \times 10^{-6}$ m$^3$ kg$^{-1}$) over an extensive range (0.09–6000 µm) of crystal sizes (Heider et al. 1996). This range covers all magnetic grains such as multidomain (MD), pseudo-single domain (PSD), stable single-domain states (SSD), and superparamagnetic (SP) behavior [38]. The domain structure is SP in crystal diameters smaller than 0.03 µm, and $\chi_{\text{lf}}$ values are more prominent and may approach $1000 \times 10^{-6}$ m$^3$ kg$^{-1}$ [39]. The magnetic properties of the particles follow in the MD > PSD > SSD > SP.

The distribution of magnetic particles in particulate particles is primarily from fine iron oxide particulate, which may be derived from different primary sources such as soil erosion and introduced into the urban topsoil or urban particulate particles [18]. The major source of these magnetic particles was anthropogenic activities like dumping waste products from metallurgical and other industries. Figure 5 shows the average concentration of frequency-dependent magnetic susceptibility of the collected urban AC filter particulate, which indicates that the particulate samples contain a significant amount of superparamagnetic (SP) grains. Further, less than 2% of the $\chi_{\text{fd}}\%$ in an AC filter particulate sample indicated that the grains are composed of frequency-dependent coarse multidomain (MD) or PSD grains (Table 1). The frequency-dependent susceptibility explains that the multidomain (MD) or PSD grains are probably derived from industrial activity, fossils, fuel combustion, and traffic pollution [35]. Ferrimagnetic grains are split into domains, distinct areas, or units of magnetization. Magnetite grains with diameters of more than 110 µm are multidomain (MD) because having more than one domain is advantageous energetically [16]. The constrained volume of tiny particles of 0.2µm permits only one domain to develop. Hence, they are known as single domains (SD) in nature. The particle intervals were 0.2–110 µm, which are the most abundant to favor more than one domain, but it shows the magnetic properties of single-domain grains; these are termed pseudo-single domain (PSD). Ultrafine particles such as <0.03 µm are SD but display unique properties. This characteristic is comparable to para-magnetism but considerably more susceptible. As a result, it is known as superparamagnetic (SP) activity. Natural and synthetically generated magnetites of available sizes were measured.
Table 1. Environmental magnetism through interpretation of the susceptibility values of frequency dependence and mass-specific low magnetic susceptibility to identify the domain nature of the grains in the study area followed by [31,35].

| χfd% | Category/Nature of Grains | Sample % from Sites |
|------|---------------------------|---------------------|
| <2   | Coarse MD grain           | 36%                 |
| 2–5  | Frequently independent grain | 32%             |
| 5–15 | SP/SD grain admixture of the multi-domain and single-domain magnetic materials | 32% |

Comparison of χlf and χfd%

| Pollution Index          | Sample % from sites |
|-------------------------|---------------------|
| Low χfd% and high χlf   | Anthropogenic input | 68% |
| High χfd% and low χlf   | Pedogenesis         | 18% |
| Same χfd% and χlf       | High heavy metal pollution | 14% |
| Low χfd% and χlf        | Normal              | 0%  |

Likewise, the particulate samples with very low χfd (<0.03%) are probably derived from a pedogenic origin, and this observation suggests that the surrounding soils do not contribute magnetic minerals to the particulate matter [32,36]. Figure 5 represents the source and magnetic characteristics of the grains in the particulate samples as SP—super paramagnetic grain, MD—frequency-independent coarse multidomain, and SP-SSD—super-paramagnetic stable single domain [38]. According to [35,37], the magnetic susceptibility and frequency-dependent susceptibility (χfd) were in low positive correlation. It indicates that the coarse particulate grains are primarily derived from anthropogenic (industrial) activities (Figure 5).

The environmental magnetic susceptibility in each sampling site varies, which may be due to soil erosion and some other anthropogenic activities. The environmental magnetism-based pollution index shows that 68% of indoor pollutants were from the anthropogenic input, 18% from the pedogenic origin, and 14% from high heavy metal pollution at the sampling sites [25,39]. According to the authors of [31]’s interpretation of the susceptibility values of frequency dependence, mass-specific low magnetic susceptibility describes the textural characteristic of a magnetic grain (Table 1). The below table explains that 36% of samples were coarse multidomain, 32% were frequency independent, and 32% were SP/SD admixture of multi and single-domain magnetic materials. Because it can create anthropogenic magnetic particles (e.g., Fe₃O₄) during coal burning, magnetic measurements may be helpful as a dating method [21]. In reality, peats, rivers, coastal, lake sediments, and fly ash containing magnetic properties are derived from fossil fuel burning and metal smelting, and industrial activity is used to explain the air quality and the source of the air pollutants [40].

3.1.3. Chemical Composition and Pollution Indices of the Air Conditioner Filter Particulate

The essential metal concentration in every sampling site was examined. The mean grouping of components in ppm is 24,790.2 for Fe, 801.2 for Cr, 100.25 for Pb, 191.17 for Cu, 865.44 for Zn, 410.2 for Mn, 436.3 for Ni, and 6.6 for Co. Particulate particles from traffic and industrial emission zones in urban environments are the main source of toxic elements such as Cd, Cu, Zn, Ni, and Pb, etc. [12]. Similarly, the minimum and maximum concentration of toxic metals in ppm are Fe (2583 to 48,636), Cr (97 to 2235), Pb (8.8 to 373), Cu (15.5 to 385.6), Zn (43 to 2270), Mn (37 to 709.7), Ni (1.5 to 1289.7), and Co—(0.48 to 15.4), which are shown in Figure 6.
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![Figure 6. The variation of heavy metal concentration in the particulate samples in the study area.](image)

The contaminants in the urban environment are mainly from transport and industrial emanation [11]. Fine particles have a high concentration of metals and trace elements in indoor and outdoor environments [13]. The main indoor sources of Mn and Zn are cigarette ash, paints, paper, cooking, and others from outdoor particulate matter while crossing ventilation and using an air conditioner [34]. References [6,11] reported that AC filters suck the mineral particles, vehicular emissions, local particulate matter, and industrial particulate matter.

Atmospheric particulate matter has been the natural sink of toxic pollutants responsible for passing through the respiratory system, and its cause creates health risks and ecological risks [41]. In recent times, researchers have been focusing on the toxic metals present in indoor particulate particles to detect their impact on human health. The pollution indices were performed by [12,42] to find potential ecological risks based on the toxicity of metals and the environmental reaction of each metal in the indoor particulate [19,43]. The pollution indices were calculated using the equation below.

\[ C_{i} = \frac{C_{i}}{C_{n}} \]  
\[ C_{d} = \sum C_{i} \]  
\[ E_{i} = T_{r} \times C_{i} \]  
\[ RI = \sum E_{i} \]

where \( C_{i} \) is the concentration of determined metals in the particulate samples, \( C_{n} \) is the background concentration of metal, \( C_{i} \) is the pollution factor of individual metals, \( C_{d} \) is the degree of contamination, and \( E_{i} \) is the potential ecological risk of individual metals; \( T_{r} \) represents the toxic values of each metal, which were estimated as Cu = Pb = Ni = 5, Zn = 1, Cr = 2, and Zn = 1. RI is the risk index of multiple elements. The classifications of heavy metal pollution and pollution indices were given in Figure 7. The result of pollution indices explains the standard factor at different levels. It is then calculated based on the single
element pollution factors, degree of contamination, and comprehensive potential ecological index, as presented in Figure 7. The box whisker plot shows the potential ecological risk of individual metals, which shows that Ni is significantly enriched, followed by Pb, Cu, Cr, Zn, Co, and Mn. However, the potential ecological risk of multiple elements indicates that the metals were under a substantial range of 300 to 600. The contamination degree of heavy metals and risk index (RI) of the trace elements were in the following order: Ni > Pb > Cu > Cr > Zn > Co > Mn.

| Elements | C_d  | Eri  | RI  |
|----------|------|------|-----|
| Mn       | 5.8  | 0.5  | 5.8 |
| Cr       | 88.1 | 14.7 | 176.3 |
| Cu       | 76.5 | 31.9 | 382.3 |
| Pb       | 83.5 | 34.8 | 417.7 |
| Zn       | 115.4 | 9.6 | 115.4 |
| Ni       | 104.7 | 43.6 | 523.6 |
| Co       | 7.4  | 3.1  | 37.0 |

| Cd | Eri | RI |
|----|-----|----|
| Value | Category | Value | Category | Value | Category |
| <8 | Low | <40 | Low | <150 | Low |
| 8~16 | Moderate | 40~80 | Moderate | 150~300 | Moderate |
| 16~32 | Considerable | 80~160 | Considerable | 300~600 | Considerable |
| ≥32 | Very high | 160~320 | High | ≥600 | Very high |

Potential ecological risk indices (RI)

Figure 7. The pollution indices of the AC filter particulate matter samples around the study area.
Figure 7 shows the assessment of pollution indices and the degree of contamination (Cd) in the study area, which is Zn (115 ppm), Ni (104 ppm), Pb (84 ppm), and Cu (76 ppm). The degree of contamination (Cd) in the study area ranges from 5.8 to 1154 pm, with an average of 68 ppm, indicating high contamination in the indoor environment. The high values of Ni and Pb are probably a result of anthropogenic activities [6,44]. The toxic metals may be from the effluent of power plants, which release large amounts of Pb, Cr, Ni, and Co compounds.

3.1.4. Air Quality Index of Indoor Particulate of SPM

The air quality index was calculated by the [2,41] method, and the standard value of SPM used in this study was suggested by the Indian National Ambient Air Quality Standards (INAAQS), reported in the 2008 CPCB report. The following equation was adapted to estimate the AQI of the study area,

\[
q = \frac{V}{V_s}
\]

where q is the quality rate of air pollutants, V is the observed value of the parameter, and Vs is the standard value recommended for the parameter. The SPM rating scale, ambient air quality index description, TSPM (µg/m³) for 24 h, and AQI of the study area are reported in Supplementary Materials Table S1. The study area has maximum AQI at the sampling sites S22 and S6 and minimum AQI values at S10 and S20. Based on The Indian National Ambient Air Quality Standards (INAAQS) for SPM, the indoor particulate of the study area falls under the moderately polluted category. The main source of particulate matter in the indoor environment an outdoor particulate matter by the invasion of fine particles through cross ventilation, cooking, smoking, and other indoor activities [8].

3.2. Outdoor Environmental Air Quality

The air quality of the outdoor environment was carried out using the continuous air quality monitoring station of the Central Pollution Control Board, Chennai division with monitoring stations at industrial areas of Manali, residential areas of Velachery, and traffic/roadside areas of Alandur Bus Depot. The meteorological data like wind speed, wind direction, and gaseous composition of the atmosphere, such as sulfur dioxide (SO₂), nitrogen dioxide (NO₂), nitric oxide (NO), carbon monoxide (CO), oxides of nitrogen (NOx), ozone (O₃), Benzene, Toluene, and O-Xylene, were measured around the study area. The overall statistical summary (minimum, maximum, average, median, kurtosis, geomean, skewness, and standard deviation) of the air quality parameters of the individual sampling site is given in Table 2. Environmental air quality reveals the status or quality of air that surrounds us in the outdoor environment [12,42]. The atmospheric gaseous composition measured using Indian National Ambient Air Quality Standards at industrial, residential, rural, and other areas ranges as follows: sulfur dioxide (SO₂ = 50; 80 µg/m³), nitrogen dioxide (NO₂ = 40; 80µg/m³), particulate matter (<10 µm) or (PM10 = 60; 100 µg/m³), particulate matter (<2.5 µm) or (PM2.5 = 40; 60 µg/m³), ozone (O₃ = 100; 180 µg/m³), carbon monoxide (CO = 02; 04 µg/m³), Benzene (C₆H₆ = 5 µg/m³ per annum), and Benzo(a)Pyrene (BaP, particulate phase = 1 ng/m³ per annum). Primary particles are formed due to combustion, soil erosion, and disintegration. Such particulate matters are dangerous to human health because they have been related to various respiratory and cardiovascular problems [42].
Table 2. Basic geostatistical summary of outdoor environmental air pollutants in the Chennai metropolis.

| Parameter Statistics | Minimum | Maximum | Average | Median | Kurtosis | Geomean | Skewness | Standard Deviation |
|----------------------|---------|---------|---------|--------|----------|---------|----------|--------------------|
| PM2.5 (µg/m³)        | 18.0    | 214.5   | 51.0    | 46.6   | 13.5     | 45.6    | 2.9      | 28.0               |
| NO (µg/m³)           | 0.3     | 30.1    | 9.8     | 7.5    | 1.0      | 8.0     | 1.0      | 5.9                |
| NO₂(µg/m³)           | 3.4     | 44.0    | 16.5    | 13.5   | 0.3      | 14.2    | 1.0      | 9.2                |
| NOₓ (ppb)            | 3.4     | 44.0    | 16.5    | 13.5   | 0.3      | 14.2    | 1.0      | 9.2                |
| CO (mg/m³)           | 0.3     | 1.9     | 0.9     | 1.0    | -0.5     | 0.9     | 0.4      | 0.4                |
| SO₂ (µg/m³)          | 1.2     | 39.1    | 8.2     | 5.4    | 7.7      | 6.7     | 2.5      | 6.2                |
| WS (m/s)             | 0.2     | 3.0     | 1.1     | 1.0    | 2.2      | 1.0     | 1.5      | 0.6                |
| WD (deg)             | 54.6    | 200.2   | 155.3   | 161.7  | 3.0      | 152.2   | -1.5     | 26.9               |
| Temperature (°C)     | 26.1    | 29.5    | 27.9    | 27.9   | -1.0     | 27.9    | 0.0      | 1.0                |
| SR (W/m²)            | 98.6    | 915.9   | 290.3   | 224.2  | 4.8      | 248.5   | 2.5      | 217.0              |
| RH (%)               | 53.5    | 82.9    | 67.5    | 66.9   | 0.9      | 67.2    | 0.1      | 6.0                |
| Ozone (µg/m³)        | 8.5     | 56.3    | 26.9    | 23.3   | 0.1      | 24.0    | 0.8      | 12.8               |
| Benzene (µg/m³)      | 0.1     | 3.9     | 1.2     | 1.4    | 4.7      | 0.9     | 1.6      | 0.8                |
| Toluene (µg/m³)      | 0.0     | 9.5     | 2.5     | 1.6    | 3.1      | 1.6     | 1.7      | 2.1                |
| O-Xylene (µg/m³)     | 0.0     | 3.0     | 1.7     | 1.7    | -1.9     | 1.1     | -0.1     | 1.2                |

Particulate matter (PM2.5 (µg/m³)), nitrogen monoxide or nitric oxide (NO (µg/m³)), nitrogen dioxide (NO₂ (µg/m³)), nitrogen oxides (NOₓ (ppb)), carbon monoxide (CO (µg/m³)), sulfur dioxide (SO₂ (µg/m³)), ozone (O₃), Benzene (µg/m³), Toluene (µg/m³), and O-Xylene (µg/m³). Wind speed (WS (m/s)), wind direction (WD (deg)), solar radiation (SR (W/m²)), temperature (degree C), and relative humidity (RH (%)).

The overall statistical summary of the outdoor environments of Chennai metropolis details is provided in Table 2. The minimum, maximum, and standard deviation of outdoor air pollutants were as follows: PM2.5 (18 to 214 ± 28 µg/m³), NO (0.3 to 30.1 ± 5.9 µg/m³), NO₂ (3.4 to 44 ± 9.2 µg/m³), NOX (3.4 to 32.8 ± 6.3 ppb), CO (0.3 to 1.9 ± 0.4 µg/m³), SO₂ (1.2 ± 0.6 µg/m³), ozone (0.1 to 3.9 ± 0.8 µg/m³), Toluene (0 to 9.5 ± 2.1 µg/m³), and O-Xylene (0 to 3 ± 1.2 µg/m³). Similarly, the meteorological parameters were as follows: WS (0.2 to 3.0 ± 0.6 m/s), WD (54.6 to 220.2 ± 26.9 deg), Temp (26.1 to 29.5 ± 1.0 degree C), SR (98.6 to 915.9 ± 217 /m²), and RH (53.5 to 82.9 ± 6.0%). Other statistical details like mean, median, kurtosis, geomean, skewness, average deviation, and standard deviation were studied [5]. The details of ambient air quality in industrial, residential, rural, and other areas as well as a statistical summary of the individual region are given in Table 2. Geometric means are used in cases where differences among the data points are logarithmic or vary by multiples of 10. Skewness characterizes the degree of asymmetry of a distribution around its mean values. Kurtosis is the measurement of peak values of the probability distribution of a real value in the random variables. The atmospheric gaseous compositions of the Manali-Industrial area were as follows: PM2.5 ranges from 24 to 214.52 with a mean of 70.38 (µg/m³), NO ranges from 10.5 to 30.1 with a mean of 15.9 (µg/m³), NO₂ ranges from 9.44 to 27.8 with a mean of 17.4 (µg/m³), NOX ranges from 11.4 to 32.8 with a mean of 18.4 (ppb), CO ranges from 0.6 to 1.26 with a mean of 0.7 (µg/m³), and SO₂ ranges from 1.97 to 39.12 with a mean of 13.9 (µg/m³). Fine particles can penetrate significantly deeper into the human body, even passing through the alveoli and cellular walls. As a result, they enter the bloodstream immediately, where they commonly cause cardiovascular disease. According to [3], the Asian population has a one-year lower life expectancy due to fine dust pollution.
The data sets of meteorological parameters, such as wind speed versus wind direction, the wind rose, and frequency distribution of wind speed, are shown in Figure 8. Throughout the whole investigation, the wind rose was seen between 15 and 25° (S) and 30 and 45° (SSE to SE), and this focuses around 25.8% of the wind flow from the industrial area of the Manali region, which is shown in Figure 8.

Figure 8. The wind rose and frequency distribution chart of the Manali-Industrial area, Velachery-Residential area, and Alandur Bus Depot-Traffic/Roadside area in Chennai metropolis.

Identifying the source of air pollutants is very important to control and prevent ambient emissions, especially from the point source. The wind rose diagrams estimate the
prevailing wind speed and wind patterns responsible for the dispersion of air contaminants in the study region. The atmospheric gaseous compositions of residential areas were as follows: sulfur dioxide (SO\textsubscript{2}—50; 80 µg/m\textsuperscript{3}), nitrogen dioxide (NO\textsubscript{2}—40; 80 µg/m\textsuperscript{3}), particulate matter (<10 µm) (PM10—60; 100 µg/m\textsuperscript{3}), particulate matter (<2.5 µm) or (PM2.5—40; 60 µg/m\textsuperscript{3}), ozone (O\textsubscript{3}—100; 180 µg/m\textsuperscript{3}), carbon monoxide (CO—02; 04 µg/m\textsuperscript{3}), Benzene (C\textsubscript{6}H\textsubscript{6}—5 µg/m\textsuperscript{3} per annum), and Benzo(a)Pyrene (BaP particulate phase—1 ng/m\textsuperscript{3} per annum) recorded by National Ambient Air Quality Standards, Central Pollution Control Board, India. Heavy particulate matter causes permanent damage to organs, developmental problems in children, lung cancer, and premature death, and it affects the central nervous system and reproductive system [23]. The impact of exposure to indoor air pollution may be observed immediately for sensitive people and after months or years for others. Immediate symptoms like eye irritation, throat pain, vomiting, dizziness, and tiredness can often present after a single exposure or after multiple exposures [4]. Breathing problems like asthma may arise shortly after exposure to air pollutants in an indoor environment. The invasion of indoor particulate matter into the human body can cause various health issues like eye irritation, respiratory problems like asthma, non-malignant respiratory diseases, lung cancer in non-smokers, bronchitis, oxygen deficiency in blood, and decreased lung function [15]. In the current indoor air pollution scenario, the increases in concentration by 2 to 5 times compared to outdoor air. The reason is the increased airflow of insufficiently filtered outdoor air through air-conditioning systems and material outgassing in the rooms.

Furthermore, the use home appliances, such as printers, various sorts of fabrics, apparel, and people themselves, are all included. As a result, filtering is particularly vital in structures and air purifiers. As a result, it is critical to be well versed on air purifiers. In certain situations, these identify pollutant removal accuracy for specified fine particle sizes (e.g., “removes 99.9% of particles as tiny as 0.3 µm”). Air purifiers are becoming more popular in India to protect oneself from hazardous and distressing air pollution (Figure S4). It is not enough to install an air purifier, it is also critical to keep the filters clean and regularly change them. Residences with poor ventilation and pets should have air purifiers installed to maintain a pollution-free interior atmosphere.

4. Conclusions

Air pollutants in indoor and outdoor environments are an emerging concern for human health and pose an ecological risk in urban settings, particularly the fine particles in the air conditioner filter particulate in indoor environments. The source of the pollutants was identified by many factors that influence indoor and outdoor air quality. Analysis of environmental magnetism through frequency-dependent, mass-specific low magnetic susceptibility confirmed that the domain nature of the particulate matters was predominantly PSD > SP-SSD > Coarse MD in the study area. The magnetic parameters and heavy metal concentrations suggested that the environmental magnetic methods are very useful tools for assessing environmental pollution in an urban region. The increased concentration of trace elements in the AC filter particulate samples can be directly absorbed, which can cause severe ecological risk and health problems in humans. The finest particulate matter that enters the indoor environment through an air conditioner can easily invade the human body and affects the respiratory system. The outdoor air quality results suggest that the source of air pollutants and their dispersion is an anthropogenic activity within the study area. This study indicates that both indoor and outdoor pollutants affect urban environmental health and ecological risk severely. Such data could assist local governments to take preventative measures to reduce particulate matter emissions. This research would be valuable in improving urban air quality and controlling traffic-related pollutants, as well as improving environmental quality in the coastal urban setting of the Chennai area. Such a study would help to raise existing awareness of indoor and outdoor air pollution by assessing its ecological harm.
Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos13101627/s1, Table S1: The rating scale of SPM, description of ambient air quality index, TSPM and AQI in the sampling sites, Figure S1: Road site area sampling sites particle size distribution, Figure S2: Commercial/Residential area sampling sites particle size distribution, Figure S3: Industrial area sampling site’s particle size distribution and Figure S4. The types of genuine AC filters can be suggested by urban air purifiers an international standard.

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