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Geomorphological Characterization of Soils under a Toposequence Located in Eastern India

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ABSTRACT

Geomorphology, which mostly deals with the form of the earth, the general configuration of its surface and the changes that take place as in the evolution of landforms, plays a vital role in the study of soil formation. The present investigation has been designed to analyze the landform and soil relationship in a geologically complex landscape of Mid-Central Table Land Agroclimatic Zone of Odisha located in Eastern India. During soil survey, horizon-wise soil samples were collected from the representative soil profiles on each landform unit for studying the geomorphological features. The depth of soil varied from 91 to 160 cm and color from red to yellow. The texture ranged from sandy loam to sandy clay loam. From the petrographic studies, the parent rock of the study area was found to be *Khondalite*. The X-ray diffraction studies of soil samples from different land types revealed the mineralogical composition of the study area to be dominated by quartz and kaolinite. The stage of soil formation in upland was observed to be at an intermediate stage ; that in case of medium and low lands at an advanced stage. Upland soils were found with less moisture, more coarse fragments ; whereas low land soils were mostly characterized by high water table, impeded drainage condition along with occurrence of mottles and clay skins. Basic soil properties of different land types were analyzed to suggest suitable land management possibilities.

Keywords Landform, Parent rock, Soil formation, Soil survey, Geomorphological characterization.

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INTRODUCTION

Geomorphology is defined as the scientific study of the earth's surface features involving interpretive description of landforms, their origin, development, nature and mechanism of geomorphic processes which evolves the landforms (Goudie 2004). It is essentially an explanatory subject emphasizing the interpretation of the upper surface of the land areas in relation to the different causes which have shaped it (Gupta 2004). In a broader sense, there is an environmental conservation imperative shared among geomorphology, geology and soil studies (Prakasam 2012). Soil is the resultant product of 5 interacting soil forming factors namely parent material, biosphere, climate, topography and time (Milne 1935, Jenny 1941). Toposequence or catena is a term used to describe variations observed in a particular geographical area due to variations in topography (relief), remaining all other factors of soil formation same (Milne 1935). In the present study, the major focus had been on parent material and time (age of the soils) with a broad objective to identify the major soil related constraints in different land typesso that suitable remedial measures for optimum land resource management could be suggested. Three representative soil profiles were exposed in three different topographic positions namely upland, medium land and low land in the selected study area of Eastern India to study the geomorphological features with respect to topography.

MATERIALS AND METHODS

Experimental site

Geographically, the study area lies in 20º37´21´´ N latitude and 85º35´55´´E longitude with a mean elevation of 308 feet above mean sea level (MSL). The study area is situated in the feet of Charakhola hills which comes under Dhenkanal forest range. Based on slope and elevation, the study area has been divided into three major physiographic units such as gently sloping upland (332 feet above MSL, slope of 3–5%), very gently sloping medium land (308 feet above MSL, slope of 1–3%) and nearly levelled low land (295 feet above MSL, slope of 0–1%). The study area is characterized by hot, dry and sub-humid climate with dry summer and mild winter. Mean annual rainfall is 1432.3 mm out of which 75.5% is received during monsoon (June to September). The mean maximum and mean minimum temperatures of the region are 33.1ºC and 21.7ºC, respectively as recorded at the local observatory.

Soil sampling and analysis

The landforms of the study area were determined through traverzing the area and elevations above MSL of different points were recorded using GPS instrument (Garmin make ; model : 76 MAPCSx). After a general traverzing of the study area, three representative soil profiles located in three different topographic positions such as upland (20º37´36.26´´N, 85º36´04.60´´E), medium land (20º37´25.30´´N, 85º36´52.83´´E) and low land (20º37´11.91´´N, 85º36´55.22´´E) were selected and exposed. The soil profiles in upland, medium land and low lands were demarcated as pedon 1, 2 and 3 respectively. The detailed morphological characteristics of these soil profiles were studied in the field as per the guidelines (All India Soil and Land Use Survey Organization 1970, Soil Survey Staff 2014). The soil samples collected from different horizons were air dried and ground with wooden hammer. Ambient soils were passed through 2 mm sieve, preserved and then subjected to various laboratory analyses. Soils were analyzed for soil color by using Munsell's soil color chart and textural class by Bouyoucos Hydrometer method (Bouyoucos 1962).

Sand fraction was separated by using different size sieves. The sieves used for fine sand fraction were 0.25 and 0.1 mm. Sample preparation for X-ray diffraction (XRD) was undertaken by procedure outlined by Jackson (1956). Powder X-ray diffraction studies were carried out in Panalytical XRD machine with Co target at the rate of 2 degrees per minute. Small piece of parent rock collected from the upland of the study rock collected from the upland of the study area was subjected to cutting followed by preparation of a polished mount. The polished mount was analyzed with Leica Optical Petrological Microscope (model DM4P) under reflected light. For detailed mineralogical study of the parent rock, the polished mount was analyzed with Field Emission Scanning Electron Microscope (FESEM) (SUPRA 55-CARL ZEISS, Gemini column) attached with Energy Dispersive X-ray (EDX) analysis.

RESULTS AND DISCUSSION

Identification of parent rock

Partly weathered parent rock was subjected to cutting

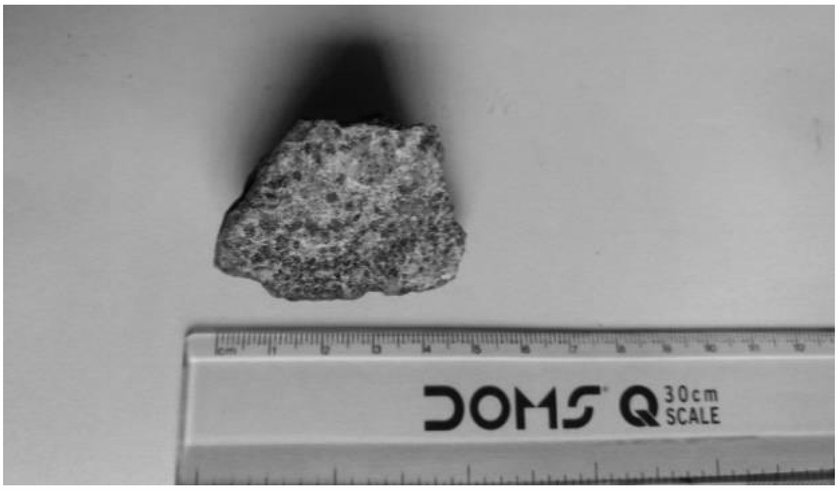

Fig. 1. Representative parent rock Khondalite of the study area.

and polished mounting for studying it under optical petrographic microscope (Fig. 1). The petrographic microscope images taken under reflected light represented the presence of altered feldspar, altered garnet (with peripheral regenesis of iron oxides) and unaltered quartz crystals within the altered garnet (Fig. 2). For more detailed study of parent rock mineralogy, the above polished mount was further subjected to study under Field Emission Scanning Electron Microscope (FESEM). The back scattered images of a portion of the mounted sample represented the distribution of O, Al, Si, Ti and Fe in partially altered garnet (Fig. 3). Again , the secondary electron images obtained by FESEM along with their respective Energy Dispersive X-rays (EDX) confirmed the presence of minerals like quartz (SiO_2), altered feldspar, altered garnet, alluminosilicates, ilmenite ($FeTiO_3$), zircon ($ZrSiO_2$) and gibbsite (Al_2O_3) (Figs. 4, 5). In general, Khonadalites contain quartz, feldspar, garnet with small quantities of zircon and silimanite (alluminisilicate) (Bhattacharya et al. 2012). Presence of these minerals in the parent rock of the study area confirmed the above to be Khondalitic in origin. This type of parent rock has also been reported by Moharana (1995) while studying the soils of Regional Research Station, G. Udaygiri of Kandhamal District of Odisha.

Fine sand mineralogy

The soil samples from the control sections of pedon 1 (25 to 91 cm), pedon 2 (15 to 65 cm) and pedon 3 (21

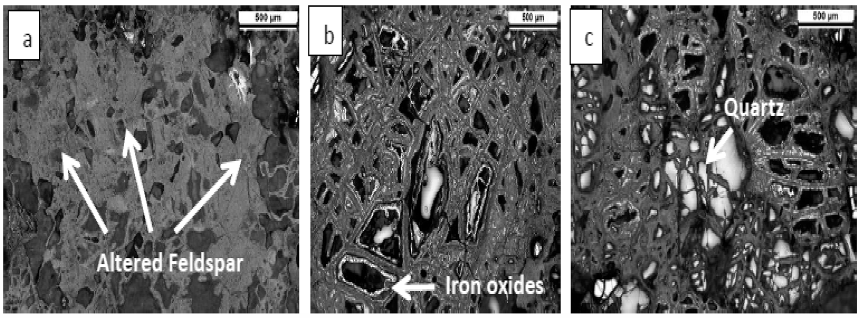

Fig. 2. Optical petrological microscope images of parent rock (a) Showing intense alteration of feldspar, (b) Showing the altered garnet with peripheral regenesis of iron oxide and (c) Showing the unaltered quartz crystals within altered garnet.

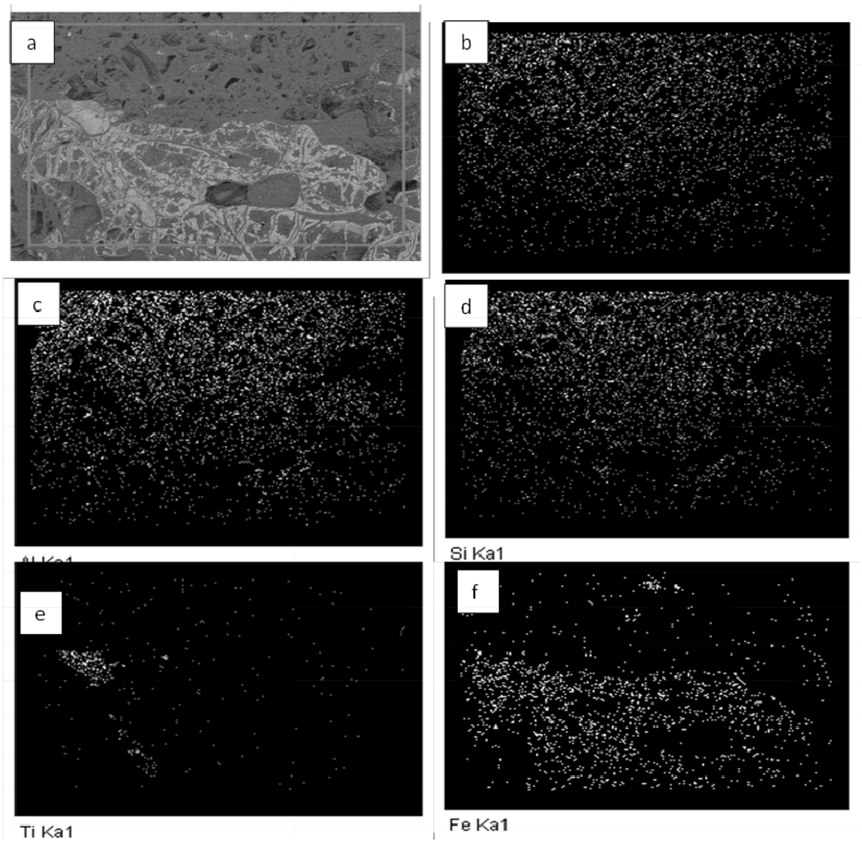

Fig. 3. Back scattered images of parent rock by FESEM (a) Having partially altered feldspar (upper half) and partially altered garnet (lower half). Images b, c, d, e and f are X-ray image maps showing distribution of O, Al, Si, Ti and Fe respectively.

to 71) cm were separated to study the mineralogical characteristics of the soils. Mineralogy of fine sand fractions (0.1 to 0.25 mm) of 4 samples comprising of parent rock (ground and sieved), soil samples from control sections of pedon 1, 2 and 3 were subjected to X-ray diffraction. The peak values at respective 2θ angles were compared with the J C PDS data book, which revealed the dominance of quartz and kaolinite (fine sand fraction also includes clay fraction) in all the samples (Figs. 6—9). The dominance of quartz in the tropical climatic regions of Odisha has also been reported by Mishra (2008), Nayak (1998).

Stage of soil formation

Both in case of parent rock sample and upland soil sample, the peaks are with broad base and are not prominent, which reflect that these are not completely weathered to soil. In other words, the upland soils are ill formed and in a state of transition (alteration) towards mature soil formation (Figs. 6, 7). This can be well correlated to the profile characteristics of pedon 1 (upland) which lacked development of B horizon. The reason behind slower rate of soil formation in upland can be attributed to the excessively drained condition, which lacked the necessary soil moisture required for undertaking chemical and biological processes of weathering (Mishra 1981, Mohamad et al. 2015). But, in case of both medium and low land soil samples, the peaks are prominent with sharp edges, indicating the weathering to be at advanced stages (Figs. 8, 9). This can be well correlated to the profile characteristics of pedon 2 and 3 (medium and low land), both of which possessed mature B horizons.

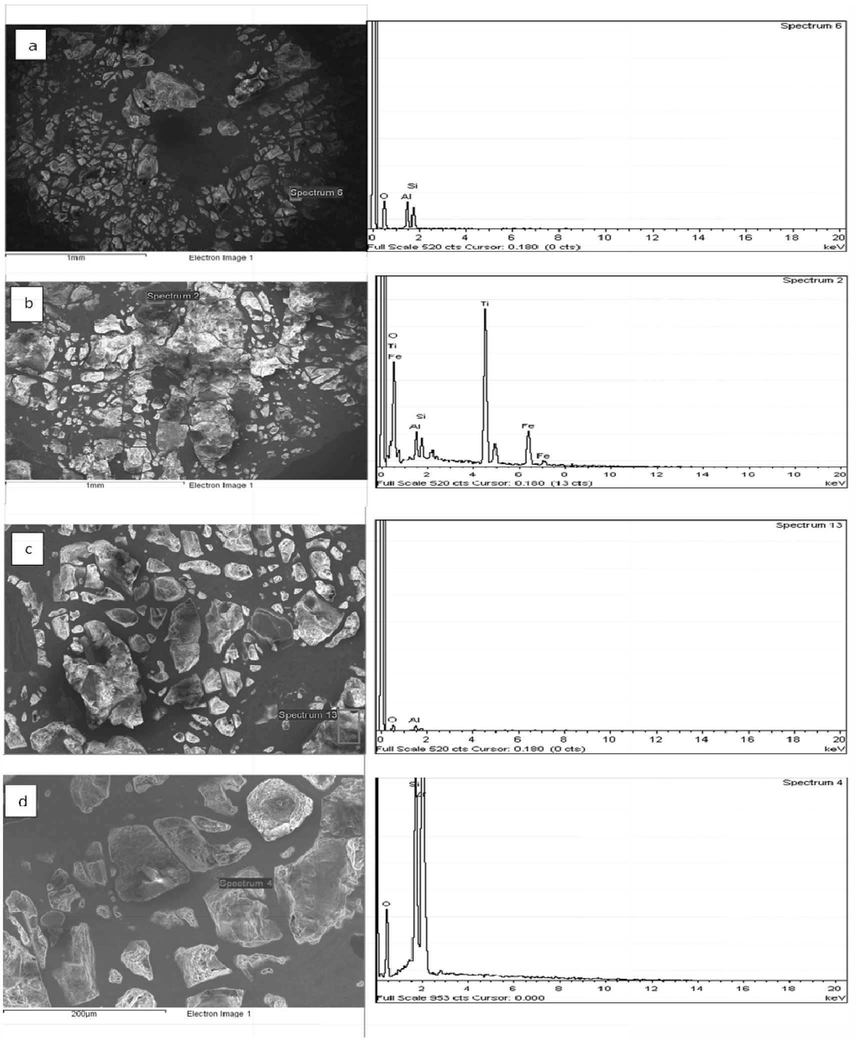

Fig. 4. Shows secondary electron images along with their EDX (Energy dispersive X-ray) analysis of parent rock by FESEM. Images a, b, c and d are images of altered feldspar (alluminosilicate), ilmenite ($FeTiO_3$), gibbsite (Al_2O_3) and zircon ($ZrSiO_2$) respectively.

The availability of optimum moisture, which is the most essential requirement to facilitate the on going weathering processes are the major driving forces for advanced stages of soil formations in medium and low lands (Mohamad et al. 2008, Sehgal 1996).

Soil genesis

Upland soil profile was found to be rich in coarse fragments and unconsolidated parent materials (pedon 1, Fig. 10a). Upland soils being at the feet of hills, receive the colluvial materials from hill slope along with the runoff water during heavy rainfall. Due to accumulation of different colluvial materials in different times, there the soil horizon development is not favored at a faster rate. So, the major geogenic and pedogenic processes operating in upland were found to be erosion and colluviation (Mishra 2005, Sarkar et al. 2014).

Medium and low land soils were observed with optimum soil moisture status (even in the summer season), which resulted in development of distinctive and clearly visible horizontal layers. Here, the

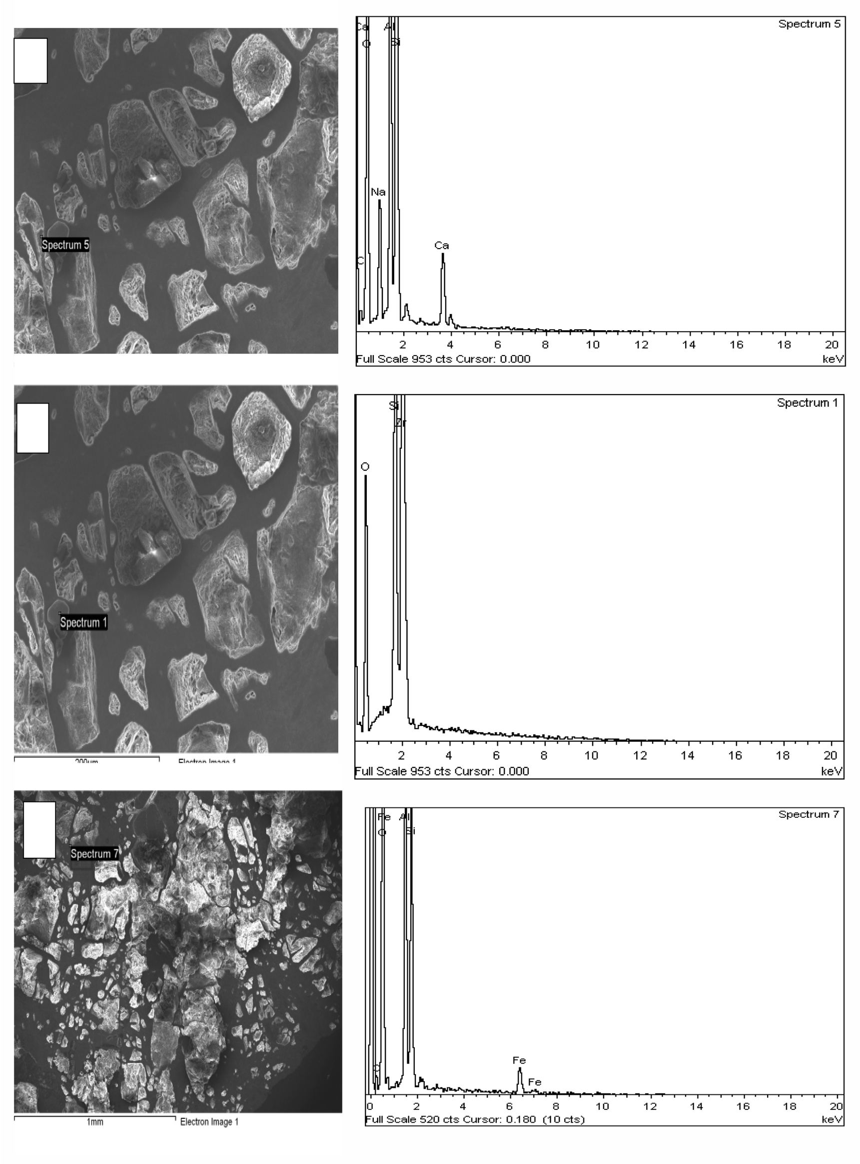

Fig. 5. Shows secondary electron images along with their respective EDX (Energy Dispersive X-ray) analysis of parent rock by FESEM. Images a, b and c are images of altered feldspar, quartz (SiO_2), iron garnet (almandine, $Fe_3Al_2 Si_3O_{12}$) respectively.

fundamental soil forming processes operating were found to be eluviation and illuviation (translocation of materials from upper to lower horizon) resulting in formation of Bt horizons (Sehgal 1996, Sarkar 2003). Also, the geogenic process of cumulization (translocation of materials from higher topographic positions and their subsequent deposition in the lower topographic positions) was found to be in operation in medium and low lands (Verish 2014). Some parts of the low land region are characterized by impeded drainage condition augmented with high water table and hence remain uncultivated throughout year.

Soil morphology

Morphological characteristics of the soils have been

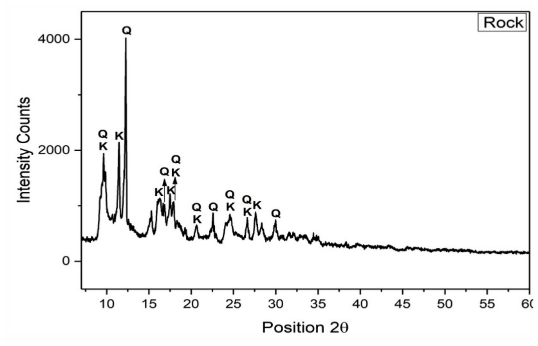

Fig. 6. X-ray diffractograms of fine sand fractions (0.1 to 0.25 mm) of parent rock (Q-Quartz, K-Kaolinite).

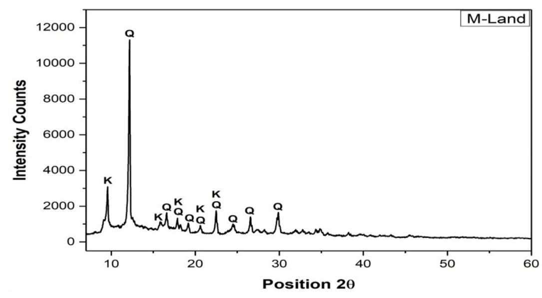

Fig. 8. X-ray diffractograms of fine sand fractions (0.1 to 0.25 mm) of medium land (Q-Quartz, K-Kaolinite).

presented in Table 1. As discussed earlier, pedon 1 was found with A–C horizons ; whereas both pedon 2 and 3 were observed with A-Bt-C horizons (Gandhi and Savalia 2014, Hakla et al. 2017, Rahman et al. 2017, Sharma and Jassal 2013). Presence of well-developed B horizons in medium and low lands can be chiefly attributed to the optimum moisture conditions prevailing in that area (Khandey et al. 2018). It has been found that the color of surface soils gradually become yellower from upland to low land which might be attributed to the effect of greater moisture regime and impeded drainage down the slope (Mishra 1981, Singh and Rathore 2015). Clay content was observed to be increasing down the slope both in surface and subsoil which could be attributed to leaching and runoff of clay particles from upper topographic positions towards lower topographic positions mostly during intensive rainfall (Giri et al. 2017, Nagendran and Angayarkanni 2010, Mishra 2005). It has been also noticed that contents of coarse fragments were abundant in upland and gradually decreased down the slope which can be attributed to unfavorable physiography, particularly the lack of moisture under excessively drained condition prevailed in upland (Mishra 1987). The soil structure mostly changed from sub-angular blocky to angular blocky down the slope which might be attributed to increase in clay percentage down the slope. It was also observed that the plasticity and stickiness of soil increased down the slope which could be well correlated with change in soil texture (Parida 2000). Lack of mottling and concretion in the upland is due to excessively drained condition, because of skeletal nature of the soil that never gets saturated to bring about alternate reducing and oxidizing condition required for the same (Mishra 2005).

CONCLUSION

The parent material of the study area was found to be Khondalite, which is rich in potash bearing feldspars.

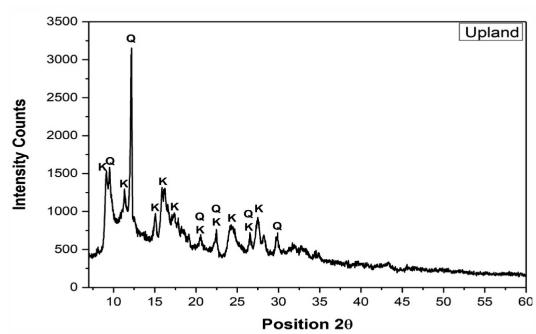

Fig. 7. X-ray diffractograms of fine sand fractions (0.1 to 0.25 mm) of upland (Q-Quartz, K-Kaolinite).

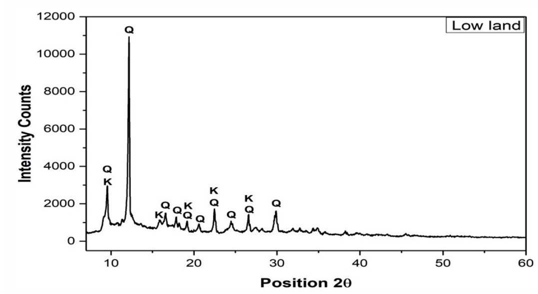

Fig. 9. X-ray diffractograms of fine sand fractions (0.1 to 0.25 mm) of low land (Q-Quartz, K-Kaolinite).

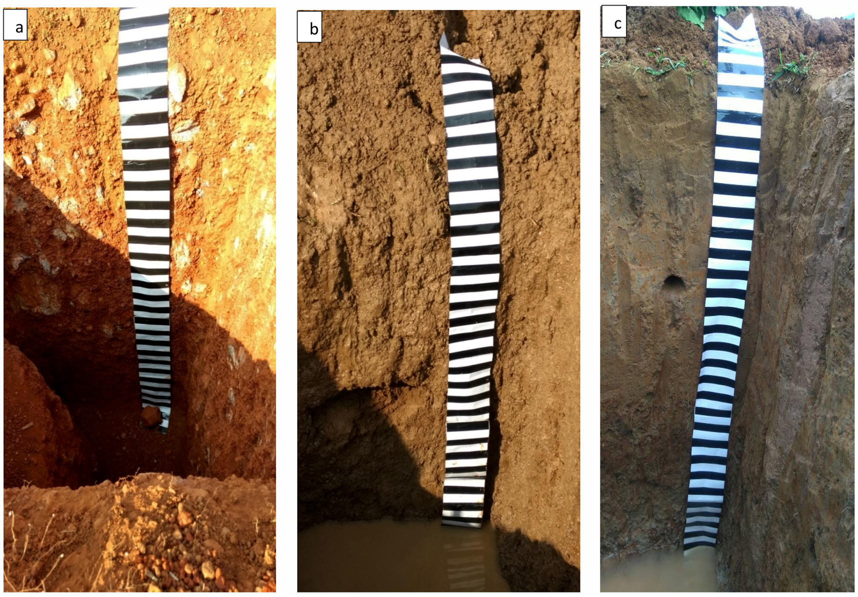

Fig. 10. a, b and c representing soil profiles of the study area in upland, medium land and low land respectively.

Soil erosion and excessively drained conditions are the major constraints of upland ; whereas, high water table and impeded drainage conditions were found to be the major constraints in low lands. So, uplands should be used for growing plantation crops, tree crops, orchards, agroforestry, agri-horti-silviculture ; that of medium land can be used for growing oilseeds, pulses, legumes and field crops ; that of low lands can be used for low land paddy cultivation and pisciculture. Land use planning for upland can be diverted for roads, buildings and construction purpose, if needed ; that of low lands should be avoided for constructions. Similarly, the major soil conservation measures those can be adopted for uplands are planting soil erosion resisting crops like *Vetiver* and sisal (*Agave sisalana*) on contours, existing earthen bunds and to do silvi-horticultural plantations ; that of medium land is to adopt contour cultivation ; that of the low land

Table 1. Morphological characteristics of the soil.

Horizon	Depth (cm)	Description
Pedon-1 (Upland) : Latitude–20°37´36.26´´N, Longitude–85°36´04.60´´E, Elevation above Mean Sea Level-331 feet		
Ap	0—18	Red (2.5 YR 5/8) ; gravelly sandy loam ; weak, fine, sub-angular blocky ; dry slightly hard, moist friable, wet non-sticky and non-plastic ; many, very fine to fine, discontinuous, random, imped, simple tubular pores ; frequent angular pebbles and cobbles ; many, very fine to fine roots ; gradual wavy boundary.
C1	18—67	Red (2.5 YR 5/6) ; very gravelly sandy loam ; weak, fine, sub-angular blocky ; dry slightly hard, moist friable, wet slightly-sticky and non-plastic ; many, very fine to fine, discontinuous, imped, irregular pores ; very frequent angular pebbles and cobbles ; common, very fine to fine roots ; gradual wavy boundary.
C2	67—91	Dark red (2.5YR 5/6) ; very gravelly sandy loam ; weak, fine, sub-angular blocky ; dry hard, moist friable, wet slightly sticky and non-plastic ; many, very fine to fine, discontinuous, imped, irregular pores ; very frequent angular pebbles and cobbles ; gradual wavy boundary.
C3	91—130	Red (2.5YR5/8) ; partly weathered compact mass of Khondalite rock.

Table 1. Continued..

Horizon	Depth (cm)	Description
Pedon-2 (Medium land) : Latitude-–20º37´25.30´´N, Longitude–85º36´52.83´´E, Elevation above Mean Sea Level-308 feet		
Ap	0—15	Yellow (10YR 8/8) ; sandy loam ; strong, moderate, angular blocky ; dry slightly hard, moist friable, wet slightly sticky ; non-plastic ; many, very fine to fine, discontinuous, random imped pores ; many, very fine to fine roots ; few, fine, hard, ferruginous concretions ; clear smooth boundary.
Bt1	15—27	Yellow (10YR 8/6) ; sandy loam ; moderate, medium, sub-angular blocky ; dry slightly hard, moist friable, wet slightly sticky ; slightly plastic ; patchy thin clay skins on vertical and horizontal ped faces and in pores ; many, very fine to fine, discontinuous, random, imped, simple tubular pores ; medium, soft, ferruginous concretions ; simple, very fine roots ; gradual wavy boundary.
Bt21	27—45	Yellow (10YR 7/6) ; sandy clay loam ; moderate, medium, sub-angular blocky ; dry hard, moist friable, wet sticky and plastic ; patchy thin clay skins on vertical and horizontal ped faces and in pores ; many, fine to medium, discontinuous, random, imped, simple tubular pores ; plentiful, medium to coarse, ferruginous concretions ; common, very fine to fine roots ; gradual wavy boundary.
Bt22	45—57	Yellow (10YR 7/8) ; sandy clay loam ; moderate, medium, sub-angular blocky ; dry hard, moist friable, wet sticky and plastic ; common, medium distinct, strong brown (7.5YR 5/8) mottles ; patchy thin clay skins on vertical and horizontal ped faces and in pores, very fine to fine, discontinuous, random, imped, simple tubular pores ; coarse, ferruginous concretions ; gradual wavy boundary.
Bt23	57—81	Light grey (10YR 7/2) ; sandy clay loam ; moderate coarse, sub-angular blocky ; dry hard, moist friable, wet sticky and plastic ; common, medium distinct, dark brown (7.5YR 5/6) mottles ; patchy thin clay skins on vertical and horizontal ped faces and in pores ; common, very fine to fine, discontinuous, random, imped, simple tubular pores ; plentiful, medium to coarse, ferruginous concretions ; gradual wavy boundary.
BC	81—103	Very pale brown (10YR 7/3) ; sandy loam ; moderate, medium, sub-angular blocky ; dry hard, moist friable, wet sticky and plastic ; dark brown (7.5YR 5/6) mottles ; few, very fine to fine, discontinuous, irregular pores ; few, fine to medium, ferruginous concretions ; gradual wavy boundary.
C	103—150	Light grey (10YR 7/2) ; sandy loam ; strong, massive ; dry hard, moist friable, wet non-sticky and non-plastic ; common, many, coarse, prominent, dark brown (7.5YR 5/8) mottles ; few, very fine to fine, discontinuous, irregular pores ; strongly weathered parent material chiefly consisting of feldspar and quartz.
Pedon-3 (Low Land) : Latitude–20º37´11.91´´N, Longitude–85º36´55.22´´E, Elevation above Mean Sea Level-295 feet		
Ap	0—9	Grayish brown (2.5 YR 5/2) ; sandy loam ; moderate, medium, sub-angular blocky ; dry slightly hard, moist friable, wet slightly sticky and slightly plastic ; many, fine, faint, reddish yellow (7.5 YR 6/8) mottles ; common, medium, discontinuous, random, imped, simple tubular pores ; few, fine, ferruginous concretions ; common, many, very fine roots ; clear wavy boundary.
A2	9—21	Grayish brown (2.5YR 5/2) ; sandy loam ; moderate, coarse, sub-angular blocky ; dry slightly hard, moist friable, wet very sticky and very plastic ; few, fine, faint, reddish yellow (7.5YR 6/8) mottles ; common, medium, discontinuous, random, imped, simple tubular pores ; few medium, hard, ferruginous concretions ; common, few, very fine to fine roots ; clear wavy boundary.
Bt1	21—54	Grayish brown (2.5 YR 5/2) ; sandy clay loam ; moderate, coarse, sub-angular blocky ; dry slightly hard, moist firm, wet very sticky and plastic ; many, fine, faint, brownish yellow (10 YR 6/8) mottles ; patchy thin clay skins on vertical and horizontal ped faces and in pores ; common, medium, discontinuous, random, imped, simple tubular pores ; plentiful, medium, hard ferruginous concretions ; common, few, very fine to fine roots ; clear wavy boundary.
Bt2	54—93	Light yellowish brown (2.5 YR 6 / 4) ; sandy clay loam ; strong, coarse, sub-angular blocky ; dry very hard, moist firm, wet very sticky and very plastic ; many, medium, prominent, strong brown (7.5 YR 5/8) mottles ; broken moderately thick clay skins on vertical and horizontal ped faces and in pores ; few, very fine, discontinuous, random, imped, simple tubular pores ; plentiful, medium to coarse, ferruginous concretions ; few, very fine roots ; clear wavy boundary.

Table 1. Continued.

Horizon	Depth (cm)	Description
Pedon-3 (Low Land) : Latitude–20º37´11.91´´N, Longitude–85º36´55.22´´E, Elevation above Mean Sea Level-295 feet		
Bt3	93—129	Light yellowish brown (2.5 YR 6/4) ; sandy clay loam ; moderate, coarse, sub-angular blocky ; dry very hard, moist firm, wet very sticky and very plastic ; many, medium, prominent, strong brown (7.5YR 4/6) mottles ; patchy thin clay skins on vertical and horizontal ped faces and in pores ; few, very fine, discontinuous, random, imped, simple tubular pores ; plentiful, medium to coarse, ferruginous concretions ; gradual wavy boundary.
C	129—160	Light yellowish brown (2.5 YR 6/4) ; sandy clay loam ; massive ; dry hard, moist friable, wet slightly sticky and non-plastic ; many, fine, faint, strong brown (7.5YR 4/6) mottles ; many, very fine to fine, discontinuous, common, fine, discontinuous, irregular pores ; plentiful, fine to medium, ferruginous concretions, strong weathered parent material of quartz and feldspar.

area is to prepare water harvesting tanks in between medium and low land to collect that runoff water during rainy season, which is to be utilized for the crops at the time of need.

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