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RESEARCH ARTICLE

Pedogenesis and clay mineralogy of semi arid tropical soil in Madurai district, Tamil Nadu

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Abstract

Four representative soil profiles from Melur block of Madurai district in Tamil Nadu were assessed for the degree of chemical weathering, pedogenesis and clay mineralogy. Morphological, geochemical and mineralogical analysis were done following standard procedures. Soils are classified as follows: Pedon 1-Keeranoor was Fine loamy, non-acid, mixed, megathermic, Typic Haplustepts, Pedon 2 - Arritapatti was Fine loamy, non-acid, mixed megathermic, Oxyaquic Haplustepts Pedon 3 - Uranganpatti was Fine, mixed, non-acid, megathermic, fluventic Haplustepts and Pedon 4 - Panangadi was Fine loamy, non-acid, mixed megathermic, Oxyaquic Haplustepts. The soils generally exhibited a sandy texture with moderate weathering nature, comprising more than 50% of fine and medium sand fractions, little textural variation suggesting more uniform weathering. Soils are slightly alkaline, except for Pedon 2, having had a higher Exchangeable Sodium Percentage (ESP) (> 15%) and Cation Exchange Capacity (CEC) (15 cmol (p^+) kg^{-1}). Mineralogical investigation revealed dominance of kaolinite and illite mixed with smectites in pedons and increased silica activity with limited lessivage. The mean Chemical Index of Alteration values ranged from 80.75 to 93.44, indicating moderate soil weathering. The ternary A-CN-K diagram displayed preferential leaching of CaO and Na_2O followed by K_2O, as plagioclase was more susceptible to weathering. Bivariate plot results of SiO_2 against (Al_2O_3+K_2O + Na_2O) indicated rapid weathering influenced by the climatic conditions.

Keywords

CIA; clay minerals; morphology; pedons; weathering index

Introduction

Soil is the complex and dynamic system forming an interface between the atmosphere, hydrosphere and lithosphere (1). Topography, climate and lithology of the environmental deposition mainly govern the soil characteristics of plains (2, 3). Tamil Nadu having semi-arid tropical climate with numerous soil types seen in all kinds of climates, occupies about 4.0 per cent (12.99 m. ha) of the total country's geographical area (4). Under a semi-arid tropical climate, laterization, clay eluviation-illuviation and calcification are the dominant soil forming processes, translocation and accumulation of major and micro elements in the soils (6, 7) which favours for sustainable productivity.

Particle size data and lithological discontinuities of soils were used for assessing the pedogenic evaluations of soils in the Aravalli ranges of India (6). The difference in successive values of sand to silt ratio and soil physico chemical properties (soil reaction, electrical conductivity, CEC, ESP, Molar ratio) were used to assess the pedogenic evaluations in plains of Tamil Nadu (8, 9). Likewise, the soil salinity ratio is used to determine the pedogenic changes and geological uniformity (10) and the soil elemental compositions, such as silica to sesquioxide, as the weathering index (WI) (11). Clay fractions in Western Rajasthan soils had higher values for silica and sesquioxide ratios were documented (12). Soil pedogenesis and chemical weathering of soil were successfully evaluated by using soil geochemical properties (Elemental composition of soil).

The Chemical Index of Alteration (CIA) and Chemical Index of Weathering (CIW), as well as the elemental composition ratios such as K/Ca and K/Na are quantitative methods used in assessing the degree of chemical weathering with respect to their mobility in soil pedons during weathering (13). CIA is employed as an ideal index in India for assessment of soil pedogenesis (14). The ternary A-CN-K and A-CNKFM diagrams to define the degree of weathering of soils in the Mahi catchment, Gujarat, were constructed and documented smectites dominance in semi-arid regions with water stress (3). Various geochemical proxies are used for evaluating the weak to moderate weathering of loess paleosol sediments in Karewa basin of the Kashmir valley (15).

Madurai, one of the historical cities in Tamil Nadu, India, is features diverse soil types supporting various cropping systems, with the Vaigai River providing water supply (16). Therefore, the present study investigates the pedogenic development of soils in relation to morphological, physicochemical, elemental and mineralogical composition in Melur block, Madurai district of Tamil Nadu.

Materials and Methods

Study area and soil sampling

The Melur block lies between 10° 03′ 36″ N latitude and 78° 33′ 58″ E longitude in the Madurai district of southeast Tamil Nadu (Fig. 1). The geology of the area mainly includes two prime rock types *viz.,* Charnockites and Khondalites, of Archaean age (17, 18). The study area is characterized by an undulating plain, with slopes ranging from 1 to 3 percent in lower physiographic positions and 3 to 8 percent in higher physiographic positions. The climate is semi-arid (dry half) with an annual rainfall of 740 mm (19). The moisture regime of the study area is Typic Haplustert and the soil temperature regime is *iso-hyperthermic* (20). Rice, sorghum, maize, cotton, legumes, vegetables and coconut are cultivated extensively.

Four representative soil pedons were selected based on variations in colour, texture and landforms in Melur block. These were identified as follows: P_1 - Keeranoor was *Fine loamy Typic Haplustepts,* P_2 - Arritapatti was *Fine loamy oxyaquic Haplustepts*, P_3 - Uranganpatti was *Fine fluventic Haplustepts* and P_4 - Panangadi was *Fine loamy oxyaquic Haplustepts.* The morphology of four profiles was described and classified (20).

Soil analytical methods

Soil samples from the selected areas were collected horizon wise, air dried and processed using a 2 mm sieve. Standard analytical procedures were followed for physical and chemical analysis.

The international pipette method (21) was adopted for determining the soil particle size distribution and available water content was measured using a pressure plate apparatus. Soil pH and electrical conductivity EC of soils were determined in 1:2.5 soil water suspension. Organic carbon (OC) content was determined by the wet digestion method (11). Cation Exchange Capacity (CEC) was estimated by displacing excess ammonia with alcohol, followed by the distillation method (11, 22).

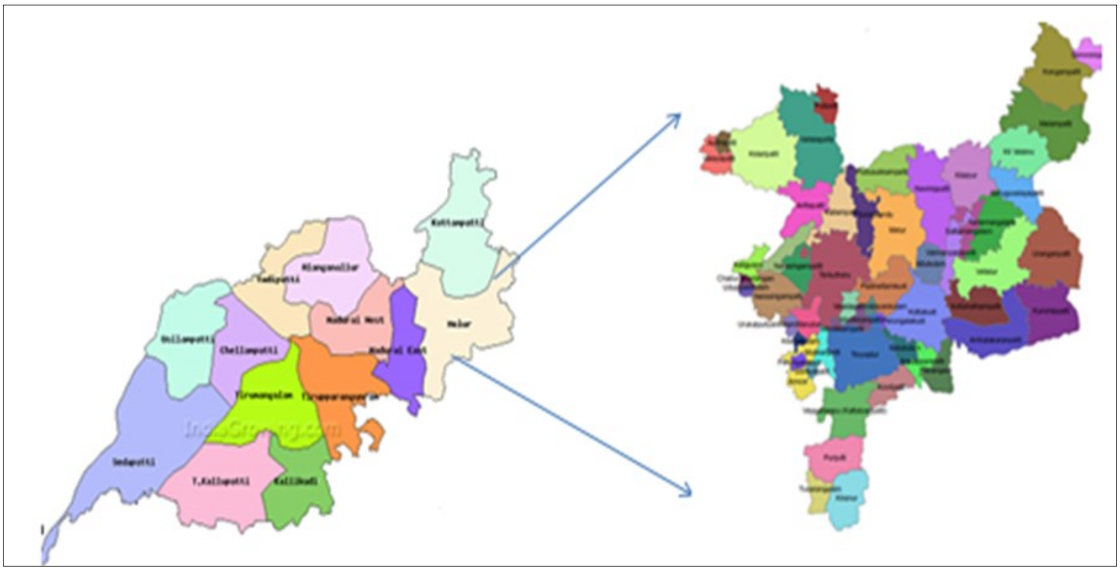

Fig. 1. Location Map of study area.

Elemental analysis

A 20 g sample was taken for elemental analysis by triacid digestion a platinum crucible (11). The silica was determined gravimetrically after sodium carbonate fusion. The other elemental oxides were determined using a flame photometer by sodium and potassium (K_2O and Na_2O) and calcium and magnesium (CaO and MgO) were determined by the Versanate method. The molar ratios of pedons are derived and weathering indices were calculated by using the Parker Weathering Index (Used as soil textural fraction data) (23), Riche's Product Index and Chemical Index of Alteration (Used as a soil elemental composition) based on the index values to elaborate the weathering stage of soil (13). The triplot diagrams were constructed as required for the conformation of weathering indices of soil were using online triplot digram software with help of elemental composition.

X-Ray Diffraction (XRD) Analysis

Clay mineralogical analysis of clay fractions was performed using XRD with random powder mounts of the clay specimens. The clay specimens were analyzed after Citrate-Dithionite-Bicarbonate treatment (CDB) (24), saturation with K and mounting on a slide and read at 25 °C, as well as after heating for two hours, at temperatures of 350 and 550°C; saturation with Mg and a reading at 25 °C before ethylene glycol solvation. The clay specimens were hooked up on oriented slides. The oriented slides were analyzed using a Rigaku Miniflex device equipped with a graphite-monochromated Cu Ká radiation source (30 kV, 15 mA) (25, 21).

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR technique was used to obtain the infrared spectrum of absorption, emission, photoconductivity, or Raman scattering of a solid, liquid or gas. Clay powder was compressed into a thin pellet and analysed with and FTIR spectrometer. The spectral data were collected by a Bio-Rad Excalibur 3000 MX FT-IR spectrometer and a helium-purged MTEC 300 photoacoustic cell. All spectral wavelengths were recorded over the 4000 - 400 cm^{-1} region with a spectral resolution of 8 cm^{-1}. Clay sample and IR transparent material like KBr (potassium bromide) were mixed in a ratio of 2:1 in a mortar and pestle for 30 minutes and then the mixture was converted into pellets by pressing with a hydraulic or hand press into a hard disk. The pellets 0.5 to 1 mm thick were scanned after placing over the transmission holder and then scanned. Typically, the pellet method provides good spectral quality with a wide range of spectra and no interfering absorbance bands (25).

Results and Discussion

Morphological characteristics

The results of the morphological features analysed are presented in Table 1 and Fig. 2. The soils were deep to very deep, with a horizon sequence of ploughed horizon (Ap), illuvial horizon with distinctive colour and txture (Bw), illuvial horizon with strong gleying (Bwg), illuvial horizon with concreations and nodules (Bc) and unconsolidated rock (Cr). The colour and texture of the soil matrix (moist) varied from dark reddish brown (2.5YR 3/4) with sandy clay loam texture in pedon 1(P_1) and pedon 2(P_2), pedon 3(P_3) and Pedon (P_4) were very dark gray (10YR3/1) to strong brown (7.5YR5/6) with clay loam to sandy clay loam texture. These variations were attributed to differences in parent material like granite-gneiss, topography and translocation of clay (26). The dominant structure of the soils varied from blocky (sub angular to angular) structure to platy structure owing to the presence of higher quantities of clay (27). Similarly, higher clay content in pedons also led to variation in consistency of soils from moderate sticky and moderately plastic to highly sticky and highly plastic (28).

Table 1. Morphological characteristics of representative pedons

Horizon	Depth of pedon	Colour (moist)	Texture	Structure	Consistence				Boundary	Roots	pH
					D	M	stickiness	plasticity			
Pedon 1:Keeranoor, 9°82.179 N, 78°17.137 E, Altitude – 121 m											
Ap1	0-14	2.5YR3/4	Scl	2msbk	sh	fi	ms	mp	cs	Mfir	7.7
Ap2	15-35	2.5YR2.5/4	Scl	2fsbk	h	fi	ms	mp	gs	Ffir	7.5
Bw	35 -48	2.5YR2.5/4	Sc	3msbk	vh	vfi	vs	vp	gs	-	7.9
Cr	48+	Non calcareous Gneiss with Feldspar									
Pedon 2 :Arittapatti,10°03.549 N, 78°17.108 E, Altitude – 143 m											
Ap	0-28	10YR3/1	Cl	2mpl	h	fi	vs	vp	cw	Mfir	8.7
BWg1	28-60	10YR5/4	Sc	2mpr	vh	vfi	vs	vp	cw	-	8.2
BWg2	60-90	10YR5/6	Sc	3mpr	vh	vfi	vs	vp	cw	-	8.5
BC	90-120	10YR5/8	Sil	1fm	s	l	ss	sp	cw	-	8.6
Cr	120+	Gneiss mixed with alluvium									
Pedon 3 :Uranganpatti, 09°99.413 N, 78°40.478 E, Altitude – 125 m											
Ap1	0-16	10YR2/1	Sic	2mabk	h	fi	vs	vp	cs	Fmir	8.5
Ap2	16-30	7.5YR5/6	Cl	2cpl	h	vfi	vs	vp	cs	Fmir	8.3
2BW1	30-59	7.5YR4/6	Cl	2cpl	h	fi	vs	vp	cs	-	8.1
2BW2	59-97	7.5YR5/6	Sic	3cabk	vh	vfi	vs	vp	cs	-	8.2
Cr	97+	Weathered granite gneiss mixed with gravels									
Pedon 4:Panangadi, 09°94.781 N, 78°36.930 E, Altitude – 155 m											
Ap	0-18	10YR4/1	Scl	1msbk	s	fi	ms	mp	cs	Ffir	7.9
BWg1	18-35	10YR4/3	Sc	3cabk	vh	vfi	vs	vp	cs	Ffir	7.2
BWg2	35-58	10YR4/2	Scl	2mcr	s	vfr	ms	mp	cs	-	7.8
BWg3	58-80	10YR5/4	Sil	1fcr	s	fr	ms	mp	gw	-	7.1
Cr	80+	Weathered gneiss with quartz gravel									

* Notations used as per soil survey staff (2017)

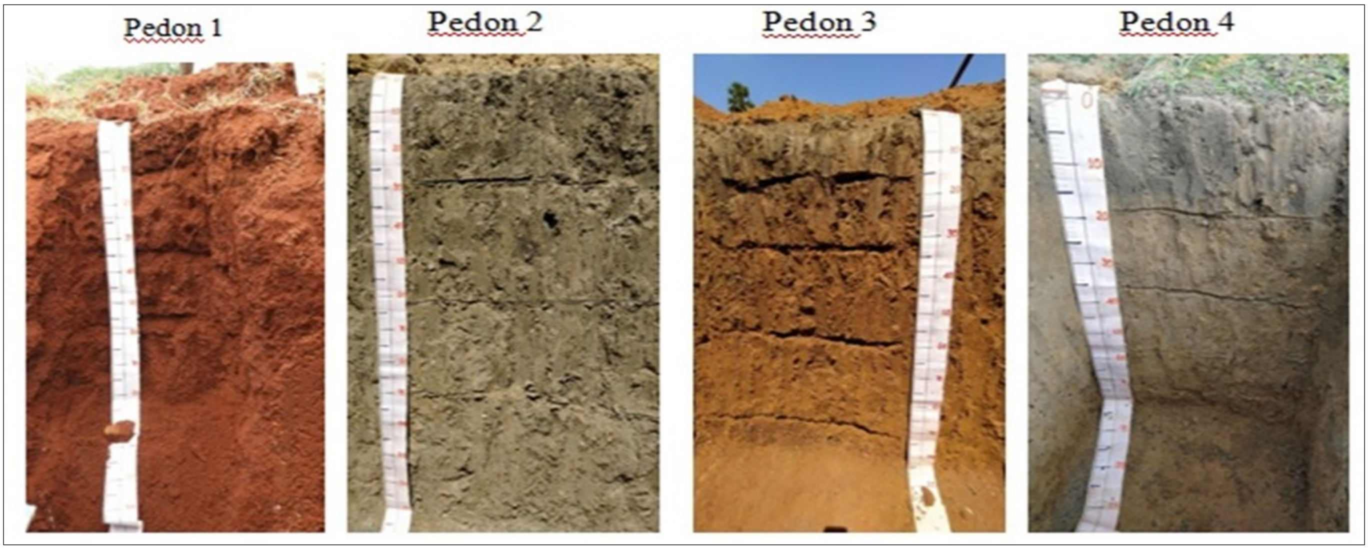

Fig. 2. Morphology of the study area.

Physical properties

Data on the soil physical properties depicted in Table 2. Sand content varied from 15.44 to 59.58 per cent in surface horizons and 13.90 to 62.15 per cent in sub surface horizons. Silt content exhibited an irregular trend with regard to soil depth due to the *in-situ* formation or distinction in the intensity of weathering of parent rock (29). Pedons clay content varied from 14.27 to 43.02 per cent, with significant increases qualify as argillic horizon, demonstrating patterns of clay illuviation and lithological discontinuity (30). Bulk density varied from 1.19 to 1.45 Mg m^{-3}, with higher values attributed to coarse textured and lower organic content of soils (31).

Chemical properties of soil

The soils across the pedons were non-saline (Table 3). These soils have low organic carbon (OC < 5 g/kg) expect Arittapatti (P_2) with medium range. CEC was medium to high with dominance of Ca on the exchangeable complex (>15 cmol (p+) kg^{-1}) in P_2 and P_3 horizons. Exchangeable Mg of soils was medium (2.11 to 10.11 cmol (p+) kg^{-1}), low exchangeable Na and low to medium exchangeable K levels. The increase in CEC with depth was due to illuviation of clay and sesquioxide content. Similarly increased ESP with depth could be due to illuviation of clay into lower depth and pedogenesis was in progress. The research findings of above might be due to the clay content of soils being qualified as argillic horizon and pattern of clay illuviation, this findings were supported by (32, 33, 34),

Elemental composition

The soils were rich in SiO_2 (~60 per cent) with some variations. (Table 4), agreed with the previous documentation (35). The average mean SiO_2 content was 61.5 per cent in P_1, 64.40 per cent in P_2, 57.72 per cent in P_3 and 65.65 per cent in P_4. The content of Silica oxide (SiO_2) in horizon B was low in P_2 and P_4 but increased in other horizons. The average means Aluminium oxide (Al_2O_3) was 10.37per cent (for P_2) to 20.5per cent for P_1. Soils had more than 5 per cent of (Iron oxide (Fe_2O_3) with downward increases in the B horizons (Table 4). The Calcium oxide (CaO), Magnesium oxide (MgO), Potassium oxide (K_2O) and Sodium oxide (Na_2O) contents were less than 1 per cent.

Table 2. Mechanical analysis and water movement related properties of soil

Horizon	Depth of pedon	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	BD (MgM^{-3})	AWC (%)	WHC (%)
Pedon 1:Keeranoor, 9°82.179 N, 78°17.137 E, Altitude – 121m								
Ap1	0-13	31.24	28.34	12.91	26.31	1.45	5.96	15.12
Ap2	13-35	39.24	22.94	7.73	28.14	1.42	4.93	4.31
Bw	35 -58	31.02	17.35	9.39	41.03	1.29	4.65	3.68
Cr	58+	Non calcareous Gneiss with Feldspar						
Pedon 2 :Arittapatti,10°03.549 N, 78°17.108 E, Altitude – 143 m								
Ap	0-28	27.65	15.35	21.0	34.61	1.32	9.25	15.23
BWg1	28-60	29.58	16.76	18.42	33.15	1.28	8.84	5.63
BWg2	60-90	31.0	15.69	21.17	28.91	1.22	7.89	2.40
BC	90-120	21.06	12.84	50.32	14.27	1.39	6.67	7.50
Cr	120+	Gneiss mixed with alluvium						
Pedon 3 :Uranganpatti, 09°99.413 N, 78°40.478 E, Altitude – 125 m								
Ap1	0-16	7.34	8.1	40.23	43.02	1.29	11.33	11.02
Ap2	16-30	12.36	13.94	41.93	30.01	1.32	10.28	7.84
2BW1	30-59	4.35	11.85	40.16	31.7	1.37	7.32	9.65
2BW2	59-97	7.21	6.98	41.74	42.1	1.19	7.47	2.45
Cr	97+	Weathered granite gneiss mixed with gravels						
Pedon 4:Panangadi, 09°94.781 N, 78°36.930 E, Altitude – 155 m								
Ap	0-18	34.21	22.36	16.15	25.4	1.43	12.16	15.36
BWg1	18-35	31.45	13.87	14.15	38.4	1.25	9.34	4.56
BWg2	35-58	34.12	20.98	16.65	26.4	1.32	5.88	1.12
BWg3	58-80	21.56	12.45	49.51	14.87	1.25	6.24	2.41
Cr	80+	Weathered gneiss with quartz gravel						

Table 3. Chemical properties of soils

Horizon	Depth of pedon	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	CEC	Exchangeable cations ($cmol(p+)kg^{-1}$)				ESP (%)
					Ca	Mg	Na	K	
Pedon 1:Keeranoor, 9°82.179 N, 78°17.137 E, Altitude – 121m									
Ap1	0-13	0.23	3.42	20.50	9.52	5.12	0.13	3.02	0.73
Ap2	13-35	0.35	4.11	21.70	11.27	4.95	1.70	1.56	8.73
Bw	35 -58	0.15	3.41	32.19	17.01	7.21	1.20	4.51	4.01
Cr	58+	Non calcareous Gneiss with Feldspar							
Pedon 2 :Arittapatti,10°03.549 N, 78°17.108 E, Altitude – 143m									
Ap	0-28	0.36	5.62	22.12	13.96	3.12	0.10	3.02	0.50
BWg1	28-60	0.16	5.64	31.0	15.21	6.14	1.02	6.02	3.59
BWg2	60-90	0.15	5.1	33.12	13.96	3.98	6.21	6.99	19.94
BC	90-120	0.17	4.98	13.12	5.23	3.2	0.69	1.98	6.22
Cr	120+	Gneiss mixed with alluvium							
Pedon 3 :Uranganpatti, 09°99.413 N, 78°40.478 E, Altitude – 125 m									
Ap1	0-16	0.18	2.61	28.12	12.12	7.96	2.12	0.02	9.54
Ap2	16-30	0.15	2.85	20.12	11.25	3.12	0.14	2.86	0.81
2BW1	30-59	0.12	2.93	20.14	11.80	3.02	1.12	2.98	5.92
2BW2	59-97	0.14	3.21	31.20	12.35	8.50	2.47	5.91	8.45
Cr	97+	Weathered granite gneiss mixed with gravels							
Pedon 4:Panangadi, 09°94.781 N, 78°36.930 E, Altitude – 155 m									
Ap	0-18	0.43	2.51	14.21	6.20	2.11	0.12	3.87	0.98
BWg1	18-35	0.29	4.36	31.00	10.65	10.11	1.12	6.88	3.89
BWg2	35-58	0.27	2.34	19.12	7.96	4.11	1.01	4.99	5.59
BWg3	58-80	0.13	3.14	10.90	2.96	3.02	0.31	2.9	3.37
Cr	80+	Weathered gneiss with quartz gravel							

Table 4. Elemental composition, molar ratios and weathering indices of soils

Horizon	Depth (cm)	Elemental composition(%)							Molar ratios					Weathering index		
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Base / R_2O_3	Base / Al_2O_3	WIP	RPI	CIA
Pedon 1:Keeranoor, 9°82.179 N, 78°17.137 E, Altitude – 121m																
Ap1	0-13	67.3	23.0	9.77	0.72	0.31	0.27	0.12	3.91	4.97	18.31	0.088	0.112	4.39	67.26	95.40
Ap2	13-35	69.1	18.0	6.93	0.91	0.23	0.31	0.17	5.23	6.52	26.53	0.127	0.158	5.05	73.51	92.83
Bw	35 -58	49.1	20.7	27.12	0.99	0.17	0.57	0.19	2.19	4.02	4.81	0.083	0.152	6.29	50.64	92.23
Cr	58+	Non calcareous Gneiss with Feldspar														
Pedon 2 :Arittapatti,10°03.549 N, 78°17.108 E, Altitude – 143m																
Ap	0-28	69.2	8.61	19.12	1.09	0.32	0.12	1.27	4.95	9.19	10.73	0.068	0.126	10.02	71.41	77.64
BWg1	28-60	58.1	11.65	27.23	0.92	0.27	0.27	1.07	11.59	51.31	14.96	0.218	0.966	9.17	59.92	83.75
BWg2	60-90	60.2	12.65	24.12	0.87	0.23	0.3	1.15	12.92	36.92	19.87	0.240	0.685	9.43	62.09	84.50
BC	90-120	70.1	8.6	18.23	0.95	0.13	0.37	1.23	13.91	38.36	21.83	0.323	0.890	10.02	72.34	77.13
Cr	120+	Gneiss mixed with alluvium														
Pedon 3 :Uranganpatti, 09°99.413 N, 78°40.478 E, Altitude – 125 m																
Ap1	0-16	50.2	9.65	37.12	1.09	0.23	0.05	1.27	5.65	13.65	9.63	0.241	0.582	9.48	51.78	80.02
Ap2	16-30	69.2	8.61	19.12	0.92	0.25	0.03	1.32	3.40	8.47	5.67	0.152	0.378	9.25	71.41	79.14
2BW1	30-59	62.5	13.25	21.23	0.97	0.17	0.02	1.07	3.64	8.08	6.64	0.156	0.346	7.96	64.45	86.54
2BW2	59-97	49.0	24.08	23.92	1.0	0.32	0.23	1.0	5.88	13.85	10.23	0.221	0.521	9.02	50.52	91.52
Cr	97+	Weathered granite gneiss mixed with gravels														
Pedon 4:Panangadi, 09°94.781 N, 78°36.930 E, Altitude – 155 m																
Ap	0-18	69.2	19.15	8.12	1.5	0.5	0.2	0.92	4.83	6.13	22.66	0.235	0.299	10.29	71.74	87.97
BWg1	18-35	58.2	16.8	22.05	1.2	0.72	0.21	0.5	3.20	5.87	7.01	0.164	0.301	8.24	59.95	89.79
BWg2	35-58	70.1	11.78	15.05	1.9	0.75	0.32	0.95	5.57	10.11	12.39	0.339	0.616	12.65	72.34	78.80
BWg3	58-80	65.1	15.65	16.23	0.9	0.9	0.35	0.6	4.25	7.06	10.66	0.203	0.337	9.03	67.13	89.43
Cr	80+	Weathered gneiss with quartz gravel														

Molar ratios and weathering indices

The mean silica: sesquioxide (SiO_2/R_2O_3) ratio of soils ranged from 3.77 to 10.84, the SiO_2/Al_2O_3 ratio ranged from 5.17 to 33.94 and the SiO_2/ Fe_2O_3 ratio from 8.04 to 16.55 in the pedons. The SiO_2/ R_2O_3 ratio increased gradually with depth due to the relatively high clay content, favouring easy weathering of primary minerals and resulting in less silica content of the soil (6). A significant increase of iron and aluminium oxide ratio in relation to depth is because of the presence of ferromagnesian parent material (7).

The Weathering Index of soils (WIP) in P_2 showed a gradual increase from 9.17 to 10.02, with notable variations in the Richier Product Index and a high in Chemical Index of Alteration (Table 4). The mean CIA values ranged from 80.75 to 93.44 and indicated moderate weathering of soil (36) and were mostly influenced by texture and clay illuvation (37). The ternary A-CN-K diagram (Fig. 3) showed preferential leaching of CaO and Na_2O, with K_2O being less plagioclase was more susceptible to weathering than potassium feldspar (13).

The polynomial relations were worked out between CIA, WIP and RPI and the regression equation was developed as given as

WIP = - 0.117(CIA)^2 + 18.73 (CIA) (R^2 = 0.684*)

CIA = - 0.061 (PIA)^2 + 14.34(PIA) - 955.3 (R^2 = 0.778**)

RPI = - 0.127 (WIP)^2 - 15.677(WIP) + 162.3 (R^2 = 0.323*)

Significant positive relations existed between CIA and RPI showed that these soils had a high RPI (ratio of SiO_2 to $SiO_2+R_2O_3$) because of their high silica content. CIA values greater than 60 indicated that soils were highly weathered nature had the presence of kaolinite and illite clay minerals. Generally, high levels of SiO_2 in the soil series as compared to Al_2O_3 and Fe_2O_3 were probably due to the amorphous silica of kaolinite (3).

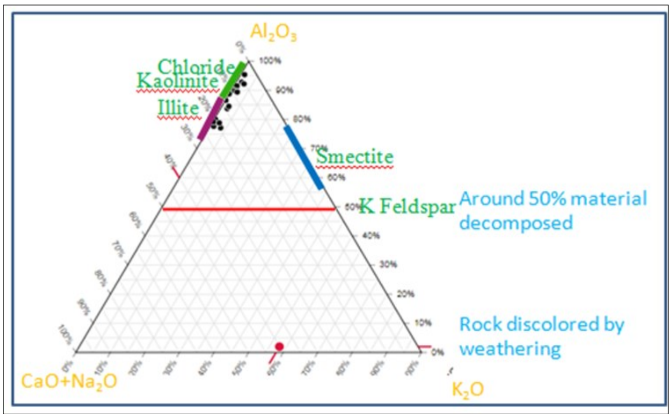

Fig. 3. A-CN-K diagram with Chemical Index of alteration of soils.

Mineralogical compositions of clay Fractions by XRD and FTIR

The clay mineralogy of the pedons are presented in Table 5, Table 6, Fig. 4 and Fig. 5. The P_1 showed that peaks observed at 27.11per cent showed the illite as the dominant clay mineral by XRD, the similar trend of results was confirmed by the FTIR spectrum with the intensity of 1030, 948 and 762 that indicated Si - O asymmetrical bending vibration. SiO_2/R_2O_3 ratios were more than 3 percent and the CIA value of P_1 was 93.48, which confirmed highly weathered nature and illite was dominating in P_1. The 24.0 per cent of the peaks for P_2 clearly depicted the presence of smectite and montmorillonite was the dominant clay mineral by the XRD peak. The same trend of results was confirmed by FTIR spectrum intensity with 1384, 1693, 873, 1633 and 1652 that indicated the O-H stretching of absorbed water molecules. These above-mentioned values and bonding indicated soils having mostly sandy texture with mixed type of

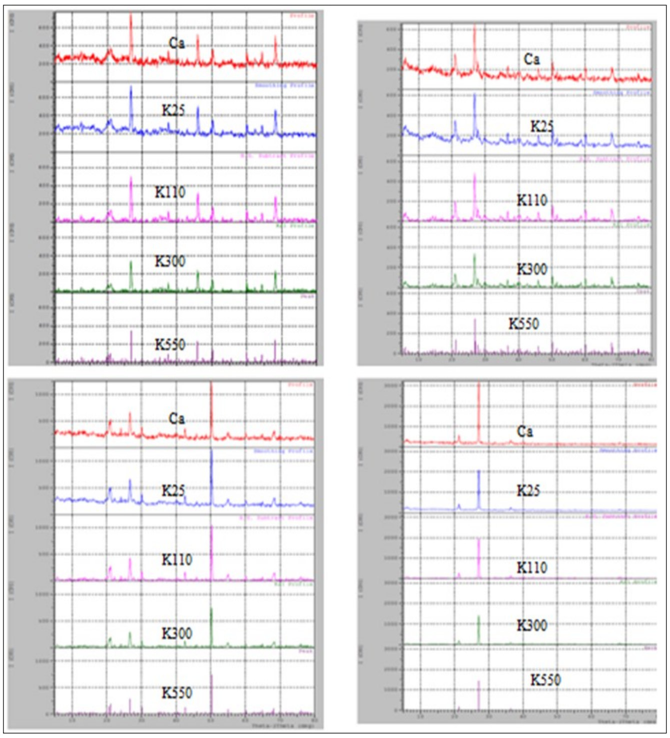

Fig. 4. XRD spectral image of clay minerals.

Table 5. Semi-quantitative estimation of clay minerals by XRD

Pedon	Minerals (%)										
	Chlorite	Vermiculite	Smectite	Mica	Illite	Kaolinite	Biotite	Albite	Ortho clase	Musco vite	Quartz
1	11.11	-	11.11	-	27.77	11.76	5.50	-	16.62	5.50	5.50
2	4.0	-	24.0	-	12.0	16.0	8.0	4.0	12.0	8.0	4.0
3	6.0	-	12.0	-	6.0	40.0	13.0	6.0	-	6.0	6.0
4.	6.0	-	-	-	13.0	40.0	13.0	6.0	-	6.0	6.0

Table 6. FTIR frequencies (cm^{-1}) observed in clay fraction

Pedon	Minerals (%)										
	Chlorite	Vermiculite	Smectite	Mica	Illite	Kaolinite	Biotite	Albite	Orthoclase	Muscovite	Quartz
1	455,432,553	-	1634,1834	-	1030,948,762	1034,914	469,	-	539	422,539	752, 795,692,
2	463,763	-	1384,1693,87 3,1633,1652	-	1032,905, 463	914, 1032,3433,	-	420, 777,	534,463, 1032	422, 539	777,
3	466,427,437	-	1652,3534, 1634,1383	-	1033,905, 779,466	912,3433, 1033,3622,3433,	-	427	447,539, 437	645	415, 779, 1652,
4.	987,825,763	-	-	-	431,990,1031	539,912,3655,3434	-	424,779,	-	535,650	795,780,

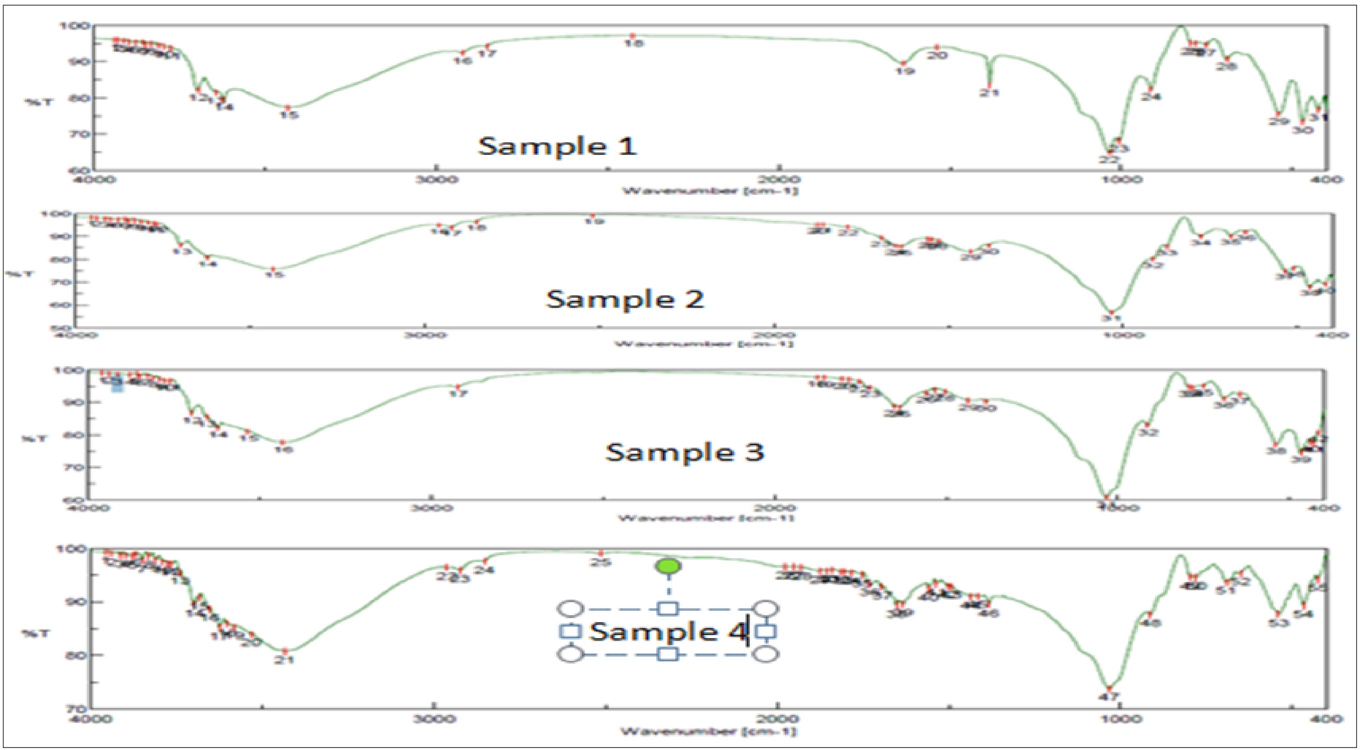

Fig. 5. FTIR spectral image of clay minerals.

clay minerals. The SiO_2/R_2O_3 ratio was more than 3 percent and the CIA value of P_2 was 80.75 which confirmed the moderately weathered smectite and montmorillonite were dominantly present in P_2. The P_3 and P_4 soils had a peak at 40.0 % which showed the presence of kaolinite as the dominate clay mineral. The same trend of results were also confirmed by FTIR spectrum intensity of 912, 3433, 1033, 3622 and 3433, which indicated that the Si-O stretching O-H deformation. The SiO_2/R_2O_3 ratios were more than 3 percent and the CIA value of P_1 was 86.49, which confirmed the highly weathered kaolinite was dominantly present in P_3 and P_4. These findings align with the previous research (38, 39).

Pedogenesis assessment

The four representative pedons analysed in relation to climate and topography showed distinct variations in matrix colour from dark reddish brown (P_1) to very dark brown/ strong brown ($P_2/P_3/P_4$), which could be due to the presence of granitic gneiss (40). The deep solum depth implied the highly weathered nature of these soils, suitable for growing a wide variety of crops like rice, maize, banana, sugar cane, pulses, tubers and plantation crops. The lithological discontinuities were also seen from the erratic distribution of total sand to silt in the pedons. Sesquioxide ratios were generally higher than 3 (41) and CIA values of 80.75 to 93.48 indicated moderate to highly weathering (42). The relative proportion of mica-smectite suggested that a dry and cold climate prevailed during deposition with decreased CIA values (37). The A-CN-K diagram (Fig. 6), showed a partial removal of Ca- and Na-bearing silicate and K-bearing minerals remained less attacked with moderate weathering under a tropical climate (43).

The presence of illite and kaolinite in P_1, P_3 and P_4 suggested an advanced stage of weathering but in P_2, increased smectite was noticed (Table 5). Lesser smectite quantity recorded was due to parent rocks and limited

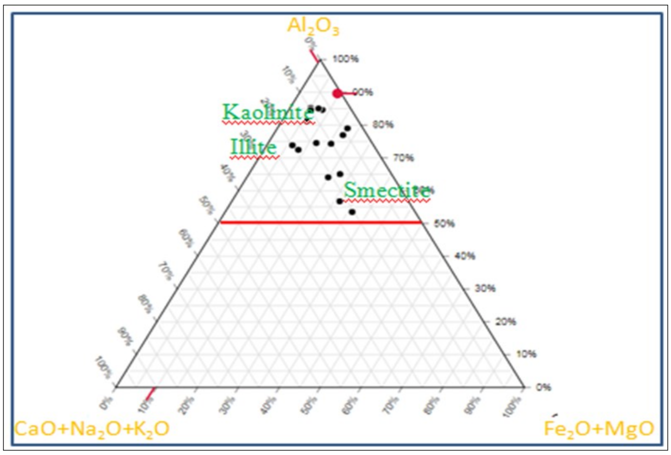

Fig. 6. A-CN-K FM diagram for clay mineral associations.

mechanical erosion in P_1, P_2 and P_3 (44, 45). Increased illite and kaolinite (P_1, P_3 and P_4) was due to an Aeolian deposition (46) and the physical weathering of biotite grains with daily and seasonal fluctuations in temperature and moisture under a semi-arid climate (47). Higher amounts of kaolinite and illite in all four soil pedons of the chosen area were inherited or transformed from mica parent material. The clay mineral formation and weathering patterns are in conformity with the ternary diagram of A-CNKFM (Fig. 6). Clay minerals that plotted closest to the residual field were kaolinite and illite with values representing 75 to 85 but had poor Mg/Fe rich phyllosilicates under alkaline (smectite) conditions in the semi-arid climate.

Conclusion

The present investigation concluded that Melur block in Madurai district had distinct lithological discontinuities which are specified from the found soil textural variations. The SiO_2 to sesquioxide ratio, CIA and WPI values of soils suggested moderate to high weathering with limited lessivage under semi-arid conditions. Moreover, the ternary plot A-CN-K and A-CNK-FM diagram showed partial removal of Ca and Na bearing minerals and least attack on K bearing minerals, also suggesting the moderate weathering status of soils. However, clay mineralogical evidence showed that the presence of kaolinite, illite and smectite in the soils indicates their formation under the influence of tropical humid climate in past years The soils are mostly deep with sandy texture, so in this area are generally we recommended the all cereals, pulses, oil seeds, vegetables and plantations crops.

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Authors' contributions

PR, PC and GP conceived of the project and designed the experiments. PR, PC, GP and KS analyzed the data. PR, GA, KD, PE and RS assisted the data, prepared figures, tables and manuscript editing. PR, PC and GP validated the statistical data. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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