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Variations in weathering of natural and man-made forest systems in the Southern Western Ghats, India

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Abstract

The study was initiated to understand the variations in weathering happening in the soils of two distinct forest systems in the Southern Western Ghats, India. Soil minerals are formed by the weathering of parent material, which is the source of soil. Understanding the association between vegetation and soil dynamics is evident and that can be used for the sustainable management of soils. Two diverse forest types including an evergreen forest and a rubber plantation were selected for the study. The soil profiles were dug up to 1.5m and collected soil samples from each horizon. These collected soil samples were used for physicochemical and mineralogical analysis which includes X-ray diffraction and scanning electron microscopy. pH was found acidic in both systems. The organic carbon percentage was observed high in the evergreen forest (3.29%) and low in the rubber plantation (0.63 %). The soils in both forest systems were classified to the order Ultisols. The mineralogical studies have shown that the soils of the evergreen forest were least weathered than the rubber plantation.

Keywords: Tropical soils; soil orders; soil mineralogy; weathering; soil chemistry; soil degradation, soil organic matter.

Introduction

Soils in humid tropical regions are considered extremely weathered due to high rainfall and temperature. Vegetation, parent material, relief, climate, and time are the five major factors that control soil formation. Among these, vegetation exerts a significant effect on the morphological, physico-chemical, and biological properties of soils[1]. Forests are considered pristine systems which maintain soil health by their root system and adding organic matter via litter fall. Human activities have changed land-use practices and also influence forest resources by changing them to agricultural uses[2]. Continuous cultivation drops the productivity of soils by decreasing organic matter contents, bulk density pH, causes soil erosion, and weakens root distribution in soil surfaces[3,4]. Changes happening in soil characters due to the conversion of natural forests for cultivation and their effects on soil productivity have developed a substantial research interest in the recent decades[5,6]. In humid tropics, these concerns have much importance as the soils are inherently low in fertility and subject to repetitive degradation cycles.

Forest ecosystems in tropical regions are with less information on their genesis and mineralogy[7]. The absence of detailed information on pedogenesis and their variations in natural forests and plantation systems in the Southern Western Ghats is very important in the management of soils in these regions. Therefore, the study was carried out, to characterise the soil profiles in natural and man-made systems and evaluate their conversions through morphological, taxonomic, and mineralogical approaches. Revealing the association between vegetation and soil dynamics is vital for the sustainable management and restoration of the soils in the region.

Materials and methods

Study area and sample collection: Two distinct vegetation systems in the Kerala part of Southern Western Ghats were selected for the study (Figure-1). Granite syenite was the geological parent material in the study area. These systems were selected to represent a natural forest and a man-made system to compare and contrast the different pedogenic processes under similar geologic parent material and altitude. Therefore, an evergreen forest (75.8153 E, 11.8236 N) and a rubber plantation (76.320187E, 11.713915 N) were selected for the study.

The selected evergreen forest was located at 900m AMSL, having a mean annual rainfall of 3000mm and a mean annual temperature of 22°C. *Bischofia javanica*, *Mesua ferrea*, *Artocarpus heterophyllus*, *Euvodia lunuankenda*, *Calophyllum elatum*, *Hopeaponga*, and *Myristica dactyloides* were found to be the dominant species in the evergreen forests. The selected rubber plantation was located at 850m AMSL, having a mean annual rainfall of 2200mm and a mean annual temperature of 23°C. It had been under continuous monoculture rubber cultivation for the past 30 years. In the selected systems, the soil profiles were dug up to 1.5m keeping as many soil-forming factors as constant (Figure-2: A, B). The soil samples were collected from each horizon from the profiles.

Analytical methods: The soil samples collected from the different locations were air-dried and sieved in a 2mm sieve before physicochemical analysis. The core method (volumetric cylinder method) was used for soil bulk density determination. Soil pH H_2O-KCl suspension was determined with a pH meter[8]. Walkley Black method was used for organic carbon estimation[9]. Soil texture was determined using the hydrometer method (Bouyoucos method). Soils were extracted with one normal neutral ammonium acetate (1N NH_4OAc) solution, and from which calcium and magnesium were estimated by atomic absorption spectrophotometry (Varian AA240) and potassium and sodium by a flame photometer (ELICO CL 378). The cation exchange capacity (CEC) was determined by the neutral ammonium acetate saturation method and base saturation was estimated by calculation[10]. Mineralogical analysis was carried out after treating the soils with hydrogen peroxide, sodium citrate, sodium bicarbonate, and sodium dithionite for removing organic matter, and iron oxides. Thus, the soils were separated to coarse sand (2–0.6mm), fine sand (0.6-0.02mm), silt (0.02–0.002mm), and clay (< 0.002mm) fractions. The separated soil particles were used for mineralogical studies by X-ray diffraction (XRD) analysis at a scanning speed of 2° 2θ/min (Bruker AXS D8 Advance). Clay particles were undergone scanning electron microscopic (SEM) analysis after mounting on an aluminum stub having LEIT-C conductive carbon cement which is coated with gold (EOL Model JSM-6390LV) to understand their surface morphology.

Results and discussion

Physico-chemical properties: The soil pH was found to be acidic in both systems. In the evergreen forest, pH was varied from 4.9 to 5.8 and in plantation, it was 4.2 to 5 (Table-1 and 2). Soils in humid tropical regions were found to be acidic due to the leaching of bases[11]. pH - KCl was found less than pH - H_2O in both the systems indicating a significant amount of amorphous clay minerals in these systems[12]. Maximum organic carbon percentage (3.29) was found in evergreen forests. The vegetation influences soil properties by increasing organic matter and by releasing nutrients[13]. The dominating tree species and the site characteristics control the organic matter formation from the decomposition of litter, which regulates the physico-chemical properties of soil. The organic carbon percentage (0.63 to 1.57) in the plantations was lower than the evergreen systems. The low organic content in plantation might be because of the cultivation practices which may quicken the oxidation of organic matter and their successive loss of carbon dioxide to the atmosphere[14]. The lower base saturation in the evergreen forests than the plantation need not be due to a better base retention potential of the plantations. High acidic and low calcium content in the selected evergreen forest has lowered the base saturation[15]. The sand percentage was found decreasing from top to bottom layers in evergreen forest and clay percentage vice versa. The evergreen forest was found to have a high sand percentage compared to the plantation. Higher sand fractions indicate the system has retained significant amounts of weather able minerals in them which confirms a relatively lower weathering compared to the plantation. Extreme soil management practices which increase further weathering processes may be a reason for increased clay content in the rubber plantation[16].

Taxonomy classification: Morphological features of the soils were studied and determined taxonomy according to the protocols specified by USDA[17]. In the evergreen forest, the clay percentage was found to increase within 15cm, CEC was less than 16meq/100 and there was a gradual reduction in organic carbon with increasing depth enabling the classification of a kandic horizon. The clay percentage was increasing from BA to Bt1 horizon. The texture in the Bt1 horizon was sandy clay loam indicating the presence of clay illuviation, hence classified as an argillic horizon. These unique features tend to classify the selected evergreen forest system in the order of Ultisols. The common occurrence of Ultisols in peninsular India was already reported[18]. As they did not show a clay decrease with the increasing depth, at the sub-group level, the soils in evergreen forests are placed under a ustic soil moisture regime. In the mineralogy class, the soils belong to a mixed category as the mineral soil has different types of minerals. The temperature regime was isohyperthermic. Hence, as per the USDA nomenclature, the soil in the evergreen system can be classified as loamy, mixed, acid, isohyperthermic, Ustic Haplohumults.

In the rubber plantation, characteristic features of argillic horizon were observed in the Bt3 horizon. The base saturation in this layer was less than 35 percent and selected plantation was placed in the order of Ultisols. Clay mineral weathering, leaching of base cations, and accumulation of clays in the subsurface horizon were commonly found in Ultisols[19]. They are acidic, highly weathered, and mature, which indicates the soils in the plantations of this region have reached maturity[20]. The presence of a ustic soil moisture regime classifies these soils in sub-group Ustic Haplohumults. Hence, as per the USDA nomenclature, the soil in the plantation can be described as fine loamy, mixed, acid, isohyperthermic, Ustic Haplohumults.

Mineralogy of soil particles: Weathering of soil minerals releases nutrients, those are the major fluxes for estimating nutrient accurate budgets for soils. In the evergreen forest, mixed-layer minerals, quartz, kaolinite, and gibbsite were found in the clay fractions (Figure-3 and 4). The presence of mixed-layer minerals in the forest systems supports the previous results of less weathering in these systems. The presence of gibbsite is commonly taken as an indication of weathering of primary aluminosilicates. The gibbsites in the tropical systems were formed not be always by a desilication process of kaolinite, but can be a leftover of a previous weathering cycle[21]. The SEM images further support this hypothesis (Figure-5) by the rounded edges of the gibbsite crystals. The absence of significant amounts of kaolinite in silt and sand fractions also indicates restricted weathering of evergreen forests in the region.

In rubber plantation, kaolinite and gibbsite were found to be the major fractions in the clay and silt fractions. The absence of easily weatherable minerals like mixed-layer minerals and mica in the coarse fractions shows the high rate of weathering in this plantation compared to natural systems. In managed systems, weathering and atmospheric deposits influence the resilience of the ecosystem. So, sustainability purposes are economically and ecologically substantial to improve the soil nutrients and providing supplementary nutrients when required for production[22].

Conclusion

Two different ecosystems of Southern Western Ghats were studied for understanding the variations in physico – chemical characters, soil taxonomy, and mineralogy. The soils from both the forest systems were classified in to the order Ultisols. Even though the soils in humid tropical regions are considered extremely weathered soils, the natural system was found to develop soil profiles at a lower rate than a managed plantation. In evergreen forests, higher organic carbon contents and the presence of easily weatherable minerals in the clay fraction confirm the younger soils with less weathering. Evergreen forests have an appreciable amount of gibbsites, but the crystal features reveal that these may be derived from the geologic parent material rather than a product of recent intense weathering. The anthropogenic activities in managed plantations have led to higher weathering rates and faster degradation. Management practices by simulating soil conditions similar to the natural forests would be a solution to control degradation in the plantation.

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Table-1: Selected physico- chemical properties of soils collected from the evergreen forest in the Southern Western Ghats.

Depth (cm)	Horizon	Texture (%)			pH		OC (%)	Available nutrients (mg/kg)				CEC (meq/100)	Base Saturation (%)
		Sand	Silt	Clay	H_2O	KCl		Na	K	Ca	Mg		
0-5	A	78	4	16	5.8	4.5	3.29	18.5	45.1	285.5	81.8	14.2	16.2
5-20	BA	76	6	18	4.9	4.2	2.36	17.1	22.9	169	32.3	12.4	10.0
20-45	Bt1	72	4	24	5.5	4.5	1.15	16.5	19.8	131.5	8.7	11.4	7.5
45-150	Bt2C	68	6	26	5.1	4.3	1.34	15.6	25.8	503	17	10.6	26.3

Table-2: Selected physico- chemical properties of soils collected from rubber plantation in the Southern Western Ghats.

Depth (cm)	Horizon	Texture (%)			pH		OC (%)	Available nutrients (mg/kg)				CEC (meq/100)	Base Saturation (%)
		Sand	Silt	Clay	H_2O	KCl		Na	K	Ca	Mg		
0-4	A	74	4	22	4.6	4.2	1.57	18	34.7	313	74.9	8	29.4
4-22	BA	66	6	28	4.2	3.8	1.07	15.5	13.8	102	30.3	10.4	8.3
22-43	Bt1	64	6	30	4.8	4.3	1.17	19	20.8	354	57.7	18.2	13.1
43-67	Bt2	72	6	22	5	4.1	1.10	16.5	15.3	334	70	21	11.2
67-150	Bt3	62	6	32	4.7	4.3	0.63	15.3	12.6	157	62.7	17.2	8.1

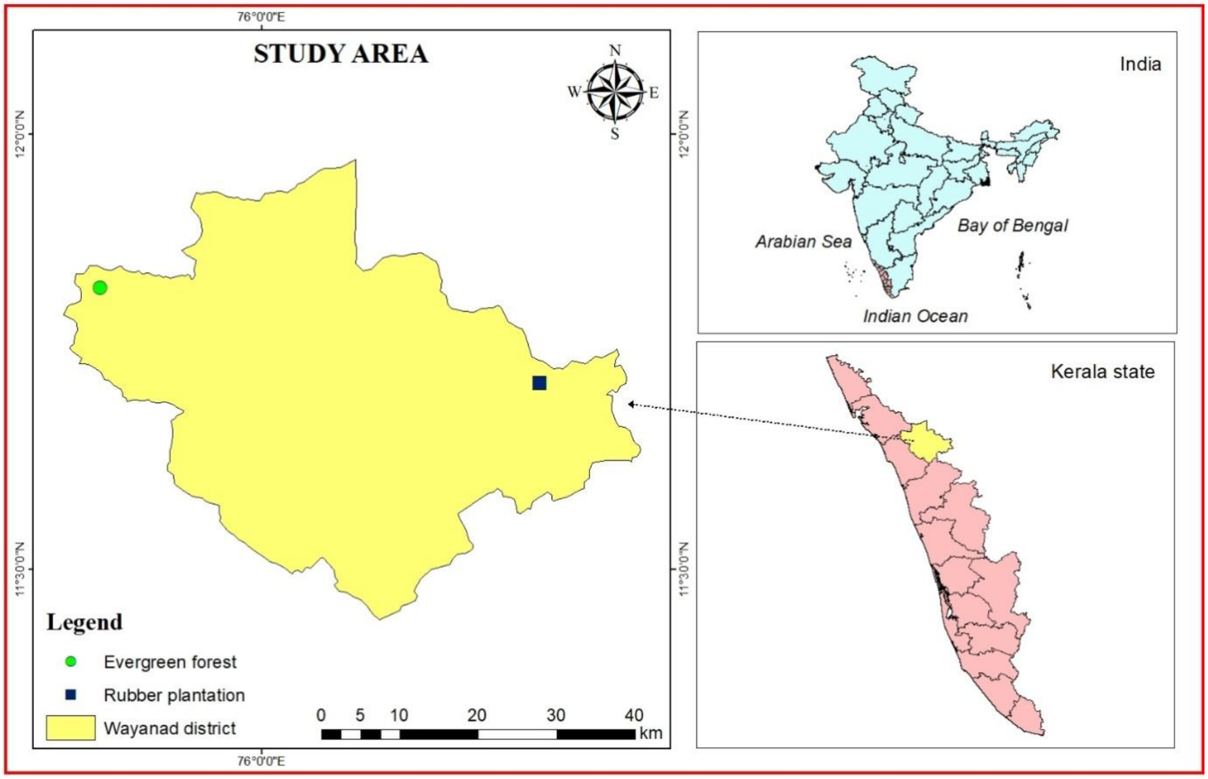

Figure-1: Sampling location.

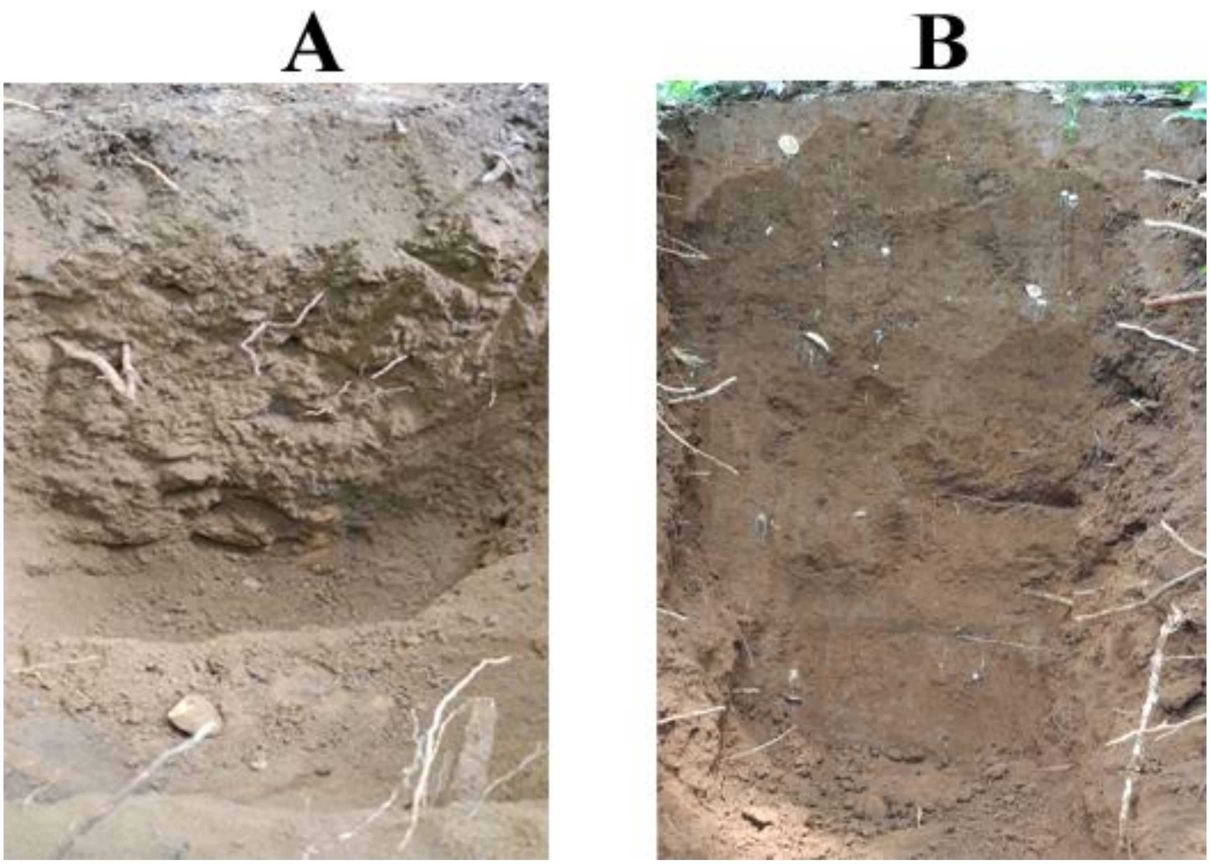

Figure-2: Soil profiles. A) Evergreen forest, B) Rubber plantation.

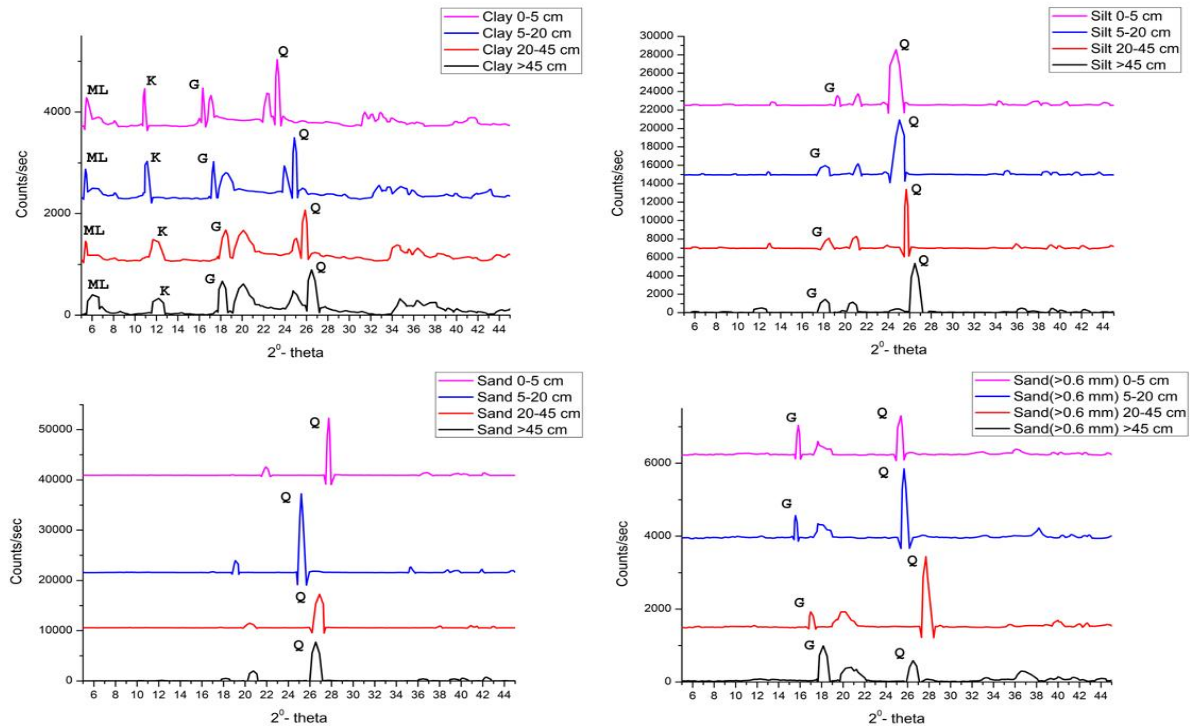

Figure-3: XRD results of soil particles collected from the evergreen forest. A) Clay, B) Silt, C) Sand less than 0.6mm, D) Sand above 0.6mm.

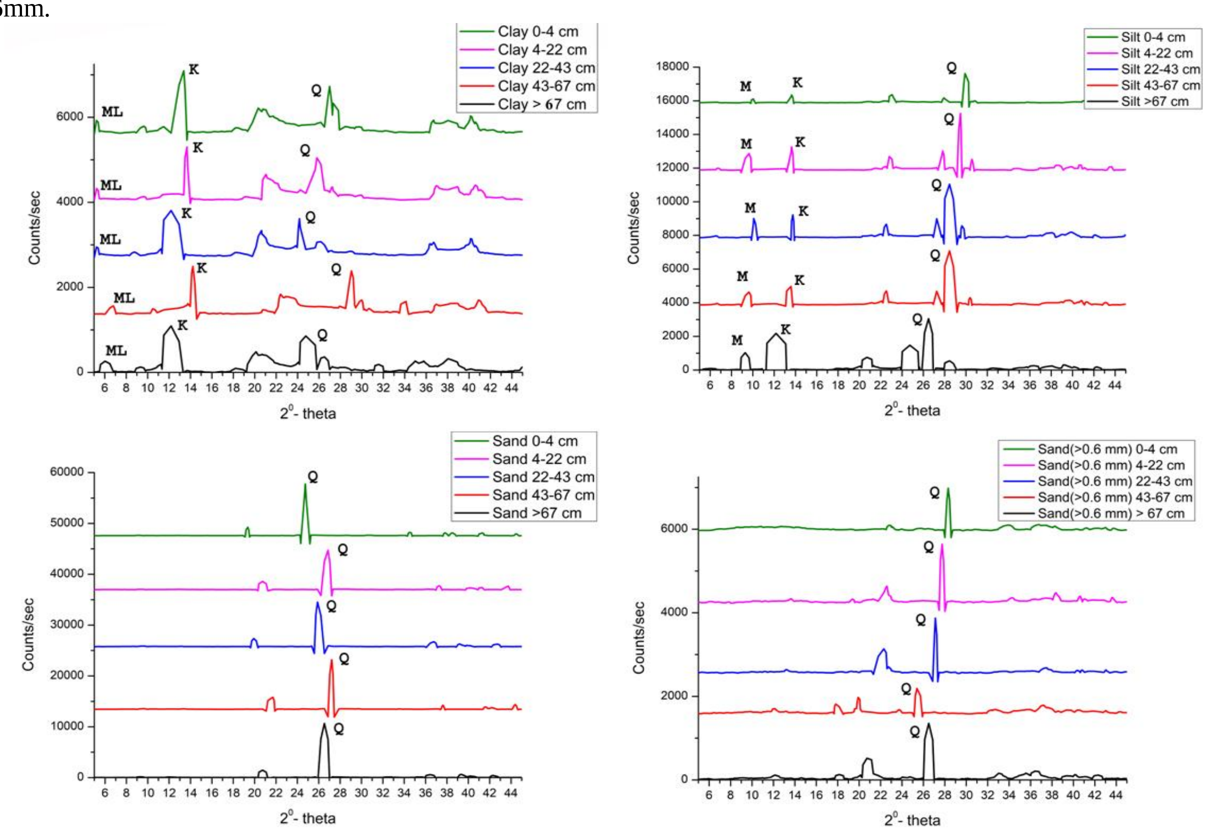

Figure-4: XRD results of soil particles collected from rubber plantation. A) Clay, B) Silt, C) Sand less than 0.6mm, D) Sand above 0.6mm.

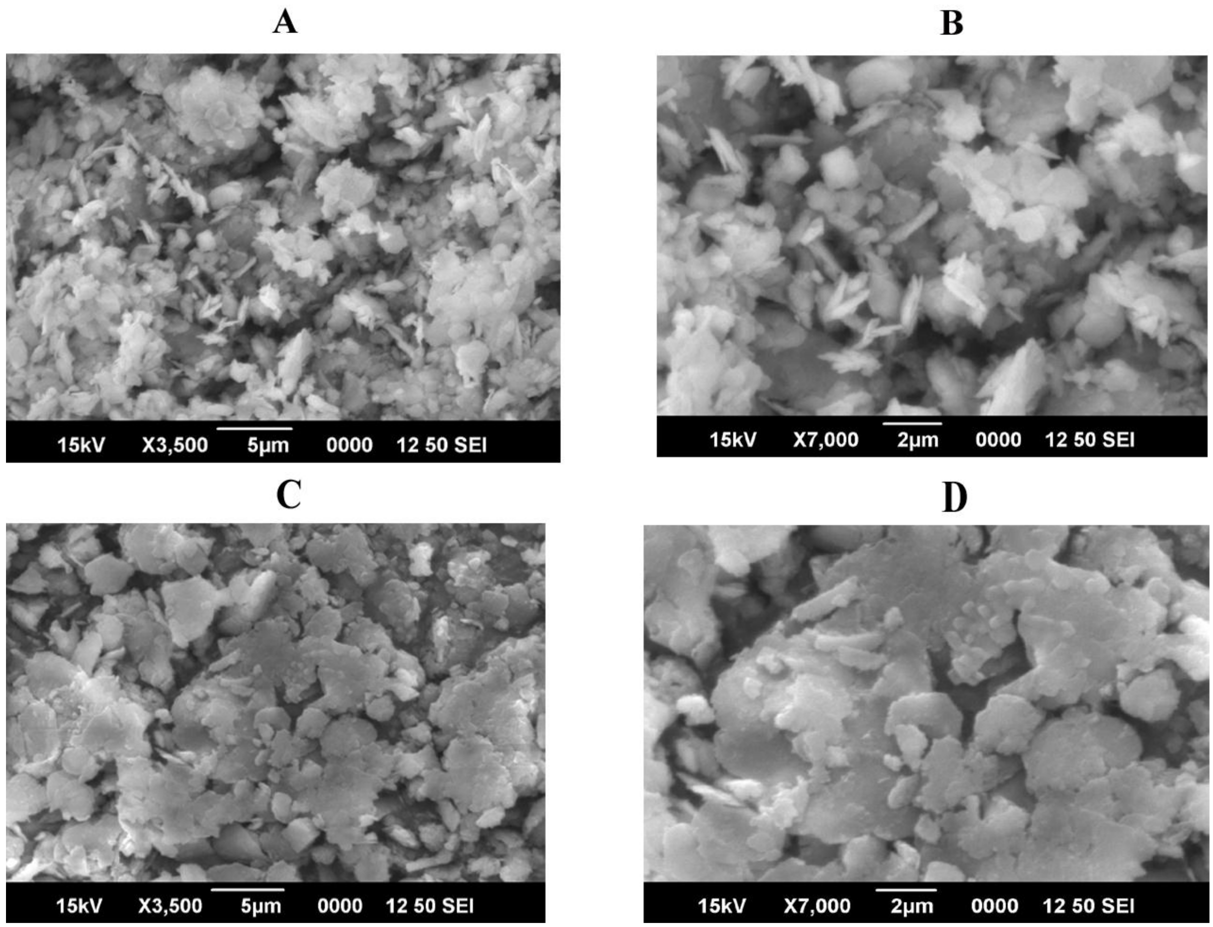

Figure-5: SEM image of clay particles. A & B Evergreen forest, C & D Rubber plantation.

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