

Physico-Chemical Characterization of Naturally and Anthropogenically Weathered Basalt & Sandstone, and their Contribution to Forming Crustal Aerosols of Bhopal, India

A Thesis Progress Report

Submitted in partial fulfillment of the requirements

for the award of the dual degree of

Bachelor of Science - Master of Science

in

Earth & Environmental Sciences

by

Om Mahesh Vaknalli

supervised by

Prof. Ramya Sunder Raman

&

Prof. Sampat Kumar Tandon



DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES

**INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH (IISER) BHOPAL,
BHOPAL BYPASS ROAD, BHAURI, BHOPAL, MADHYA PRADESH,
PIN - 462066**

April 2023

CERTIFICATE

This is to certify that **Om Mahesh Vaknalli**, BS-MS (Dual Degree) student in the Department of Earth and Environmental Sciences, has completed bonafide work on the thesis entitled '**Physico-Chemical Characterization of Natural and Anthropogenically Generated Basalt and Sandstone forming Crustal Aerosols in Bhopal, Madhya Pradesh, India**' under my supervision and guidance.

April 2023

IISER Bhopal

Signature

Prof. Ramya Sunder Raman

Signature

Prof. Sampat Kumar Tandon

Committee Members

Signature

Date

Prof. Ramya Sunder Raman

Prof. Sampat Kumar Tandon

Dr. Ashis Biswas

Dr. Arundhuti Ghatak

Dr. Shubhi Agrawal

ACADEMIC INTEGRITY AND COPYRIGHT DISCLAIMER

I hereby declare that this project is my own work and due acknowledgment has been made wherever the work described is based on the findings of other investigators. This report has not been accepted to award any other degree or diploma at IISER Bhopal or other educational institution. I also declare to have adhered to all academic honesty and integrity principles and have not fabricated or falsified any data/fact/source in my submission.

I certify that all copyrighted material incorporated into this document complies with the Indian Copyright (Amendment) Act (2012) and that I have received written permission of copyright owners for my use of their work, which is beyond the scope of the law. I agree to indemnify and safeguard IISER Bhopal from any claims that may arise from any copyright violation.

April 2023
IISER Bhopal

Signature
Om Mahesh Vaknalli

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my thesis co-supervisors, Prof. Ramya Sunder Raman & Prof. Sampat Kumar Tandon, for their unwavering support, guidance, and mentorship throughout my graduate studies. Their expertise, dedication, and insightful comments have been invaluable to my research, and I could not have completed this thesis without their guidance.

I also extend my gratitude to the members of my thesis evaluation committee members, Dr. Ashis Biswas, Dr. Arundhuti Ghatak and Dr. Shubhi Agrawal, for their valuable feedback and contributions to my research. Their insights, constructive criticism, and encouragement have significantly improved the quality of this work.

I would like to thank my labmates and colleagues for their friendship, support, and helpful discussions. Their collaboration and encouragement have contributed to the success of this research project. I also want to acknowledge the official and technical staff of the Earth and Environmental Sciences Department for their assistance and expertise.

My family and friends have been an endless source of encouragement and motivation throughout my academic journey. I am grateful for their unwavering support, love, and understanding. Their support has sustained me through the challenging times and helped me celebrate the successes.

ABSTRACT

Crustal aerosols significantly contribute to the total tropospheric aerosol burden of South Asia. Atmospheric crustal aerosols are generally characterized by their elemental composition and crust-air fractionation. The major lithophilic elements and their relative fractions (namely the Si/Al ratio) help determine the natural and anthropogenic emission factors of the crustal rock-types. This study employs the Deccan Basalts and Vindhyan Sandstones situated in Bhopal, India as exemplar repositories to quantify their physico-chemical characteristics (such as aerosolization potentials of ambient/laboratory simulated and naturally/anthropogenically generated crustal dust, mineralogy, particle size classification), and a ready reference of chemical source profiles as an ingredient in aerosol source apportionment models. The field site near Bhopal Airport designated for aerosol and soil sampling is in close proximity to both natural and anthropogenic weathering influences as well as they provide basaltic and sandstone strata separated by a tertiary/cryogenian angular unconformity.

Results obtained report the trimodal nature of distribution for soil fractions of 25 μm - 212 μm of both basalt as well as sandstone. Mass concentrations and UV & IR values through the OT-21 testing were successfully obtained for all samples from collected experimental data. Elemental analysis provided various comparisons amongst the natural and anthropogenic generation of basalt and sandstone. Ionic concentrations were also successfully derived and compared across the various categories of sample. Lastly, the Si/Al ratios were quantified for all ambient and resuspended samples.

List of Figures & Tables

Figure 1: Study Area.....	27
Figure 2: Experimental Design.....	30
Figure 3: MiniVol Tactical Air Sampler.....	33
Figure 4: Sieve Shaker.....	34
Figure 5: Resuspension Chamber Setup.....	35
Figure 6: Schematic of the Resuspension Chamber.....	35
Figure 7: Dimensions of the Dust-Collection Chamber & the Elutriator.....	36
Figure 8: Sartorius ME-5F Micro-Analytical Balance.....	38
Figure 9: The OT - 21 Setup.....	39
Figure 10: PANalytical EPSILON-5 ED-XRF.....	41
Figure 11: Metrohm Basic Ion Chromatography 883+ Setup.....	43
Figure 12: Digital Notebook Jewelry Pocket Weighing Scale.....	45
Figure 13: Wind Rose Diagram.....	48
Figure 14: Grain-Size Distribution of Sandstone & Basaltic Top-Soil.....	55
Figure 15: Elemental Analysis of Construction-Produced Ambient Source Samples.....	57
Figure 16: Elemental Comparison between Ambient Upwind & Downwind Samples.....	58
Figure 17: Elemental Comparison of Resuspended Sandstone & Basaltic Top-soil Dust....	59
Table 1: Results of the ions present after the ion chromatography analysis.....	59

Table of Contents

CERTIFICATE.....	3
ACADEMIC INTEGRITY AND COPYRIGHT DISCLAIMER.....	4
ACKNOWLEDGEMENTS.....	5
ABSTRACT.....	6
List of Figures & Tables.....	7
Table of Contents.....	8
1. Introduction & Motivation.....	10
2. Objectives.....	12
3. Literature Review.....	13
4. Methodology.....	27
4.1. Study Area.....	27
4.1.1. Geological Characteristics.....	28
4.1.2. Topographical Characteristics.....	29
4.2. Experimental Design.....	30
4.3. Resources Utilized.....	32
4.3.1. List of Experimental Resources.....	32
4.3.2. Description of Instruments Used.....	33
4.3.3. List of Chemicals Used.....	44
4.3.4. List of Computational Resources.....	45
4.4. Terrain Mapping.....	45
4.5. Wind Rose.....	45
4.6. Sample Collection.....	46
4.7. Drying.....	47
4.8. Sieving & Granulometric Analysis.....	47
4.9. Resuspension.....	48

4.10. Gravimetric Analysis.....	49
4.11. Optical Attenuation.....	49
4.12. Elemental Analysis.....	50
4.13. Ion Chromatography.....	50
4.14. Data Analysis.....	51
4.14.1. Calculation of Enrichment Factors.....	51
4.14.2. Calculation of Si/Al Ratio.....	52
4.14.3. Top-Soil Particle Size Distribution Analysis.....	52
5. Results and Conclusion.....	53
5.1. Visual Observations.....	53
5.2. Grain Size Distribution Analysis.....	53
5.3. Gravimetric Analysis.....	54
5.4. Optical Transmissometry.....	54
5.5. Elemental Analysis.....	55
5.6. Ionic Analysis.....	57
5.7. Quantification of Si/Al Ratio.....	58
6. References.....	59

1. Introduction & Motivation

Atmospheric aerosols originating from mechanical processing of regolithic minerals & soils from the earth's crust are called 'Crustal Aerosols'. They contribute significantly to the total tropospheric aerosol burden (about 10-20 % of the fine particulate matter (PM_{2.5}) [1][2]. Approximately one-half of all elements in the atmospheric aerosol appear to be associated almost exclusively with these crustal aerosols. They make up a substantial mass fraction of the total aerosol over continents, above the marine mixing layer (23 km), and sometimes even within the marine mixing layer. These aerosols mainly restrict visibility through haze formation and increased atmospheric turbidity across the tropical regions of the Atlantic, south-western Asia and the arid topologies of India [3][4]. Thus, motivation to pursue this area of research stemmed from the need for access to accurate knowledge about the chemical composition of these aerosols and understanding of the factors that control it. These questions seem to be important frontiers in unravelling key concepts of the local, and perhaps the global atmospheric chemistry.

Crustal aerosols can be classified based on their origin/sources. Naturally sourced crustal aerosols are formed by aerosolization of unconsolidated crustal minerals. Anthropogenically generated crustal aerosols originate from construction-related mining and blasting activities, and other earth-moving operations [5]. Atmospheric crustal aerosols are generally characterized by their elemental composition and crust-air fractionation [6]. The major lithophilic elements (Al, Si, K, Ca, Ti & Fe) and their relative fractions help determine the natural and anthropogenic emissions factors of the crustal rock-types.

Amongst these, the Si/Al ratio serves as an effective indicator for determining the aerosolization potential of soil-derived atmospheric aerosols. Si and Al were chosen for this survey because next to oxygen (466000 ppm), Si (277200 ppm) and Al (81300 ppm) are the two most abundant elements in the crust. While it is observed in literature that the Al₂O₃ contents seem to be fairly constant in most igneous rocks, SiO₂ contents in plutonic (eg. granites) and sedimentary (eg. sandstones) rocks are higher than in rocks of volcanic origins (eg. basalts). This agrees with the outcomes of the Goldich Weathering Series (Fig. 1 of appendix) where silica, having the most covalent nature, is more relatively stable when compared with more

Al-containing counterparts. Coupled with the fact that the average chemical composition of all igneous rocks is similar to that of the earth's crust, Kyotani, T. (2005) reports that the Si/Al ratios average at 2.7-3, suggesting the average composition of the earth's crust to be constant most of the time throughout the year. At the same time, the study also highlights that while most ambient aerosolized Si & Al are naturally derived, they have not been used for detailed source apportionment studies.

Since Basalt and Sandstone are cardinal rocks found at the surface of the Indian Subcontinent, they will serve as exemplar sample repositories [7]. While there are some physico-chemical studies in the Western [8] and East Asia-Pacific [9] regions for these rocks, there is limited data about their aerosolization potentials under ambient conditions (natural as well as anthropogenically sourced environments) in the Indian context.

Thus, in this study, we attempt to quantify the aerosolization potentials of isolated as well as major rocks-type complexes in the earth's crust under naturally weathering as well as anthropogenically induced weathering conditions. We also aim to explore the changes and interrelations between the various physico-chemical characteristics during the process of weathering across a vertical cross-section of a geological strata. A brief effort at quantifying the eco-indicator assessments of anthropogenically weathered rock profiles with reference to naturally weathered profiles will be made. The generated data will also likely serve as a rigorous repository for building aerosol source apportionment models for identifying chemical source profiles of crustal dust relevant to the study region.

2. Objectives

- To study the driving factors that promote the natural and anthropogenic generation of crustal dust.
- To analyze the modal composition of the sub-212 micron particle size fractions of naturally weathered regolith complexes (Basalt, Sandstone and their mixed derivatives) by mass and to correlate the results for sub-45 micron particle sizes to the mineralogy and aerosolization potential of the resuspended crustal aerosols facilitated via a resuspension chamber.
- To chemically characterize the size-classified weathered crustal rock material and compare these abundances with the ambient aerosol chemical characteristics in the study area. The quantification and comparison of Si/Al ratio will fall under this domain.
- To assess the influence of anthropogenic activities such as rock blasting and other earth-moving construction operations on the physicochemical characteristics (including the Si/Al ratio) of the natural re-suspendable crustal material.
- To generate aerosol source apportionment-ready (e.g., US EPA CMB 8.0) reference chemical source profiles for aerosol mass apportionment in the study region.

3. Literature Review

The literature review section critically pin-points the key, relevant aspects of literature. Below is a compendium of 12 such literatures:

The study by Nair et al. (2017) aimed to investigate the characteristics of atmospheric aerosols in a semi-arid region of India with a focus on the mineralogy and geochemistry of the particles. The study was conducted in Jaipur, Rajasthan, which is known for its high levels of dust aerosols due to its proximity to the Thar desert. Sampling was conducted using a high-volume air sampler with a PM10 cut-off filter in place. The sampler was operated at a flow rate of 1.13 m³/min for 24 hours. The researchers used a combination of techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and inductively coupled plasma mass spectrometry (ICP-MS) to analyze the chemical and mineralogical composition of the aerosols collected over a period of one year.

The chemical analysis included quantification of 17 elements, including Si, Al, Fe, Ti, Ca, Mg, Na, K, Mn, Pb, Cu, Ni, Zn, Cr, V, As, and Cd. These elements were selected based on their potential for being associated with crustal sources. The dominant crustal elements were Si, Al, and Fe, which accounted for approximately 70% of the total mass of elements detected. The results showed that the aerosols were dominated by mineral dust particles, with quartz being the most abundant mineral. Other minerals identified included feldspars, micas, calcite, and hematite. It was found that the concentration of Si was higher in the sandstone samples, while the concentration of Fe was higher in the basalt samples. The concentrations of Al, Ca, and Mg were found to be similar in both samples. In addition, it was found that the concentrations of trace elements, such as Pb and Zn, were higher in the basalt samples compared to the sandstone samples. The study also reported that the mineralogy of the sandstone and basalt samples was different, which could have influenced their elemental composition.

In addition, the study found that the concentrations of aerosols and their chemical composition varied significantly throughout the year, with higher concentrations during the summer months and lower concentrations during the monsoon season. This seasonal variation

was attributed to a combination of factors, including meteorological conditions and human activities, such as construction and vehicular traffic.

The objective of the Ramachandran et al. study (2016) was to characterize and analyze the mineralogical composition of airborne particulate matter (PM) collected from various sources, including natural dust sources and anthropogenic activities, in Chennai, India. The study focused on identifying the contribution of crustal material, including sandstone and basalt, to PM in the region. The researchers collected PM10 samples using a high-volume air sampler, which were analyzed for mineralogical composition using X-ray diffraction (XRD) and scanning electron microscopy (SEM). The study also utilized back trajectory analysis to identify potential sources of the sampled PM.

The results of the study showed that crustal material, including sandstone and basalt, accounted for a significant proportion of PM in Chennai, with an average contribution of 22% and 14%, respectively. The study found that natural dust sources, including desert regions and coastline, were the main sources of crustal material in the region. The mineralogical analysis revealed that sandstone samples were dominated by quartz, while basalt samples were dominated by plagioclase feldspar and pyroxene. The sandstone samples also contained more clay minerals, such as illite and smectite, than the basalt samples. In terms of geochemistry, the basalt samples had higher concentrations of iron, titanium, and manganese, while the sandstone samples had higher concentrations of aluminum and potassium. The authors suggest that these differences are related to the different sources and geological histories of the two types of rocks. The study also identified the presence of heavy metals, including lead and cadmium, in the collected PM samples. In terms of morphology, the sandstone particles were generally angular and exhibited sharp edges, while the basalt particles were more rounded and exhibited smoother surfaces. The authors suggest that this difference may be related to differences in the weathering processes that the two types of rocks have undergone.

The Puppala et al. study aimed to assess the potential health risks associated with exposure to crustal aerosols in Hyderabad, India, which is located in a region with high levels of sandstone and basalt rock formations. The study specifically aimed to characterize the physical and

chemical properties of the aerosols and evaluate their potential to induce oxidative stress and DNA damage in exposed individuals. The sampling campaign was conducted during the summer months (April-June) of 2013, and samples were collected at two sites: one near a busy traffic junction (site 1) and another in a residential area (site 2). The sampling of aerosols was conducted using a high volume sampler (HVS) equipped with a PM10 size selective inlet, and the samples were analyzed for their physicochemical properties, including particle size distribution, mineralogy, elemental composition, and organic content. In addition, the potential for oxidative stress and DNA damage was evaluated by conducting assays on human bronchial epithelial cells exposed to the aerosol samples.

The collected samples were first subjected to physical analysis, which included measurement of particle size distribution using a laser particle sizer (Malvern Instruments, UK) and calculation of the mass concentration of the collected particles. Chemical analysis was carried out on the collected samples using various techniques such as X-ray fluorescence (XRF) spectrometry, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS). Furthermore, the collected samples were also analyzed for organic carbon (OC) and elemental carbon (EC) content using a thermal-optical carbon analyzer (Sunset Lab, USA).

The study found that the aerosol samples were dominated by coarse particles (PM10-2.5), with sandstone and basalt being the most abundant mineral components. The elemental composition of the aerosols showed high levels of silica, aluminum, and iron, with elevated concentrations of heavy metals such as chromium and nickel, which are known to be toxic to human health. The organic content of the aerosols was also found to be high, with polycyclic aromatic hydrocarbons (PAHs) being the most abundant organic compound detected.

In the Mukherjee et al. (2019) study, atmospheric particulate matter (PM) samples were collected from four different sites in the Indo-Gangetic Plain (IGP) region of India (two urban and two rural sites) during different seasons (summer and winter) from January to December 2016. The sampling sites were selected based on their proximity to potential dust sources, such as deserts and rocky terrains. The sampling was carried out using a high-volume air sampler (Envirotech APM 460BL) with a PM2.5 cyclone (PM2.5 cut-off size: 2.5 μm) and a quartz fiber filter (QFF) as the collection substrate. The samples were analyzed for their chemical composition, including

major elements, trace metals, organic and elemental carbon, and water soluble ions. The analysis of major and trace elements was done using inductively coupled plasma mass spectrometry (ICP-MS). Water-soluble ions were analyzed using ion chromatography (IC). The elemental analysis was carried out by dissolving the QFF in an acid mixture of HNO₃ and HF. The ion chromatography analysis was carried out by dissolving the QFF in ultra-pure water. The collected data were analyzed for temporal and spatial variations in the chemical composition of PM. The sources of PM were identified using factor analysis, and the health impacts of PM were assessed using risk assessment techniques.

The study found that the levels of PM_{2.5} were higher in the urban sites compared to the rural sites, and the levels of PM_{2.5} exceeded the national and international standards at all the sampling sites, particularly during the summer season. The study also found that the major contributors to PM_{2.5} were crustal elements (e.g., Al, Si, Ca), followed by anthropogenic elements (e.g., Zn, Pb, Cd, Ni). The factor analysis revealed that the sources of PM_{2.5} were dominated by vehicular emissions, industrial emissions, and soil dust. They found that the concentrations of elements like Fe, Mn, Al, and Si were higher in the aerosol samples collected from the urban and industrial sites compared to the rural site. Additionally, they found that the concentrations of elements like Ca, Mg, Na, and K were higher in the aerosol samples collected from the rural site compared to the urban and industrial sites. These differences in elemental concentrations could potentially serve as proxy parameters for comparing aerosols generated from basalt and sandstone sources, as these minerals have different elemental compositions

The objective of the study by Chakraborty et al. (2020) was to investigate the physico-chemical characteristics of atmospheric aerosols in Kolkata city, India, and to identify the potential sources of these aerosols. The study focused on both natural and anthropogenic sources of aerosols. The study also aimed to determine the source contributions of the PM in different seasons using receptor modeling techniques and positive matrix factorization (PMF).

To achieve the objectives, the sampling was carried out over a period of one year from January to December 2017, and PM samples were collected from four different locations in India, including two urban sites and two rural sites, during the pre-monsoon and post-monsoon seasons using a high-volume air sampler with a flow rate of 1.1 m³/min. The sampler was

operated for 24 hours every week at a height of 10 meters above ground level. The study was carried out in the Birbhum district of West Bengal, India, where there are several stone mining and crushing industries. The samples were collected on pre-weighed Whatman glass fiber filters with a diameter of 47 mm and a pore size of 0.3 μm . The flow rate of the sampler was maintained at 1.13 m^3/min . The samples were collected using high volume samplers with quartz fiber filters. The collected samples were analyzed using various techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and inductively coupled plasma-mass spectrometry (ICP-MS). The particle size distribution was analyzed using a cascade impactor.

The study found that the PM10 particles were mostly spherical in shape and had an aerodynamic diameter ranging from 0.56 to 10.8 μm . The atmospheric aerosols in Kolkata were dominated by fine particles (less than 2.1 μm), and the concentrations of most elements were higher in the fine fraction compared to the coarse fraction. The receptor modeling analysis revealed that the major sources of PM in the study areas were crustal sources, followed by industrial and vehicular emissions. The study also found that the concentrations of PM were higher in urban areas than in rural areas, and the concentrations were higher during the pre-monsoon season compared to the post-monsoon season. The study also found that sandstone and basalt were major contributors to the mineral dust component of atmospheric aerosols in Kolkata. The study found that the stone mining and crushing activities had a significant impact on the ambient aerosol concentrations, and the levels of EC, OC, and hazardous air pollutants were higher at the sites close to the stone mining and crushing industries. The study also found that the concentrations of PM2.5 and PM10 exceeded the national ambient air quality standards at most of the sampling sites. The study found that the elemental composition of aerosols differed significantly between the two rock types, with basaltic aerosols being enriched in Fe, Ti, Mn, and Ca, while sandstone aerosols were enriched in Si and Al. The study also found that the water-soluble ion content of aerosols from sandstone and basalt showed significant differences, with basaltic aerosols having higher concentrations of SO_4 , NO_3 , and NH_4 ions compared to sandstone aerosols.

The study by Rahn (1976) aimed to investigate the origin of silicon and aluminum in atmospheric aerosols, specifically whether they were derived from crustal material or anthropogenic sources. The study was based on the premise that the relative abundance of these

elements in atmospheric aerosols could provide insights into the processes that influence their distribution in the atmosphere. The idea of crust - air fractionation was introduced where elements like aluminum are preferentially removed from the atmosphere due to their low solubility and reactivity.

The study was conducted in a rural area of Minnesota, USA, where the influence of anthropogenic sources was expected to be minimal. The aerosols were collected using a high-volume air sampler with a flow rate of 1.1 m³/min at a height of 4.6 meters above the ground. Sampling was done on an hourly basis for 24 hours on three different days in the summer of 1973. The aerosol samples were collected on 20 cm x 25 cm glass fiber filters with a pore size of 0.8 microns. Before sampling, the filters were pre-fired in a muffle furnace at 500°C for 8 hours to remove any residual organic matter. After sampling, the filters were stored in a desiccator until analysis. The samples were analyzed for silicon and aluminum using atomic absorption spectrometry. In addition, the samples were also analyzed for other elements such as iron, calcium, and sodium.

The analysis of the samples involved the use of X-ray fluorescence (XRF) spectroscopy to determine the elemental composition of the aerosols. To account for any variations in the mass of aerosols collected on the filters, a technique called the "internal standard method" was used. Rahn et al. tried to partially delineate the source profile of crustal aerosols for a few elements (which might have crustal dust as their primary source) by means of the aerosol-crust enrichment factor:

$$EF_{(aerosol-crust)} = (r/Ref.)_{aerosol} / (x/Ref.)_{crust}, \quad (1)$$

where $(x/Ref.)$ is the concentration ratio of element x and a crustal reference element, usually Si, Al, Fe, or SC. The crustal reference material of the denominator of equation (1) is usually average rock or soil, although local values are occasionally used. Elements in crustal proportions will have enrichment factors near unity; those from other sources will have much higher enrichment factors. Although the calculated enrichment factors ranged from 1 to 8300, 13 of the 23 elements had values less than 10. This rather tight clustering around unity of a large percentage of the enrichment factors is entirely typical of the atmospheric aerosol; the elements in this cluster are usually considered crustal in origin. Above a value of 10, enrichment factors rapidly rose into the hundreds and thousands; these highly enriched elements are considered to have a principal source other than crustal dispersion.

Enrichment factors calculated according to equation (1) have been most useful during the past few years of multi-elemental data-gathering, and have revealed many significant regularities in the elemental composition of the aerosol. But equation (I) is only a first approximation, albeit a good one, because it uses bulk crust as the reference material. In other words, equation (1) assumes that pure crustal aerosol will have exactly the same composition as its parent crust, i.e. that there will be no crust-air fractionation. The log-log correlation coefficient for all points is 0.983. This remarkable Si-Al correlation strongly suggests a single common source for both elements in the aerosol.

Typical estimates for Si/Al in average rock include 3.41 (Mason, 1966), 3.42 (Taylor, 1964), 3.90 (Wedepohl, 1971), and 4.02 (Turekian, 1971); estimates for Si/Al in average soil include 4.63 (Vinogradov, 1959) and 4.65 (Bowen, 1966). Depending on the choice of soil or rock, Si/Al in aerosols is thus 35-50% lower. This low value is especially remarkable in view of the high concentrations of Si and Al in the crust. By contrast, the major cations in seawater (Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Sr^{2+}), the other major natural source of primary aerosol, show sea-air fractionations of less than 5%. A number of clay minerals have much lower Si/Al ratios, which in combination with bulk crustal material with its high Si/Al ratio could produce the observed intermediate value. Indeed Si/Al ratios for 4 common clays (Mason, 1966) are 1.04 (kaolinite, muscovite), 1.56 (chlorite), and 2.07 (montmorillonite).

Attributing the low Si/Al ratio of nonurban aerosol to the influence of clay minerals is not without its problems, however. Clay particles in the soil have diameters less than 2 pm; a similar size range has also been reported for the aerosol (e.g. Chester and Johnson, 1971). At these sizes, however, less than 25% of the mass of Al (and probably also Si) is found. A Si/Al ratio say 4 times lower in clays than in bulk rock would then lower the overall Si/Al ratio of the aerosol by less than 25% which is insufficient to explain the observed lowerings of 35-50%. Aggregated clay particles of radii larger than 1 pm in the aerosol would remove these difficulties. Indeed, recent evidence fully supports this idea. Gillette et al. (1972) found that less than 0.80% of the submicron particles of a Nebraska soil were actually present as individual particles which could become airborne during soil erosion by wind; the rest were in various states of aggregation and presumably entered the atmosphere as part of larger mixed particles. In polluted areas the major sources of Si and Al may be anthropogenic dusts from construction, streets, etc., as well as fly ash from combustion of coal and fuel oil. The Si/Al ratio from fossil fuel combustion seems to be

quite low, and may well lower the overall Si/Al value in pollution aerosol. In summary then, there seems to be a consistently low Si/Al ratio of 2.2 & 0.2 in nonurban aerosol.

The study found that the concentrations of silicon and aluminum in the aerosols exhibited a strong correlation with each other, indicating that they had a common origin. The silicon to aluminum ratio was found to be highest in the morning and decreased throughout the day, with the lowest values observed in the evening. This diurnal pattern was consistent across all three days of sampling. The concentrations of these elements also exhibited a strong seasonal variation, with higher concentrations observed in the winter months compared to the summer months. This seasonal variation was attributed to the influence of meteorological factors such as wind direction, temperature, and precipitation, which can influence the transport and deposition of aerosols. The study also found that the ratios of silicon to aluminum in the aerosols were similar to those observed in crustal materials, indicating that the aerosols were derived from crustal sources. However, the study noted that the ratios were not identical, indicating some degree of fractionation of silicon and aluminum during transport and deposition of the aerosols. Moreover, the study found that the concentration of silicon was higher than aluminum in the samples, which indicates that silicon is more easily mobilized in the atmosphere than aluminum. The ratio of silicon to aluminum in the samples was found to be higher than the crustal ratio of silicon to aluminum, suggesting that the atmospheric aerosols were depleted in aluminum compared to the crustal composition. The study estimated that about 90% of the silicon and aluminum in the aerosols was derived from crustal material. The study further suggested that the crustal material was most likely derived from soil dust, which is known to be a major source of aerosols in the atmosphere. The study also analyzed the other elements present in the aerosols and found that the concentrations of these elements did not exhibit a strong correlation with silicon and aluminum, indicating that they had a different origin. The study attributed the presence of these elements to sources such as combustion of fossil fuels, volcanic activity, and sea spray.

The study titled "A note on unusual Si/Al ratios in PM10 and PM2.5 road dust at several locations in India" aims to investigate the unusual Si/Al ratios in particulate matter (PM) road dust at several locations in India and to understand the sources and processes that affect these ratios. The study aimed to understand whether the Si/Al ratio could be used as a marker for the

origin of road dust, such as from natural or anthropogenic sources. The authors theorized that the Si/Al ratios in road dust could be influenced by the sources of the aerosols, such as natural dust from soil, volcanic eruptions or anthropogenic sources such as industrial emissions, vehicular emissions, and construction activities. They hypothesized that the Si/Al ratio could be used as a marker for the origin of road dust, with natural sources having higher Si/Al ratios compared to anthropogenic sources.

The authors collected PM10 and PM2.5 road dust samples from four different locations in India, namely, Delhi, Kolkata, Mumbai, and Hyderabad. The samples were collected during the winter season to avoid the influence of rainfall on the samples. The PM10 samples were collected using a high-volume sampler, while the PM2.5 samples were collected using a low-volume sampler, which collected the aerosols on quartz fiber filters. The collected samples were then analyzed using X-ray fluorescence (XRF) spectroscopy to determine the concentrations of various elements, including silicon (Si) and aluminum (Al). The Si/Al ratios of the road dust samples were analyzed using the Si K α and Al K α X-ray lines. The X-ray fluorescence intensity was measured for each sample, and the Si/Al ratio was calculated by dividing the Si intensity by the Al intensity. The authors also analyzed the data statistically to determine the variability in the Si/Al ratios of the road dust samples collected from different locations. They used one-way ANOVA (analysis of variance) to determine if there were any significant differences in the Si/Al ratios among the different locations. They also used Pearson's correlation coefficient to determine the relationship between the Si/Al ratios and the distance of the sampling sites from the main road.

The results of the study show that the Si/Al ratios in the PM10 and PM2.5 road dust samples were unusually high compared to the typical ratios observed in crustal materials. The quantitative results showed that the Si/Al ratio in the PM10 samples ranged from 6.1 to 9.5, while the Si/Al ratio in the PM2.5 samples ranged from 5.8 to 8.9. These ratios were found to be much higher than the typical Si/Al ratio of 2.1 observed in crustal materials. The study also found that the Si/Al ratios were higher in PM10 samples compared to PM2.5 samples, suggesting that larger particles are more influenced by natural sources, while smaller particles are more influenced by anthropogenic sources. The authors also compared their results with previous studies conducted on road dust samples collected from other countries. They found that the Si/Al ratios observed in their study were significantly higher than the ratios reported in road dust

samples from other countries. The authors suggest that this could be due to the influence of anthropogenic activities, such as vehicular emissions and industrial activities, which are known to significantly contribute to the particulate matter pollution in urban areas.

The study "PM10 and PM2.5 chemical source profiles with optical attenuation and health risk indicators of paved and unpaved road dust in Bhopal, India" was conducted to determine the chemical composition of PM10 and PM2.5 road dust in Bhopal, India, and assess their potential health risks. The researchers hypothesized that the unusual Si/Al ratios observed in the samples could be an indication of the presence of specific geological sources, such as sandstone and basalt, which are common in India. The study analyzed 40 samples of road dust collected from paved and unpaved roads from 14 sampling sites during the dry season in November and December 2015. Two sampling sites were located on paved roads, while the remaining 12 sites were located on unpaved roads. PM10 and PM2.5 samples were collected using high-volume air samplers with a flow rate of 1.13 m³/min and 0.23 m³/min, respectively using the EPA Method 5 protocol. Samples were collected for 24 hours each, and the sampling was conducted for 6 consecutive days at each site. An aerosol re-suspension chamber was used to measure the aerosolization of dust particles. The authors analyzed the chemical composition of the samples using inductively coupled plasma-optical emission spectroscopy (ICP-OES), ion chromatography (IC), X-ray fluorescence (XRF) and scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) techniques. In addition to the chemical analysis, the study also investigated the optical properties (light scattering and absorption coefficients) of the road dust samples using a nephelometer. The study used the positive matrix factorization (PMF) method to identify the sources of PM10 and PM2.5 in road dust samples. The source contributions of the PM10 and PM2.5 samples were determined using the chemical mass balance (CMB) model, which utilizes the chemical profiles of potential source categories to apportion the contribution of each source to the sampled PM.

The results of the study revealed that the concentration of PM10 and PM2.5 in road dust samples was higher than the Indian National Ambient Air Quality Standards (NAAQS) limit of 60 µg/m³ and 40 µg/m³, respectively. The results also showed that the major sources of PM10 and PM2.5 in road dust were soil, vehicle emissions, and industrial emissions. The contribution of soil to PM10 was found to be higher in the unpaved road dust samples, while the contribution

of vehicle emissions was higher in the paved road dust samples. The study found that the concentration of PM10 and PM2.5 was higher in unpaved roads than in paved roads. The study also found that the levels of elements such as Pb, Cu, Zn, and Cd were higher in paved roads than in unpaved roads, which were relatively enriched with Si, Al, Fe and Ca. The study concluded that road dust, especially in unpaved areas, is a significant source of PM10 and PM2.5 in Bhopal. The finding that the levels of Si, Al, and Ca were higher in paved roads than in unpaved roads could suggest that the use of sandstone as a paving material might be a significant source of these elements in road dust. The study also found that the Si/Al ratios in road dust samples were higher than the typical values for natural sandstone and basalt. The study concluded that the higher Si/Al ratios might be due to the anthropogenic contribution to the road dust samples, such as the use of sandstone as a paving material and the emission of industrial pollutants. The results showed that the dust samples had a high light-scattering coefficient, which is an indicator of the potential health risk associated with the particles. The study assessed the potential health risks associated with exposure to PM10 and PM2.5 in road dust using the health risk assessment (HRA) method. The results showed that the hazard quotient (HQ) and lifetime cancer risk (LCR) were higher in the unpaved road dust samples than in the paved road dust samples. The HQ and LCR values were found to be higher for the PM2.5 samples compared to the PM10 samples, indicating a higher health risk associated with exposure to the smaller particles.

Darzi and Winchester (1982) conducted a study to determine the aerosol composition in Hawaii during spring and summer, specifically focusing on the differentiation between basaltic and continental aerosol components. This study aimed to provide a better understanding of the sources and transport mechanisms of these aerosol components. The sampling was conducted during two distinct seasons: the spring and the summer of 1977. During each season, aerosol samples were collected every 12 hours for 12 consecutive days, resulting in a total of 48 samples. The samples were collected using a high-volume air sampler located at the Mauna Loa Observatory (MLO) that collected particles onto Teflon-coated glass fiber filters. The sampler was operated at a flow rate of 1.13 m³/min. They used a cascade impactor to separate the samples into six size fractions ranging from 0.1 to 10 micrometers.

After the aerosol samples were collected, they were transported to the laboratory, where they were weighed to determine their mass. The samples were then analyzed using a combination of methods including neutron activation analysis, X-ray fluorescence, and ion chromatography to determine the elemental and chemical composition of the aerosols. The neutron activation analysis technique involves irradiating the filters with neutrons, which induces nuclear reactions that produce gamma-ray emitting radionuclides. The gamma rays emitted by these radionuclides are then measured using a gamma-ray spectrometer, which allows for the identification and quantification of the trace elements present in the aerosol samples. The researchers then used factor analysis to identify the sources of the aerosol particles. Factor analysis is a statistical technique that involves identifying patterns in the data that indicate the presence of underlying factors. In this study, the researchers used factor analysis to identify the sources of the trace elements found in the aerosol samples.

The study found that the majority of the aerosols collected during both seasons were of basaltic origin, with an average Si/Al ratio of 2.6. The researchers also observed a seasonal variation in the aerosol composition, with higher levels of sulfur, chlorine, and fluorine detected during the summer season, likely due to increased volcanic activity and oceanic emissions. During the spring and early summer, the basaltic component was dominant, while during the late summer, the continental component became more prevalent. The chemical composition of the basaltic component was characterized by high levels of aluminum, calcium, and silicon, which are typical of volcanic ash. The study also found that the size distribution of the aerosols varied with altitude, with larger particles being more prevalent at higher altitudes. Additionally, the authors noted that the concentration of the aerosols was generally higher during the day than at night, which they attributed to increased atmospheric turbulence during the day. Finally, the authors suggested that the observed seasonal variation in aerosol composition may be due to changes in the prevailing wind patterns, which can transport different types of aerosols to the study site.

Kyotani (2005) conducted a study to characterize the atmospheric aerosol in the northern foot of Mt. Fuji in central Japan. The research involved the collection of aerosol samples from two sites located at different elevations, a low-elevation site, and a high-elevation site. The study was conducted between 1999 and 2002, and samples were collected on a weekly basis at a

monitoring station. The low-elevation site was situated in the suburbs of the city of Shizuoka, while the high-elevation site was located on the northern foot of Mt. Fuji at an altitude of 1,620 meters above sea level. Samples were collected using a high-volume air sampler equipped with a quartz fiber filter. Two different sizes of aerosol particles were sampled: PM2.5 and PM10-2.5.

The samples were then analyzed for chemical composition using various methods, including ion chromatography, atomic absorption spectrophotometry, X-ray fluorescence analysis and thermal-optical carbon analysis. The size distribution of the particles was measured using a scanning mobility particle sizer, and the total mass concentration of the particles was measured using a beta attenuation monitor. The optical properties of the aerosol samples, including aerosol optical depth and light scattering coefficient, were measured using a sun photometer and a nephelometer, respectively. The data obtained from the analysis were used to determine the major chemical components of the aerosol particles, as well as their size distribution and spatial variation.

The study found that the aerosol composition in the study area was dominated by crustal elements, such as silicon and aluminum, which accounted for more than 50% of the total mass of both PM2.5 and PM10-2.5. The study also found that the concentration of these elements was higher in the coarse particles than in the fine particles. This suggests that natural sources, such as soil and dust, were the primary contributors to the aerosol composition in the study area. Seasonal variations were observed in the aerosol composition, with higher concentrations of crustal elements observed during the winter months. This is likely due to the influence of seasonal meteorological patterns on aerosol transport and deposition. The mean size distribution of the aerosols was bimodal, with a dominant mode around 0.5 μm and a smaller mode around 2 μm .

The article "Geochemistry of aerosols of northwestern part of India adjoining the Thar desert" by R.K. Bajpai, M.K. Sharma, and A.K. Rai focuses on the chemical characterization of aerosols in the northwestern region of India adjacent to the Thar desert. The objectives of the study were to determine the chemical composition of the aerosols, identify their sources, and assess their impact on the environment and human health. The sampling was carried out during two seasons, namely the pre-monsoon (April-June) and post-monsoon (September-November) seasons. The six sampling sites included three urban sites (Jaipur, Jodhpur, and Bikaner) and three rural sites

(Phalodi, Kuchera, and Osian). A total of 27 aerosol samples were collected during the study period. The aerosol samples were collected from both urban and rural areas using high-volume samplers at a flow rate of 1.1 m³/min. The aerosol samples were collected on pre-fired and pre-weighed 8-inch diameter glass fiber filters with a pore size of 0.3 µm. The filters were then weighed again to determine the mass concentration of aerosols.

The samples were analyzed for their chemical composition using various techniques, such as X-ray fluorescence, ion chromatography, ICP-MS and atomic absorption spectroscopy. The authors also used a scanning electron microscope (SEM) to analyze the morphology and size of aerosol particles. The SEM analysis revealed that the aerosol particles were predominantly spherical in shape, and their size ranged from submicron to several microns.

The study found that the aerosols in the region were dominated by crustal elements such as silicon, aluminum, and calcium, which indicated that windblown dust from the Thar desert was a major source of aerosols in the region. The study also found that the concentrations of trace elements such as Ba, Sr, and Rb were elevated, which could be attributed to the presence of minerals such as feldspar, mica, and quartz in the aerosols. The study also analyzed the seasonal variations in aerosol chemistry and found that the concentrations of most elements were higher during the summer season, which could be attributed to increased dust emissions due to high temperatures and low humidity. The study suggests that the aerosols in the northwestern part of India are likely to have a significant impact on human health and the environment. The high concentrations of crustal elements in the aerosols may lead to respiratory problems, such as asthma and bronchitis.

4. Methodology

4.1. Study Area



Figure 1: Study Area

The 1.675 km^2 rectangular study area is located in Abbas Nagar, which lies roughly 3.5 km to the NE of Bhopal Airport and 7 km to the NW of Bhopal Railway Station. The area is chosen such that a disconformity laterally bisects it. The disconformity has a strike of 20 degrees N. The eastern boundary of the disconformity houses the Kaimur Sandstone from the neo-Proterozoic Era (710 million years ago) while the west borders the Deccan Basaltic Provinces from the end-Cretaceous Period (66 million years ago).

A geological field study was conducted to analyse the geological and topographical features of the study area.

4.1.1. Geological Characteristics

The sandstone belongs to the Upper Vindhyan supergroup. Its mineralogy consists of 95% quartz along with some heavy ultra-mafic minerals, thereby classifying it as Quartz Arenite. It was observed that the compact rock was relatively undeformed and had a higher specific gravity relative to other sandstones due to the scarcity of intergranular spaces (low porosity). This was likely due to deep burial of the sandstone, leading to an increase in temperature and pressure, thereby metamorphosing into quartzite. The arenite from our study area was found to be nearing completion of metamorphosis, as indicated by the absence of identifiable particles of groundmass as well as the presence of mafic xenolith enclaves. The arenite was observed to have 3 distinct sets of joint planes. The bedding plane was near-horizontal with a 5 - 20 degrees dip towards the N. This suggested that the beds were subjected to sedimentary dipping only. The other two joint planes were conjugate in nature and were likely formed due to compression shear fracturing. Also known as exhumation joints, they were formed due to the increase in bulk volume of the rock along the process of stress relaxation/exhumation when the deep-buried arenite resurfaced due to isostatic adjustments. The attitudes of the conjugate shear joints were noted along with the orientation of the angle bisector (N-S dipping), which indicated the direction of maximum horizontal stress. Extensive cross-bedding was observed which is suggestive of a shallow marine or riverine depositional environment. Paleocurrent directions were also plotted through the analysis of the cross-bedded layers. Thin strata of micaceous shale along with mudstone cement were also observed between the significantly thicker strata of arenites, further emphasizing the presence of a fluvial riverine depositional paleoenvironment.

The basalt belongs to the Deccan Traps formed by the Reunion hotspot volcanism during the northward drift of the Indian Plate. Mineralogically speaking, clinopyroxene and plagioclase feldspar were the most dominant minerals. The flood basalt is of a subalkaline tholeiitic composition i.e. most of the Mg members from the parent magma were already fractionated out of the melt during cooling, leading to heavy presence of Fe-members in its mineralogy. The

characteristic spheroidal weathering of basalts was observed. A visual comparison of the two rock bodies suggested that the weathering rates of the basalt seemed faster as compared to those of the sandstone.

4.1.2. Topographical Characteristics

The city of Bhopal has a mean altitude of 500 metres above sea-level. The basaltic region stands at a lower elevation of 500 to 520 metres while the sandstone region is at a higher elevation range between 500 and 560 (IT Park main building area) metres. Denser arboreal vegetation was observed throughout the basaltic region while scantier shrubby growth and grasslands were observed in the sandstone region.

The 1.675 km² study area is fairly populated (roughly 5000 people) and partially harbours 4 major institutions: Rajeev Gandhi Proudyogiki Vishwavidyalaya (RGPV), Information Technology (IT) Park, Mahaveer Institute of Medical Sciences & Research (MIMS) and the Ram Krishna Dharmarth Foundation (RKDF) University. RGPV and RKDF are based on basaltic terrains while MIMS and the IT Park are situated on sandstone landmasses. The northern parts of the study area contain agricultural parcels. The Aerocity Road is a major 6-lane highway that cross-cuts the region of study in the northern half. Beside the highway, several smaller roadways are gridded through the study area. A building construction site towards the eastern end of the study area was located and selected for conducting the ambient source aerosol sampling. According to the mean annual wind directions found through the wind rose, the IT Park main building and the Trade Pavilion building were chosen as appropriate upwind and downwind sites with respect to the construction site respectively. All three locations were equipped with the MiniVol Air sampler setups for sample collection of ambient PM_{2.5} aerosols.

4.2. Experimental Design

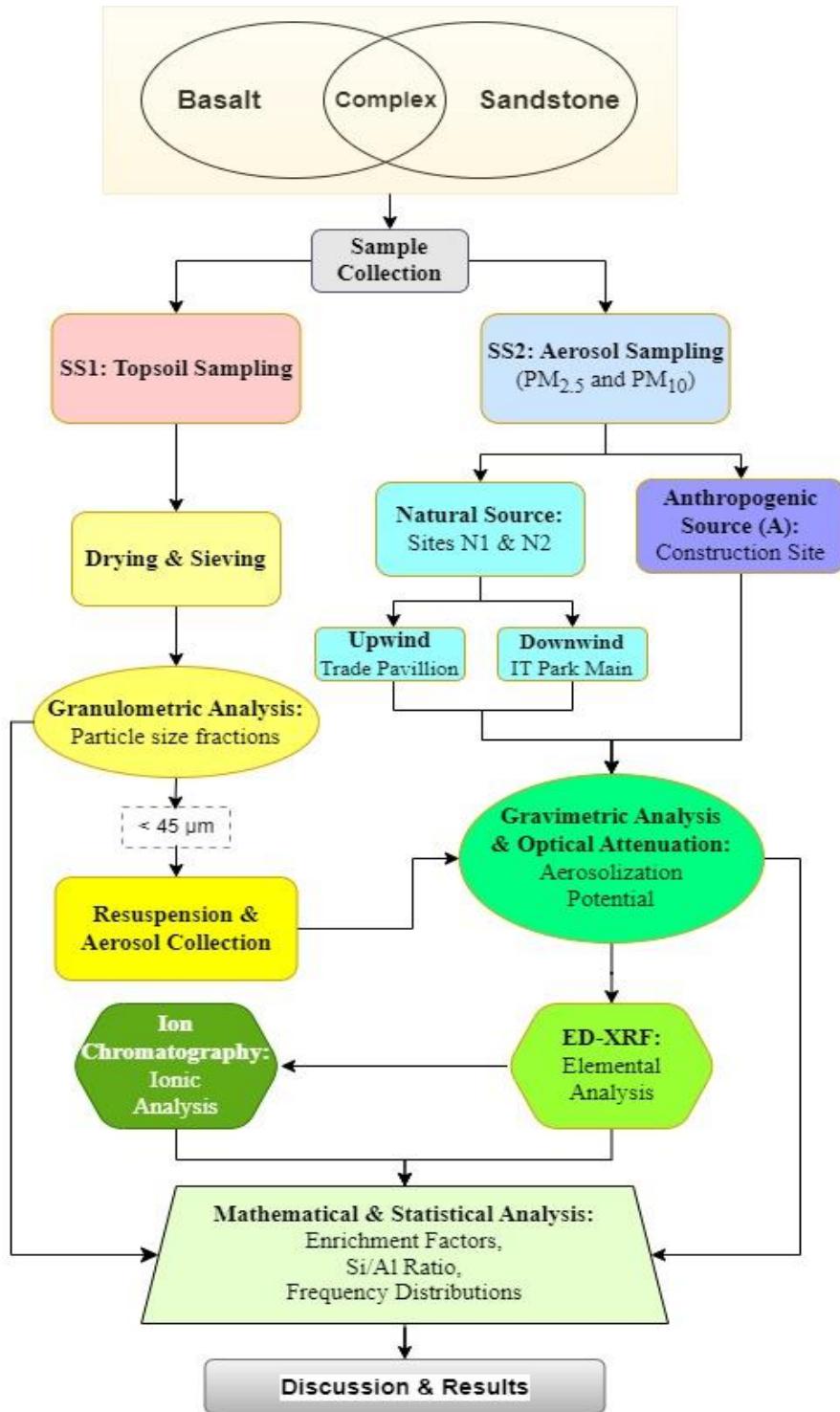


Figure 2: Brief experimental design. The steps involving physical analyses are represented by ellipses while those of chemical analyses are represented by hexagons.

Two broadly categorized sampling strategies were employed under the experimental design. SS1 involved the collection of top-soil samples across the entire study area (sandstone, basalt and their mixed derivatives close to the disconformity). Post collection, the samples were dried in an oven for a day before sieving and subjecting them to a granulometric analysis. Particle sizes smaller than 45 microns were collected separately and resuspended using a controlled air-flow in a closed chamber. Resuspended PM_{2.5} dust was collected into PTFE filters and subjected to physicochemical analysis. SS2 involves collection of ambient aerosols in the proximity of the construction site. The strategy was further divided into ambient collection of anthropogenically and naturally generated aerosols. N1 and N2 were chosen as upwind and downwind sites respectively relative to the construction site. Daily ambient sampling was performed simultaneously at both sites using QFF and PTFE filters. The anthropogenic source impacts were analysed by collecting ambient dust generated by the earth-moving machinery at the construction site. The PM_{2.5} samples were collected onto QFF and PTFE filters in 6-hour bouts.

4.3. Resources Utilized

4.3.1. List of Experimental Resources

- 45 Polytetrafluoroethylene (PTFE) filters
- Zip-Lock Bags
- Ice Packs
- Surgical Masks
- 10 Quartz Fibre Filters (QFF)
- Kimchi tissues
- Tweezers
- Filter cassette opener
- 40 petri dishes
- Rectangular strips of Parafilm
- Permanent Marker
- Gloves
- Inch Tape
- Brown and Cello Tapes
- Trowel
- 8 sets of Dust Pans & Brooms
- 2 Plastic Trays
- Cleaning brush
- Butter Papers
- Wiping Clothes
- Porcelain Bowls / Aluminium Foil
- Glass Fritted Filter (GFF)
- Spatula
- Standard Volumetric Flask, 1000 mL
- Standard Volumetric Flask (A Grade)
- Volumetric Pipette (10 mL)
- Polypropylene Bottles with Lid (> 47 mm diameter)
- Vial holders
- 30 centrifuge tubes
- 30 0.45 μm nylon disposable syringe filters

4.3.2. Description of Instruments Used

1. MiniVol Tactical Air Sampler (TAS)



Figure 3: MiniVol Tactical Air Sampler

The MiniVol Tactical Air Sampler (TAS) is a compact, lightweight, and portable air sampling instrument designed for the collection of particulate matter in ambient air. It uses a precision-engineered diaphragm pump to draw air through a preloaded filter cassette, which collects particulate matter from the air. The instrument is capable of sampling at flow rates ranging from 1 - 10 liters per minute, depending on the sampling requirements. The MiniVol TAS is equipped with an electronic flow control system that maintains a constant flow rate throughout the sampling period, ensuring accurate and reproducible results. The collected filters can be analyzed for various air pollutants, including PM10, PM2.5, and other fine and coarse particulate matter. The MiniVol TAS is widely used in air quality monitoring and research applications, as well as in occupational health and safety assessments.

2. D-4320 W.S. Tyler® Ro-Tap® 8" Sieve Shaker

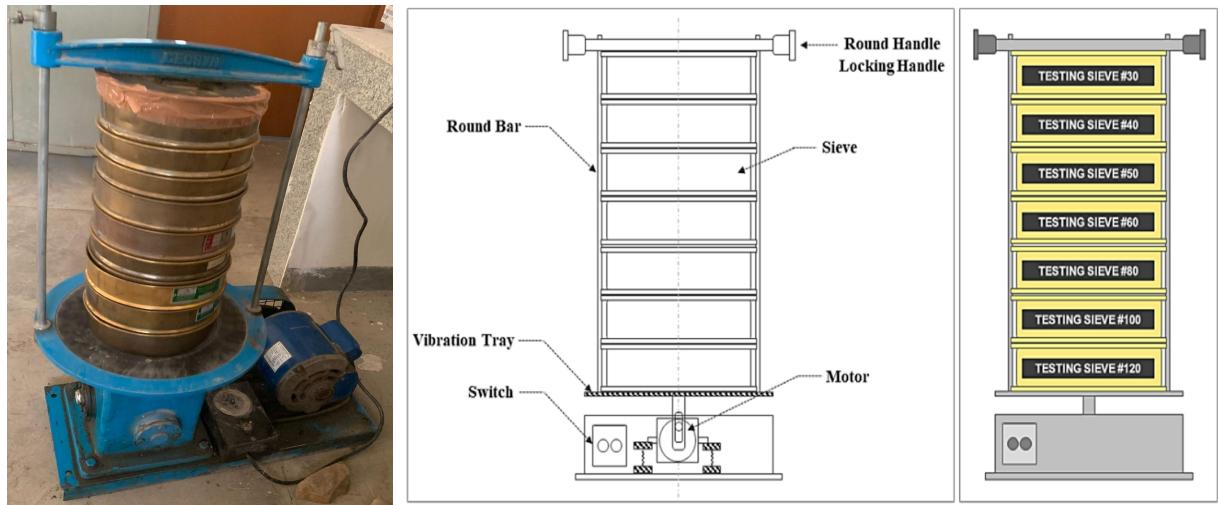


Figure 4: Sieve Shaker at IISER Bhopal Rock Facility (left), Schematic of an assembled sieve shaker (right)

The model used is similar to the D-4320 W.S. Tyler® Ro-Tap® 8" Sieve Shaker which is an instrument used to accurately and efficiently perform particle size analysis of dry powders and granular materials. The instrument consists of a circular steel sieve stack with up to eight sieves, which are fixed onto a vertically mounted motor. The motor drives a horizontal circular motion with a uniform tapping action, producing vertical and lateral movement of the sample on the sieves. This motion causes the sample to pass through the sieve openings and collect on the pan below. The instrument is equipped with an automatic timer to control the duration of the sieving operation. The Sieve Shaker is commonly used in industries such as mining, construction, agriculture, and environmental monitoring to determine the size distribution of particles in materials such as soil, sand, gravel, and minerals.

3. Resuspension Chamber



Figure 5: Resuspension Chamber setup at IISER Bhopal ACE Lab

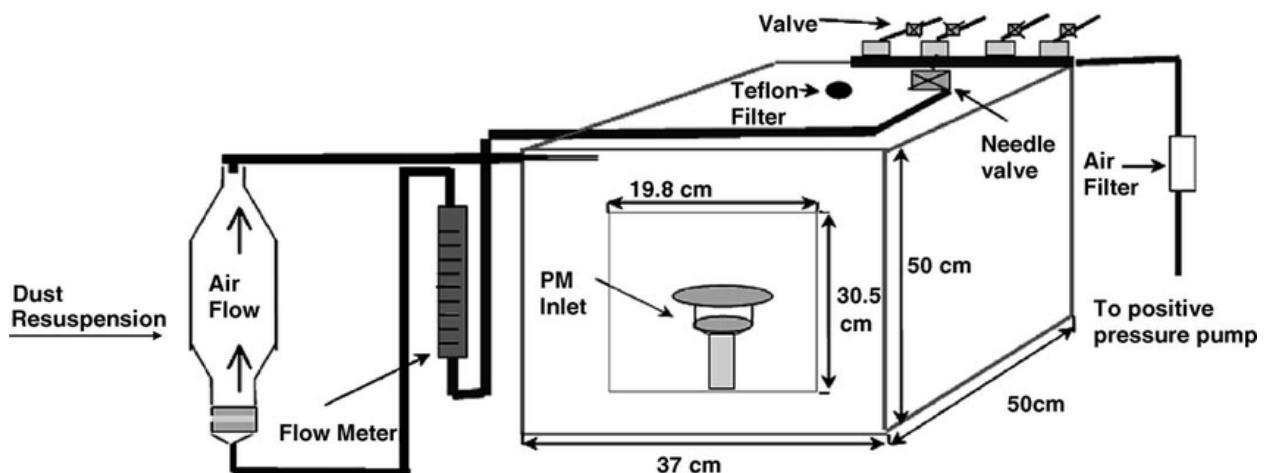


Figure 6: Schematic of the resuspension chamber setup

The instrument used is a modification of the UC Davis resuspension chamber and is used for studying the behavior of particulate matter (PM) in the atmosphere. It is used to simulate the resuspension of PM from surfaces, such as road dust or soil, into the air. The instrument consists of several parts, including an elutriator, dust collection chamber and a controlled air flow system.

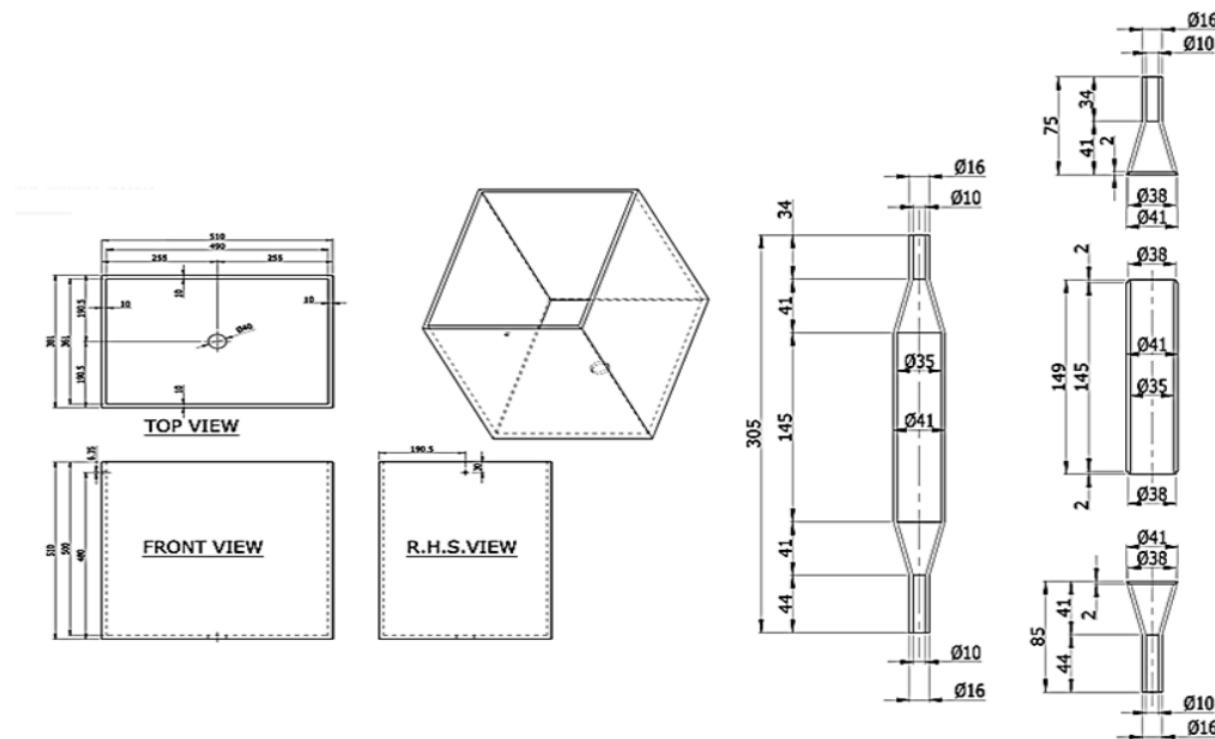


Figure 7: Dimensions of the dust collection chamber (left) and the elutriator (right)

The elutriator is responsible for generating and maintaining the desired concentration of particles in the test aerosol. It consists of a series of graduated chambers connected by a series of adjustable valves. The flow of the aerosol through the chambers is regulated by the position of the valves, which allows for the selection of particles of different sizes. The elutriator has a maximum flow rate of 50 L/min, and the particles can be sized from 0.5 μm to 10 μm .

The dust collection chamber is the main component of the instrument and is a rectangular box with an interior volume of approximately 1 cubic meters. The top of the chamber is made of a transparent material such as acrylic, allowing the researcher to observe the resuspension process inside the chamber. The chamber is equipped with several ports that allow for the introduction of test surfaces, air flow, and instrumentation. The chamber is designed to allow for

the measurement of both the resuspended PM mass and the size distribution of the particles.

A controlled air flow system is a crucial component of any resuspension chamber. The instrument is equipped with an air-pump (compressor), which generates a controlled air flow over a sample of the PM-containing material. It allows researchers to control the air flow rate & frequency inside the chamber, which in turn affects the resuspension of particles from surfaces. The system consists of a compressor, ducting, and a series of adjustable dampers that allow the researcher to control the air flow rate. The blower is typically a high-capacity, low-pressure unit that can deliver air flows of up to 500 cubic feet per minute (CFM) into the chamber. The solenoid network is responsible for controlling the flow of air and fluid in the UC Davis resuspension chamber. It consists of a series of valves that can be opened and closed electronically to allow air and fluid to flow in specific directions. The solenoid network is controlled by a computer program that can adjust the timing and sequence of the valve openings to create specific flow patterns. This allows for precise control over the elutriator and other components of the resuspension chamber, ensuring accurate and reproducible results. The resuspended PM is then collected on filters for subsequent analysis.

4. Sartorius ME-5F Micro Analytical Balance



Figure 8: Sartorius ME-5F Micro-Analytical Balance

The Sartorius ME-5F Micro Analytical Balance is a highly precise analytical balance used for accurately weighing small amounts of materials. It has a capacity of 5.1 grams and a readability of 0.1 micrograms, making it suitable for measuring very small quantities of materials. The balance has a compact design and features a draft shield to protect the sample from environmental factors such as air currents and dust. The balance operates on a high-precision electromagnetic force compensation mechanism that ensures accurate weighing results. It also features a monolithic weighing system that reduces the effects of vibrations and other disturbances, ensuring reliable and precise measurements. The balance is equipped with an

easy-to-use touchscreen display that provides intuitive navigation and allows for quick and easy adjustments to the settings. The Sartorius ME-5F also features built-in calibration and self-diagnostic functions, which help to ensure the accuracy and reliability of the balance over time. The balance is equipped with a USB interface, which allows for easy transfer of weighing data to a computer or other device for analysis and record-keeping.

5. Magee Scientific Soot Scan Optical Transmissometer - 21



Figure 9: The OT - 21 machine at IISER Bhopal ACE Lab

The Magee Scientific Soot Scan Optical Transmissometer - 21 (O.T. - 21) is an instrument used for real-time measurement of black carbon or soot concentrations in air. The instrument operates

by using a laser to illuminate a small volume of air containing particles, and then measures the attenuation of the laser beam as it passes through the sample. The attenuation of the laser beam is directly proportional to the concentration of black carbon particles in the sample. The O.T. - 21 is capable of measuring black carbon concentrations over a wide range, from 0.001 to 500 $\mu\text{g}/\text{m}^3$, with a resolution of 0.001 $\mu\text{g}/\text{m}^3$. The instrument has a response time of 1 second and is able to measure soot concentrations at a rate of 1 Hz, making it suitable for use in high-speed sampling applications. The instrument includes a built-in sampling pump, which draws air through a filter before it is analyzed by the transmissometer. The filter is used to remove large particles from the sample, ensuring that only small black carbon particles are measured. The O.T. - 21 is also equipped with a temperature and humidity sensor to correct for changes in ambient conditions, which can affect the accuracy of the measurements. The O.T. - 21 is designed for use in a variety of applications, including air quality monitoring, atmospheric research, and combustion studies. It is capable of measuring soot concentrations in both indoor and outdoor environments, and can be used to study the effects of air pollution on human health and the environment.

6. PANalytical EPSILON 5 Energy Dispersive X-Ray Fluorescence (ED-XRF)



Figure 10: PANalytical EPSILON-5 ED-XRF

The PANalytical EPSILON 5 Energy Dispersive X-Ray Fluorescence (ED-XRF) instrument is a powerful tool for elemental analysis of a wide range of solid and liquid samples. The instrument

utilizes X-rays generated by a tube, which are directed towards the sample. When the X-rays strike the sample, they cause the emission of secondary X-rays characteristic of the elements present in the sample. These secondary X-rays are detected by an energy-dispersive detector, and their energy is measured to determine the elemental composition of the sample.

The EPSILON 5 ED-XRF instrument is equipped with state-of-the-art technology for high-precision analysis. It has a high-resolution detector, which allows for the detection of even trace amounts of elements in the sample. The instrument can analyze elements from sodium to uranium, with detection limits ranging from sub-ppm to percent levels depending on the element and sample matrix.

The instrument is also designed for ease of use, with an intuitive user interface and automated sample handling capabilities. It can accommodate a range of sample types, including solids, powders, liquids, and thin films, and has various sample preparation accessories such as presses, fusion machines, and dilution units. The instrument also has a range of safety features, including interlocks to prevent accidental exposure to X-rays.

Applications of the EPSILON 5 ED-XRF instrument are diverse, and include analysis of metals, minerals, polymers, ceramics, environmental samples, and geological samples. It is widely used in industries such as mining, metallurgy, environmental monitoring, and quality control of raw materials and finished products.

7. Metrohm Basic Ion Chromatography 883+ (IC)



Figure 11: Metrohm Basic Ion Chromatography 883+ setup

The Metrohm Basic Ion Chromatography 883+ (IC) instrument is a high-performance liquid chromatography (HPLC) system that is designed to separate and quantify different types of ions in a sample. The IC system is a versatile and reliable tool that can be used in a wide range of applications, including environmental analysis, pharmaceutical testing, and food and beverage analysis.

The basic components of the Metrohm IC system include an injector, pump, column, detector, and data analysis software. The injector is used to introduce the sample into the system, while the pump is used to deliver the mobile phase through the column. The column is packed with a stationary phase that separates the ions based on their size, charge, and other

physicochemical properties. The detector is used to measure the concentration of each ion as it elutes from the column. Finally, the data analysis software is used to process the raw data and generate a final chromatogram that shows the ion concentrations in the sample.

The Metrohm IC system is capable of analyzing a wide range of anions and cations, including common environmental contaminants such as nitrate, sulfate, and chloride, as well as trace metals such as lead and mercury. The system is highly sensitive and accurate, with detection limits as low as parts per billion for some ions.

One of the key advantages of the Metrohm IC system is its ease of use. The system is fully automated, with pre-set methods and software that simplifies the sample preparation and analysis process. The instrument also features an intuitive user interface that allows for easy operation and monitoring of the analysis.

8. Coarse spring balance



Figure 12: Digital Notebook Jewelry Pocket Weighing Scale

The Digital Notebook Jewelry Pocket Weighing Scale is a compact, lightweight, and portable weighing scale used to measure small quantities of materials with high precision. The instrument has a maximum capacity of 500 grams with an accuracy of 0.01 grams, making it ideal for weighing jewelry, precious stones, medicines, and other small items.

The weighing scale features a digital display that shows the weight in grams and ounces. It is equipped with a tare function that allows the user to reset the scale to zero after placing the

weighing tray, which is useful when measuring small quantities of materials. The weighing tray is made of stainless steel, which is durable, corrosion-resistant, and easy to clean.

The instrument is powered by two AAA batteries, which provide long-lasting power for extended use. The scale also has an auto shut-off function that conserves battery life when the instrument is not in use. The scale has a compact size and can easily fit in a pocket or purse, making it convenient for fieldwork or travel.

Other instruments used are:

- Metrohm U Electrode
- Drying Oven
- Fume Hood
- Micropipette (100 μL - 1000 μL)
- Ultra-sonicator
- Wrist-action Shaker Machine
- Anemometer
- Brunton Compass
- GPS
- Hair Dryer

4.3.3. List of Chemicals Used

1. Sodium Bicarbonate: As anionic eluent solution for performing Ion Chromatography
2. Sodium Carbonate: As anionic eluent solution for performing Ion Chromatography
3. Methane Sulphonic Acid: As cationic eluent solution for performing Ion Chromatography
4. Ethanol: Used as a cleaning agent during soil sampling, drying, sieving, resuspension and ion chromatography
5. Acetone: Used as a leaching agent and for cleaning the GFF
6. DI: Used as a cleaning agent and a solvent
7. MiniVol Impactor Grease

4.3.4. List of Computational Resources

1. R Studio, version 3
2. ArcGIS 3.0
3. Google Earth
4. Google Sheets

4.4. Terrain Mapping

The sandstone-basalt disconformity was geologically and topographically mapped for attributes such as latitude, longitude, altitude, joint plane and disconformity attitudes (dip, strike, dip-direction), petrological & sedimentary features as well as terrain classification. A detailed account of the above attributes is provided in the “4.1 Study Area” section of this report.

4.5. Wind Rose

A wind rose for the study area was created by taking wind speed and direction data from the Central Control Room for Air Quality Management, Central Pollution Control Board (CPCB) for the year 2022.

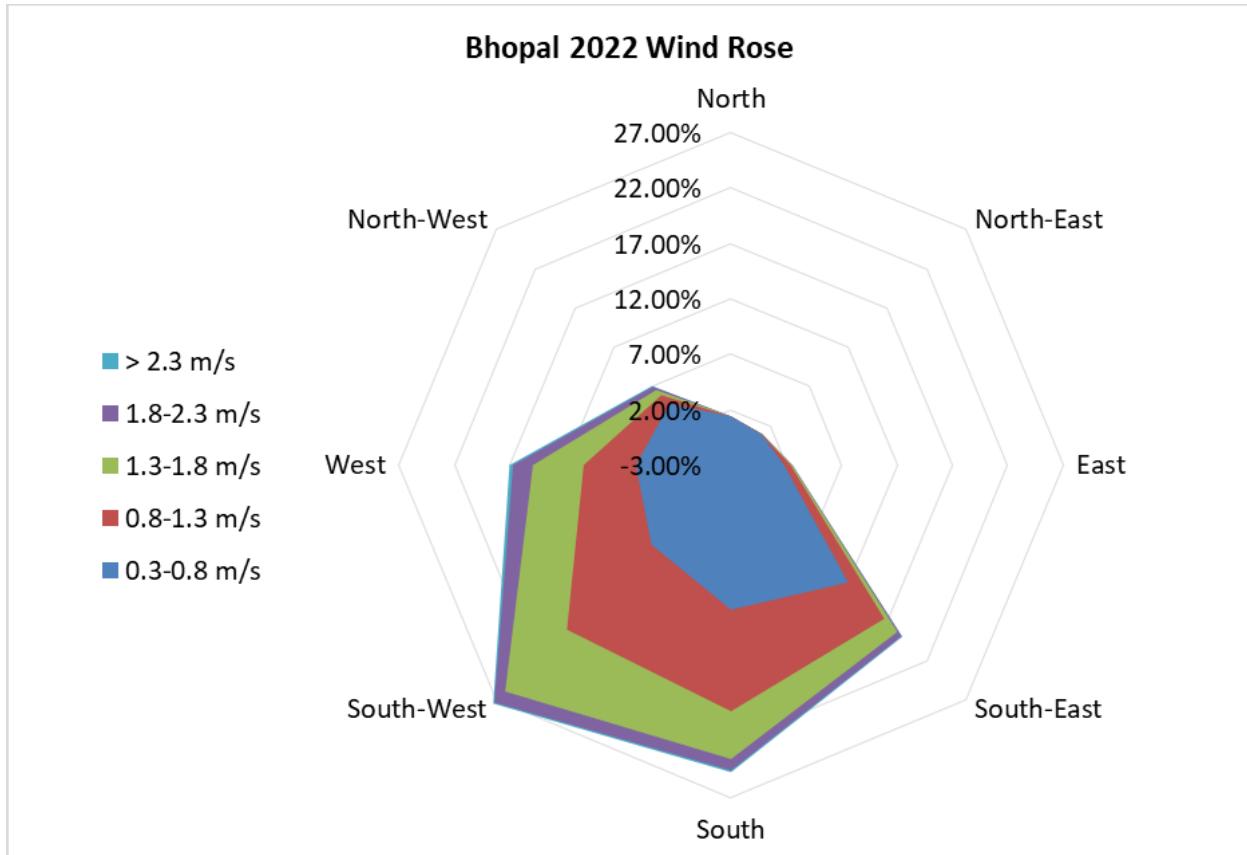


Figure 13: Annual Wind Rose of TT Nagar, Bhopal 2022

As can be seen in the wind rose, the dominant wind directions are in the S, SW directions. Wind speeds between 0.3 - 1.3 m/s are modes of the distribution.

4.6. Sample Collection

The sampling strategy was followed as given in the experimental methodology figure. A total of 17 top-soil samples were collected under SS1 while 10 construction-source-site ambient samples and 10 naturally weathered ambient samples (5 upwind, 5 downwind) were collected. The top-soil samples were collected by gently sweeping the top-soil from less vegetated soil exposures using a set of plastic broom and dust pan. Care was taken to minimize the loss of sample by avoiding turbulent sweeping and deposition motions during collection and transferring of soil samples (during the steps of drying and sieving).

The construction-source-site ambient aerosol samples were collected at a temporal resolution of 6 hours. Supplementary measurements of hourly wind speed, hourly wind direction, horizontal distance from dust source and height of sampler from source were recorded. The naturally weathered ambient sample collection involved a 23 hour sampling time with a break from 9:30 to 10:30 am. The air samplers were routinely wiped for dust accumulation, the impactors were re-greased on a daily basis and the filters were changed before each sample.

4.7. Drying

The samples were dried at 105 degrees celsius for 24 hours. Weights of the sample were noted before and after the soil-drying procedure using a coarse spring balance.

4.8. Sieving & Granulometric Analysis

Test sieves baskets of 8 different sizes (ASTM Sieve Nos: 70, 100, 140, 170, 200, 230, 270, 325, 500) along with the lid and collection pan were pre-weighed. The sieve baskets, top-cover lid and bottom-collection tray were then vertically stacked. Note that the pore numbers of the test sieves trend downward-increasing. 500 grams of a top-soil sample was weighed and placed into the topmost sieve. Air-tight sealing of all loose joints using a nylon tape ensured the minimization of contamination as well as loss of sample during the process of sieving. The stacked-sieves arrangement was then loaded onto the vibration tray and screw-fixed using the locking handle. The shaker was run for 1 hour at a frequency between 140 and 300 oscillations per minute (OPM). In general, higher frequencies may be used for smaller particle sizes and lower frequencies for larger particle sizes. A resting time of at least 30 mins was maintained before destacking the sieve baskets to allow for the settling of fine particulate matter before weighing the collected fractions.

All sieve baskets, cover lid and collection tray were post-weighed along with the collected soil fractions. Soil fractions resuspendable under ambient conditions (< 45 microns) were stored separately in butter paper containers. The rest of the soil fractions were stored in zip-lock bags in a cool, dry place. The test sieves, lid and collection tray were washed with DI and blow-dried between two samples. The sieves were tissue-wiped with ethanol between two triplicates.

4.9. Resuspension

Initial setup:

The dust resuspension and collection chambers were cleaned with DI and dried using a blow-dryer. A pressurized tubing was used to connect the air pump to the flowmeter. The piping from the flow meter is divided into 2 outlets, each connected to a port of the 2-valve solenoid network: T1 and T2. The air from T1 was channeled to the bottom of the resuspension chamber. The T2 port is open to the atmosphere and with the help of the inbuilt timer, it acts as an OFF switch, thereby making a periodic puffing system possible. The air exchange openings at the top of the dust collection chamber were refitted with fresh PTFE filters.

Procedure:

A PTFE filter was cut to size and placed on the glass fritted bed. A glass fritted filter (GFF) was placed on this. 1 gram of <45 micron soil particle-size fraction was weighed and deposited on top of the GFF before reassembling the resuspension chamber. 3.5 lpm laboratory air was forced through the resuspension and collection chambers. A puffing routine of 10 seconds “ON” time followed by 30 seconds “OFF” time was repeated for 15 minutes. The dust-air mixture was simultaneously sucked at a rate of 5 lpm for 15 minutes from the dust collection chamber through a PM2.5 impactor onto a 45 mm pre-weighed PTFE filter fitted on a MiniVol air sampler.

The dust collection chamber, fritted bed & its parts as well as the subcomponents of the PM impactor were cleaned using ethanol and tissue paper after every resuspension. The GFF was sonicated for 15-30 mins in a small beaker containing DI and a few drops of acetone followed by

drying for at least 3 hours in the fume hood. The PTFE filter placed on the fritted bed was replaced after every resuspension. The PTFE filter in the air sampler was equilibrated for 24 - 48 hours at 20 - 25 degrees celcius temp and 35 - 45% relative humidity (RH) levels before post-weighing it.

4.10. Gravimetric Analysis

To determine the masses of PM10 and PM2.5, all the PTFE filters were weighed before and after sampling using a Sartorius®ME-5F micro analytical balance with a response time of 10s and a sensitivity of 1 μ g. The micro-balance was placed in an environment that was temperature and humidity controlled, with a maintained temperature of approximately 23°C and relative humidity ranging between 35-38%. Before weighing, the filters were left in the controlled environment for a 24-hour period to equilibrate. In addition, the sample's electrical charges were eliminated using a Metrohm® U electrode before weighing.

4.11. Optical Attenuation

The bench-top optical transmissometer (Magee Scientific Soot Scan® OT-21) was used to determine the optical attenuation of samples collected on Teflon filters at 370 and 880 nm. A blank filter was inserted into the filter blank slot and the machine approved it. The sample was then tested for UV and IR indices of OT-21 testing. The OT-21 measures the optical attenuation (ATN) at each wavelength, which is defined as $ATN = -100 \ln(I/I_0)$, where I and I_0 are the intensity of light transmitted through the loaded filter and blank filter at the given wavelength, respectively.

4.12. Elemental Analysis

Elemental analysis was conducted using the PANalytical EPSILON 5 Energy Dispersive X-ray fluorescence (ED-XRF) system. The mass of trace elements in each sample was determined by analyzing Teflon filters. The system was equipped with twelve secondary targets to select appropriate excitation energies to measure the concentrations of different target analytes. For this study, the analysis of samples and uncertainty estimation followed protocols similar to the IMPROVE Standard Operating Procedure for XRF analysis of filter substrates using the EPSILON 5 (IMPROVE SOP 301, 2014). Elemental analysis was carried out by placing the samples into the ED-XRF machine after cleaning the sample slots. Each sample ran for a time duration of 40 mins.

4.13. Ion Chromatography

After ED-XRF analysis, the Teflon filters underwent leaching with water and then were subject to Ion Chromatography analysis for both anions and cations, using the Metrohm® Basic IC 883. For leaching, 20 ml of ultrapure water was used, followed by 1.5 hours of sonication and twelve hours of mechanical shaking. Before analysis, the samples were filtered through 0.2 μm syringe filters. An isocratic separation technique was employed using a Metrosep A Supp 4 250/4.0 column and a 1.8 mmol/L Na₂CO₃/1.7 mmol/L NaHCO₃ eluent for anions, and a Metrosep C 4 100/4.0 column and 1.7mmol/L Nitric acid/0.7 mmol/L dipicolinic acid eluent for cations.

4.14. Data Analysis

4.14.1. Calculation of Enrichment Factors

The Enrichment Factor (EF) of all chemical species in relation to their abundance in the Upper Continental Crust (UCC) was determined. To adjust for the natural variability of trace elements in the UCC, the masses of elements are standardized by an element in the crust that is least likely to be influenced by human activities. This normalization allows for the evaluation of anthropogenic contributions to elements while accounting for the natural variability in UCC abundance. Among the normalizers used for estimating EF, Al is the most successful and widely used (Pant et al., 2015). The Al-normalized Enrichment Factor (EF_j) for an element 'j' is calculated as follows:

$$EF_j = \frac{\left(\frac{MF_j}{MF_{Al}}\right)_{\text{Sample}}}{\left(\frac{MF_j}{MF_{Al}}\right)_{\text{UCC}}}$$

where MF_j and MF_{Al} represent the mass fractions of the element and Al, respectively. EF values ≤ 2 , $2 < EF \leq 5$, $5 < EF \leq 20$, $20 < EF \leq 40$, and $EF > 40$ correspond to minimal enrichment, moderate enrichment, significant enrichment, very high enrichment, and extremely high enrichment, respectively (Kartal et al., 2006).

4.14.2. Calculation of Si/Al Ratio

The Si/Al ratio was quantified by using results of relative abundances of elements obtained from the elemental analysis using the ED-XRF system.

4.14.3. Top-Soil Particle Size Distribution Analysis

The granulometric analysis of the top-soil yielded a top-soil grain size distribution by mass. Observations regarding maxima-minima, inflection, modality, etc were noted.

5. Results and Conclusion

5.1. Visual Observations

The best sandstone top-soil deposits were observed on exposed, unvegetated regolith clearances. The relatively low-lying deposits were gulfed by adjacent higher elevated vegetation and regolith bodies. When viewing a vertical cross-section, the larger particles-sizes were housed at the top and smaller particles were consequently stratified below them.

5.2. Grain Size Distribution Analysis

Granulometric Analysis

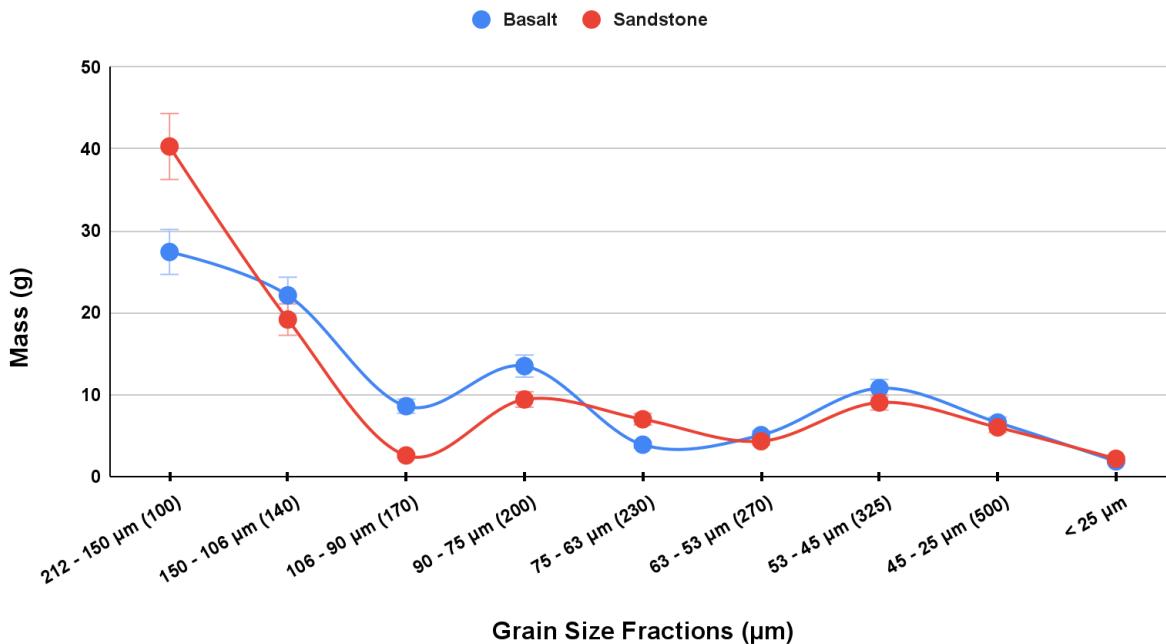


Figure 14: Grain-size distribution by mass of sandstone & basaltic sub-212 micron top-soil

The granulometric analysis revealed a trimodal nature of distribution for soil fractions of 25 µm - 212 µm of both basalt as well as sandstone. The frequency peaks occurred at bin pore sizes (ASTM values) of 100, 200 & 325. Note that the peak at ASTM No. 100 is a boundary peak and is subject to shift towards larger grain size fractions owing to the unavailability of smaller pore number test sieves. The graph above shows the average grain size distribution for both basalt and sandstone for 10 top-soil samples (4 basalt, 6 sandstone).

5.3. Gravimetric Analysis

The average mass concentration of a 6-hour construction source ambient sample is 29.7072 mg/m³. The average mass concentrations of the 23-hour upwind and downwind ambient sampling are 6.338 mg/m³ and 8.640 mg/m³ respectively.

5.4. Optical Transmissometry

The average UV and IR values provided by the OT-21 system are as follows:

- Construction source ambient sample: UV = 28.25, IR = 9.75
- Upwind ambient samples: UV = 47, IR = 17.5
- Downwind ambient samples: UV = 67.5, IR = 27

5.5. Elemental Analysis

Following are the results of the elemental analysis:

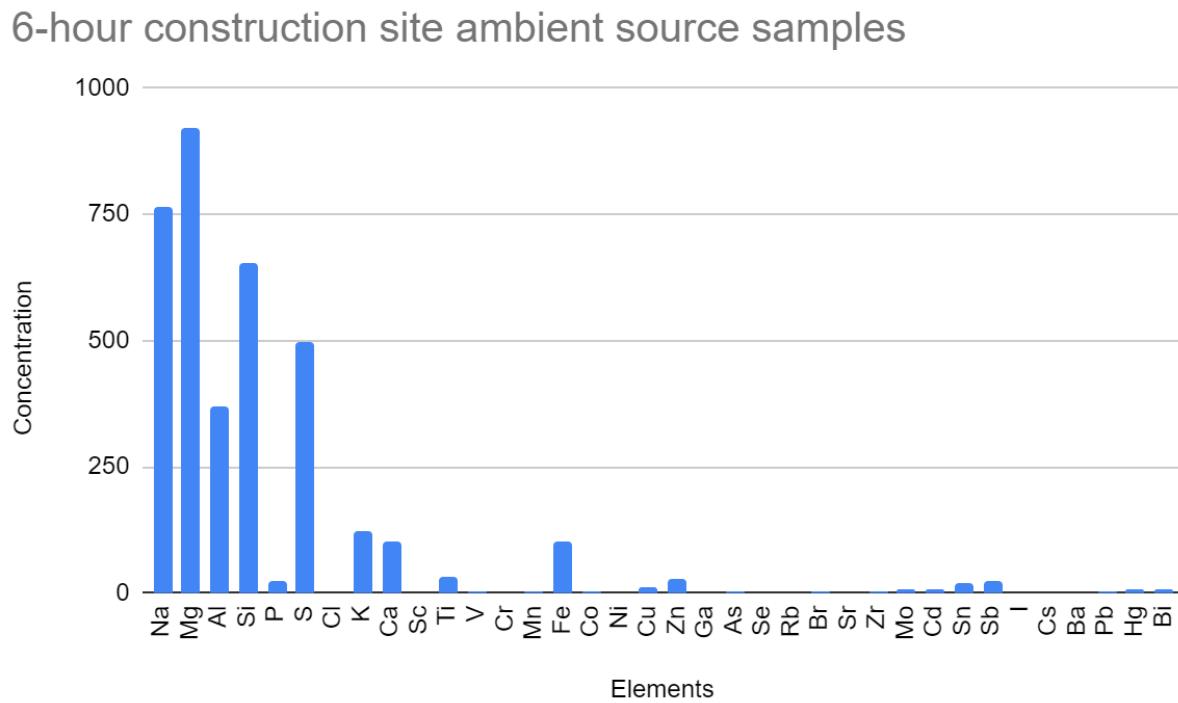


Figure 15: Elemental analysis of construction-produced ambient source samples

The construction site ambient source samples reveal that crustal components dominate the overall composition of the aerosols with the abundance of crustal elements such as Si, Al, Fe, Ca,

Na, Mg, K, Ti, P and Mn.

23-hour ambient samples

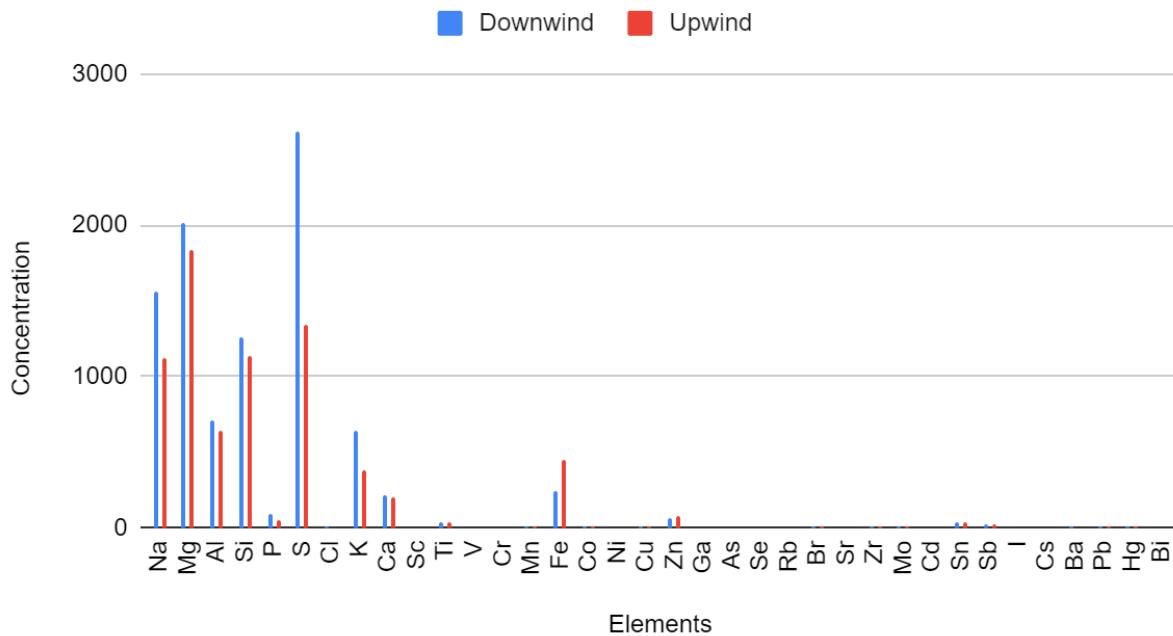


Figure 16: Elemental comparison between ambient samples upwind & downwind of the construction site

The comparison between downwind and upwind samples reveal a marginally albeit heavier loading on the downwind samples compared to its upwind counterparts. The downwind samples seem to be relatively enriched in Na, K and S and depleted of Fe, suggesting that these elements could be aerosolized at the construction site. However, the chemical profile of the construction source site does not readily agree with this conclusion. Therefore, further analysis on this study site is warranted to draw more meaningful conclusions.

Resuspended PM2.5 Basalt vs. Sandstone

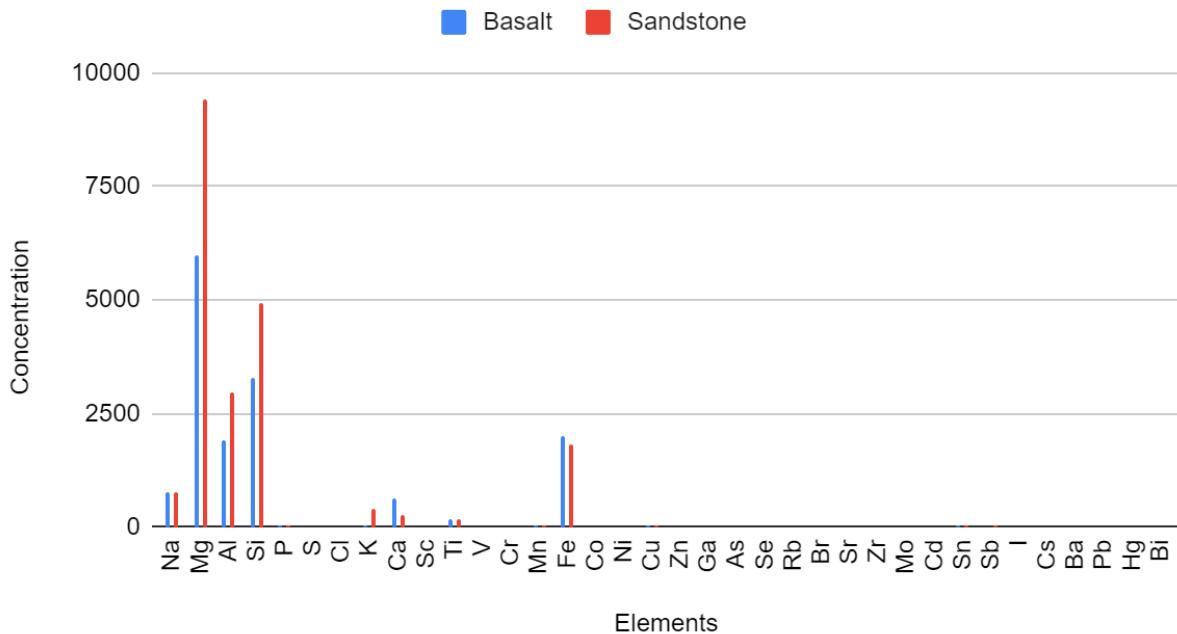


Figure 17: Elemental comparison between resuspended PM2.5 sandstone & basaltic top-soil dust

The chemical profile of PM2.5 sandstone aerosol is observed to be slightly more enriched in its Mg, Si, K & Al contents and Ca-depleted compared to its basaltic counterpart.

5.6. Ionic Analysis

Ionic Species	Ambient Samples (ppm)		Resuspended Basalt (ppm)	Resuspended Sandstone (ppm)	Source Samples (ppm)
	Upwind	Downwind			
Ionic Species	Na+	0.2746	0.2477	0.1497	0.317975
	Ca2+	0.46195	0.73845	0.66535	0.6650125
	K+	0.25695	0.3326	0.0533	0.119125
	Mg2+	0.03395	0.0367	0.04695	0.0564
	NH4+	0.85975	1.41675	0.08465	0.23885
	Cl-	0.28795	0.305	0.2136	0.379075
	SO4 2-	2.47195	4.0804	n.a.	0.05055
	F-	0.07515	0.0706	0.18165	0.087675
	NO3-	0.3364	0.4288	0.1775	0.5230666667

Table 1: Results of the ions present after the ion chromatography analysis

Only 8 ionic species (4 cations, 4 anions) were present at significant concentrations across all aerosol samples as seen in the table above.

The downwind samples appear relatively enriched in Ca^{2+} , K^+ , NH_4^+ , SO_4^{2-} and NO_3^- . Among the inter-regolith comparisons, sandstone seems to host more Na^+ , K^+ , NH_4^+ , NO_3^- while basalt holds more Ca^{2+} and F^- . SO_4^{2-} was negligibly present in the sandstone while it was absent in the basalt.

5.7. Quantification of Si/Al Ratio

1. Construction source ambient sample: 1.764
2. Upwind ambient samples: 1.7860
3. Downwind ambient samples: 1.7606
4. Resuspended basalt samples: 1.7316
5. Resuspended sandstone samples: 1.6624

The upwind and downwind ratios were near equal while a significant deviation of Si/Al ratios was observed between the basalt and sandstone samples with basalt being relatively more enriched by silica.

6. References

1. Patterson, E. M. (1981). Optical properties of the crustal aerosol: Relation to chemical and physical characteristics. *Journal of Geophysical Research: Oceans*, 86(C4), 3236-3246.
2. Rahn, K. A. (1976). Silicon and aluminium in atmospheric aerosols: crust-air fractionation?. *Atmospheric Environment* (1967), 10(8), 597-601.
3. Prospero, J. M., and T. N. Carlson, Vertical and areal distribution of Saharan dust over the west equatorial North Atlantic Ocean, *J. Geophys. Res.*, 77, 5255-5265, 1972
4. Bryson, R. A., & Baerreis, D. A. (1967). Possibilities of major climatic modification and their implications: Northwest India, a case for study. *Bulletin of the American Meteorological Society*, 48(3), 136-142.
5. Chen, S., Jiang, N., Huang, J., Xu, X., Zhang, H., Zang, Z., ... & Feng, T. (2018). Quantifying contributions of natural and anthropogenic dust emission from different climatic regions. *Atmospheric Environment*, 191, 94-104.
6. Samiksha, S., & Raman, R. S. (2017). A note on unusual Si/Al ratios in PM10 and PM2.5 road dust at several locations in India. *Chemosphere*, 181, 376-381.
7. Ronov, A. B., & Yaroshevsky, A. A. (1969). Chemical composition of the earth's crust. Washington DC American Geophysical Union Geophysical Monograph Series, 13, 37-57.
8. Darzi, M., & Winchester, J. W. (1982). Resolution of basaltic and continental aerosol components during spring and summer within the boundary layer of Hawaii. *Journal of Geophysical Research: Oceans*, 87(C9), 7262-7272.
9. Kyotani, T. (2005). Characterization of atmospheric aerosol in the northern foot of Mt. Fuji, central Japan. *Water, air, and soil pollution*, 164(1), 43-56.
10. Shrivastava, J. P., & Pattanayak, S. K. (2002). Basalts of the eastern Deccan volcanic province, India. *Gondwana Research*, 5(3), 649-665.
11. Shrivastava, S., Singh, V., & Usmani, H. U. Petrographic classification and Provenance study of Bhander Sandstones of the Vindhyan Supergroup, in the NW Part of Bhopal, Madhya Pradesh, India.
12. Gill, T. E., Zobeck, T. M., & Stout, J. E. (2006). Technologies for laboratory generation of dust from geological materials. *Journal of hazardous materials*, 132(1), 1-13.
13. Samiksha, S., Raman, R. S., Nirmalkar, J., Kumar, S., & Sirvaiya, R. (2017). PM10 and PM2.5 chemical source profiles with optical attenuation and health risk indicators of paved and unpaved road dust in Bhopal, India. *Environmental Pollution*, 222, 477-485.

6.1. Web References

1. <https://www.911metallurgist.com/blog/sample-preparation-methods-for-xrf-analysis>
2. <http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/elabund.html>
3. <https://en.wikipedia.org/wiki/Soil>
4. <https://www.merriam-webster.com/dictionary/disaggregate>
5. <https://www.britannica.com/science/weathering-geology>
6. <https://byjus.com/biology/soil-profile/#:~:text=A%20soil%20profile%20is%20a,known%20as%20the%20soil%20profile>.
7. <https://study.com/academy/lesson/what-is-topsoil-definition-composition-uses.html>
8. <https://www.britannica.com/science/gravimetric-analysis>
9. <https://filab.fr/en/our-services/our-analysis-services/laboratory-granulometric-analysis/>
10. https://d3pcsg2wjq9izr.cloudfront.net/files/1356/products/42632/1356_2_202107162304553242711_raw.jpg