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Mineralogical Characterization of PM_{10} over the Central Himalayan Region †

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Abstract: The air quality of the Himalayan region of India is deteriorating due to the increasing load of particulate matter that is emitted from various local and regional sources, as well as to the transit of dust-related pollutants from the Indo-Gangetic Plain (IGP) and surrounding areas. In this study, the mineralogical characteristics of coarse mode particulate matter (PM_{10}) was analyzed using the X-ray diffraction (XRD) technique from January to December 2019 over Nainital (29.39° N, 79.45° E; altitude: 1958 m above mean sea level), a central Himalayan region of India. XRD analysis of PM_{10} samples showed the presence of clay minerals, crystalline silicate minerals, carbonate minerals, and asbestiform minerals. It was shown that quartz minerals with significant levels of crystallinity were present in all the samples. Other minerals that are contributing to the soil dust were also observed in the analysis ($CaFe_2O_4$, $CaCO_3$, $CaMg(CO_3)_2$, calcium ammonium silicate hydrate (C-A-S-H), gypsum, kaolinite, illite, augite, and montmorillonite). The minerals ammonium sulphate, hematite, and magnetite were also found in the samples and are suggested to be from biogenic and anthropogenic activities, including biomass burning, fuel combustion, vehicle exhaust, construction activities, etc. This study indicated that the majority of the minerals in PM_{10} that were present in this Himalayan region are from soil/crustal dust.

Keywords: PM_{10}; Himalayas; XRD; dust; clay minerals; sources

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1. Introduction

The Indian Himalayan Region (IHR) is renowned for its pristine nature, ecological fragility, abundant biodiversity, and remarkable vulnerability, making it one of the most crucial regions on the Earth [1–3]. The central Himalayan region of India is widely recognized for its unique geological and environmental attributes [4–6]. Urbanization in and around the Himalayas has led to increased energy consumption, resulting in disturbances to the temperature of the Himalayas and the degradation of its air quality [7,8]. One of the main reasons for the deteriorating air quality is an increase in the load of particulate matter (PM) emissions over the region. These PM emissions are known to generally rise from local and regional sources, as well as from the migration of dust-related pollutants from the Indo-Gangetic Plain (IGP) and surrounding areas [4,5,9]. Hence, to achieve a better understanding of the composition, sources, and potential impact of PM in the central Himalayan region, mineralogical characterization of PM_{10} has been conducted. This study aims to analyze and identify the mineral components present in the PM, particularly focusing on the coarse-mode particulate matter (PM_{10}) fraction.

2. Materials and Methods

2.1. Study Area and Sampling

This study was conducted in ARIES, Nainital, a central Himalayan region of India (29.39° N, 79.45° E, 1959 m amsl) (Figure 1). Twenty-four-hour PM_{10} sampling was performed from January to December 2019 using a high-volume sampler with an average flow rate of 1.2 m^3 min^{-1} and with a flow accuracy of ±2% of full scale. Detailed information regarding sampling procedures and instrumentation can be found in earlier publications [5].

Figure 1. Study Area: ARIES, Nainital (Source: Google Earth).

2.2. X-ray Diffraction Analysis

X-ray diffraction (XRD) analysis was performed on the collected PM_{10} samples to determine the mineralogical characteristics. The XRD technique made this possible by identifying and quantifying the mineral contents in the sample based on their unique diffraction patterns. The XRD measurements were conducted using a Rigaku Ultima IV instrument. The samples were scanned during the XRD investigation at a Bragg angle (2θ) varying from 10 to 60 degrees to gather the X-ray diffraction data; 3° per minute was the scanning speed employed. As the X-ray source, a copper (Cu) Kα-line with a wavelength of 1.54 Å was used. Mineral identification was carried out by comparing the peak positions (2θ) from the XRD data with the reported literature [10–12] and the RRUFF database of a reference standard.

3. Results and Discussion

3.1. Mineralogical Composition

The XRD analysis of PM_{10} revealed the presence of various minerals. Illite, kaolinite, montmorillonite, quartz, dolomite, calcite, magnetite, hematite, gypsum, halite, mascagnite, augite, albite, wollastonite, and calcium aluminum silicate hydrate (C-A-S-H) are the common minerals that were detected in all the samples (Table 1). Figure 2 shows the XRD pattern of the mineral contents that were present in PM_{10} samples. It is important to note that these minerals may be found in various environmental contexts, and their presence can have different implications depending on the concentrations. Additionally, some of the minerals mentioned can have multiple sources and pathways of formation. Understanding their sources and impacts is crucial for environmental and health considerations.

Table 1. Minerals, corresponding XRD peak positions (2θ).

Mineral	Chemical Composition	2θ
Quartz	SiO_2	20.64, 26.50, 40.46
Dolomite	$(Ca, Mg (CO_3)_2)$	30.70, 37.56, 50.52, 50.94
Augite	$(Ca, Mg, Fe)_2Si_2O_6$	19.80, 30.70, 34.64, 40.46, 40.84, 41.92, 49.56
Albite	$Na(AlSi_3O_8)$	13.74, 14.74, 15.96, 23.28, 24.60, 27.96, 53.26
Calcite	$CaCO_3$	23.28, 29.36, 36.06, 47.88, 48.30
Kaolinite	$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$	19.80, 20.64, 21.34, 23.28, 24.60, 36.06, 37.56, 38.96, 40.46, 40.85, 47.88, 52.72, 55.22, 56.74
Illite	$(K, H_3O^+) (Al, Mg, Fe)_2(Si, Al)_4O_{10}[(OH)_2, (H_2O)]$	17.36, 26.82
Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2SiO_4(OH)_2{\cdot}nH_2O$	19.80, 21.34, 34.64
Magnetite	Fe_3O_4	56.74
Hematite	Fe_2O_3	40.84, 49.56
Gypsum	$CaSO_4{\cdot}2H_2O$	20.64, 23.28
Halite	NaCl	31.88, 56.74
Mascagnite	$(NH_4)_2SO_4$	20.64, 29.36, 34.64, 38.96
Wollastonite	$CaSiO_3$	23.28, 51.96, 53.26
C-A-S-H	$Ca_{12}Al_2Si_{18}O_{51}(OH)_2{\cdot}18H_2O$	29.36

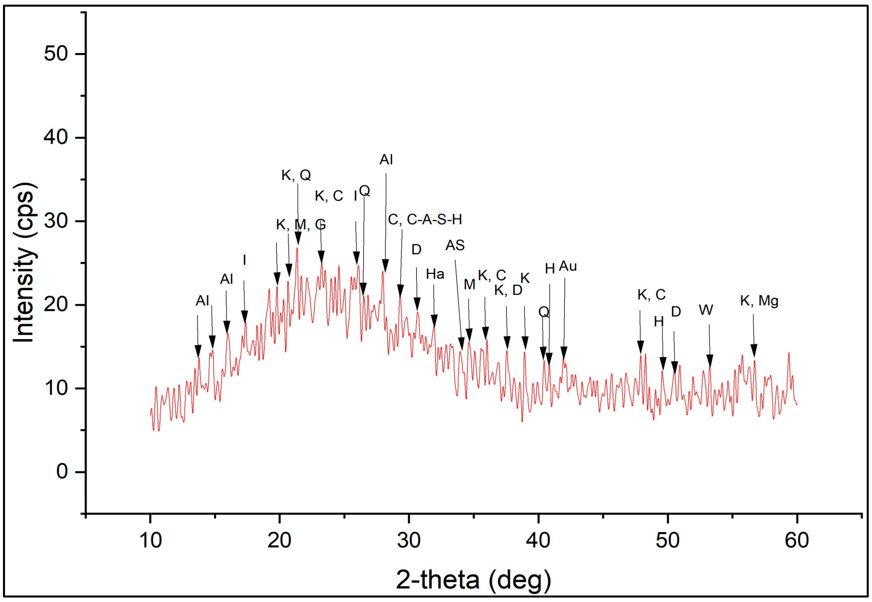

Figure 2. XRD pattern for the PM_{10} sample. Quartz (Q), dolomite (D), albite (Al), augite (Au), illite (I), kaolinite (K), montmorillonite (M), hematite (H), magnetite (Mg), gypsum (G), wollastonite (W), mascagnite (AS), and halite (H).

3.2. Soil-Dust Composition

We used a quartz fiber filter that has a silicate composition for the sampling of PM_{10} samples, and also, it is the mineral that is present in the soil/crustal dust samples. Quartz minerals with significant crystallinity were consistently detected in all the samples, indicating their ubiquitous presence. Previous studies illustrated that the presence of quartz mineral in the samples was due to the geographical characteristics of the respective locations, i.e., soil, land cover, land-use pattern, road length, etc. [10–15]. Dolomite, albite, and augite (small amount) are other minerals detected in the PM_{10} samples, which have natural/geological origin, i.e., they originated from soil and road dust, weathering of rocks, etc. [10,11,16].

3.3. Anthropogenic Contribution

The minerals calcite, kaolinite, illite, montmorillonite, magnetite, hematite, gypsum, and wollastonite were found in PM_{10} samples that originated from both geogenic as well as biogenic and anthropogenic sources. The minerals illite [10,11,17], kaolinite [10–12,16], and montmorillonite [11,14] primarily originated from geological processes and various industrial processes, agricultural activities, combustion activities (fossil fuel, biomass burning, etc.) and were also responsible for the generation of these minerals in the air [5,10,14,16]. Hematite [11,14,15] and magnetite [12] both are Fe-containing minerals that primarily originated from soil erosion, the weathering of rocks, and dust storms and also from various human activities such as iron and steel production, combustion (vehicular emission and power plants), and iron and steel wear from brake pads and tires [13–16]. Candeias et al. (2020) illustrated that the mineral containing Fe, Cu, Zn, S, Al, Ti, and Sb composition originated from anthropogenic activities like brake pads, brake disc abrasion, road wear, etc. [15]. Gypsum [12], C-A-S-H [10,12], and wollastonite [12] are the minerals of which Ca majorly contributed to their composition. These minerals originated through mining, construction, and demolition activities [10,12]. Mascagnite, i.e., ammonium sulphate, is a major contributor through a secondary reaction that is occurring in the atmosphere [12]. The main sources of mascagnite in PM_{10} are fossil fuel burning (coal and oil), industrial emissions, biomass burning, waste incineration, etc. [6]. Halite is the salt mineral that is used as a de-icing agent during winters [12]. Various studies illustrated the transport of dust aerosols from the Indo-Gangetic Plain (IGP), the Thar Desert, the Bay of Bengal (BoB), and other regional countries toward the IHR [3,5].

4. Conclusions

Through the mineralogical characterization of PM_{10} collected over the central Himalayan region of India from January to December 2019, valuable insights have been gained regarding the types of minerals present in the airborne particles. The present study sheds light on the sources and origins of these minerals, such as natural dust, anthropogenic emissions, or a combination thereof. Certain minerals such as quartz, dolomite, albite, and augite have been found in this study to have natural origins. Additionally, minerals like illite, kaolinite, montmorillonite, hematite, magnetite, gypsum, calcium aluminum silicate, ammonium sulphate, halite, etc., associated with the biogenic and anthropogenic activities like combustion, mining, construction, demolition, etc., have also been detected. Hence, by understanding the mineralogical characteristics of PM, policymakers, scientists, and environmentalists can gain crucial insights into the sources, compositions, and potential health impacts of PM.

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