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Research Article

Geochemical Interpretations of Laterite Associated Soils of East Coast Andhra Pradesh

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Abstract

Six representative laterite associated soils on peneplains of somasila project area of Nellore district, Andhra Pradesh of archean age schists under hot semiarid climate were studied to trace out pedogenic characteristics limiting crop production. The morphology of these soils showed that a distinct dark yellowish red to red matrix with hue 7.5YR in Allimadugu (P1) to red with hue 2.5YR in Venkateshwara Palem(P2) with increasing intensity of redness and clay in B horizons. These soils were assessed as easily susceptible to erosion as evidenced with increasing trends of silt to clay ratio, structural stability index and the molar ratio's of silica to sesiquioxide ratio more than 2. The chemical balance sheets constructed using silica as invariant and the results showed that there is a considerable gain of iron, aluminium oxides and substantial losses of Ca, Mg and K oxides in the genetic B horizons. These soils were classified in the subgroups of Entisols, Inceptisols and Alfisols considering clay illuviation, per cent base saturation, lithic contact and ustic soil moisture regime. The ratio of dithionite iron to total iron showed high degree of lateritization in relation to field morphology but yielded poor relation with weathering indices such as MPWI (modified product weathering index), chemical index of alteration (CIA) and Parker index (PI). These slightly acid to neutral soils were evaluated as marginally suitable for ground nut, and sorghum with poor status of carbon to nitrogen ratio(<8), available nitrogen, phosphorus and potassium but respond well high input management levels to attain high yield.

Laterite associated soil in Nellore

Keywords: Ferruginous soils, Nellore schist belt, Somasila project, Weathering indices

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Introduction

Chemical weathering is one of the most important processes that change the chemical composition of soils and distribution of elements in weathering products that differ from parent rocks. Chemical compositions of soils have been used effectively to evaluate weathering and soil formation conditions, to trace the provenance of soils [1] and to reconstruct paleoclimate records [2, 3]. Thus, quite a number of studies have been carried out in the past several decades to investigate chemical weathering [4, 5]. Previous studies show elements that are conserved in temperate zone, such as Ti and Zr, are mobile during extreme chemical weathering in tropical regions [6]. Probing into element behaviour during weathering is pivotal to understanding element mobilization and redistribution during chemical weathering. In addition, laterites, the products of extreme weathering, account for over 85% of the present world soil cover [7].

Quantitative characterization of weathering in soils is made through development of weathering indices [8, 9]. The chemical index of alteration [10], chemical index of alteration [11] and plagioclase index of alteration, (PIA) [12] serve as examples of the decomposition of unstable minerals. According to the principles of soil genesis, alkali and alkaline earth elements move through soil horizons prior to silicon as weathering progresses [13]. The soils studied represent Gelic Cambisols and Gelic Gleysols of Calypsostranda, Western Spitsbergen showed strong relationship of Fed/Fet % to determine the degree of the soil weathering indicator on par with the Parker’s indicator [14].

Laterite and lateritic soils are formations peculiar to India and some other tropical countries with intermittently moist climate. In India they cover a total area of about 248,000 sq. Kilometres in the states of Karnataka, Kerala, Madhya Pradesh, the Eastern Ghat regions of Orissa, Maharashtra, Malabar and parts of Assam [15]. The laterite and lateritic soils occur in the districts of Srikakulam, Visakhapatnam, East Godavari, Nellore and Medak of Andhra Pradesh. Laterite soils cover an area of 82,869 hectares in the Medak district occupying 61,793 ha (56.6%) in Zaheerabad area alone followed by Sadasivapet [16]. The general characteristics of laterite associated soils in Kerala were reported [17], of Nellore district of Andhra Pradesh [18] and of Medak district [19]. Silica as invariant was used to workout geochemical mass balance sheet of laterite associated soils of somasila project [20]. The distinguishing feature of these laterite soils is development of strong chroma and redder hue accumulation of clay, and relatively minor accumulation of Fe and Al sesquioxides in the B horizon with silica to sesequioxide ratio less than 2 [21]. In India, therefore, comprehensive understanding of the behaviour of elements during extreme weathering in the tropical laterite profile may aid in our understanding of the mechanisms of weathering and help to better explain the chemical record in soils. In this paper, we compare the composition of weathering products in terms of elements mobilization and redistribution during the processes of advanced to extreme weathering in tropical climates.

Experimental methods and materials

Study area

The study area is part of Somasila and Telugu Ganga project area in Nellore district, Andhra Pradesh. This area lies between 14^{0}05’N latitude and 79^{0}08’E longitude (**Figure 1**) at an elevation of 50metres above mean sea level (MSL). The topography is found to undulating to rolling peneplains with laterite exposures and red to dark reddish brown soils. The climate is semiarid monsoonic with distinct seasons such as south west (June to September), north east (October to December), winter (January –February) and hot summer (March to May). As such, the climate of the district is generally dry and salubrious. Generally April, May and June are the hottest with maximum temperature of 41.2^{0}C in May whereas November, December and January records minimum temperature of 21.9^{0}C during 2013-2014.

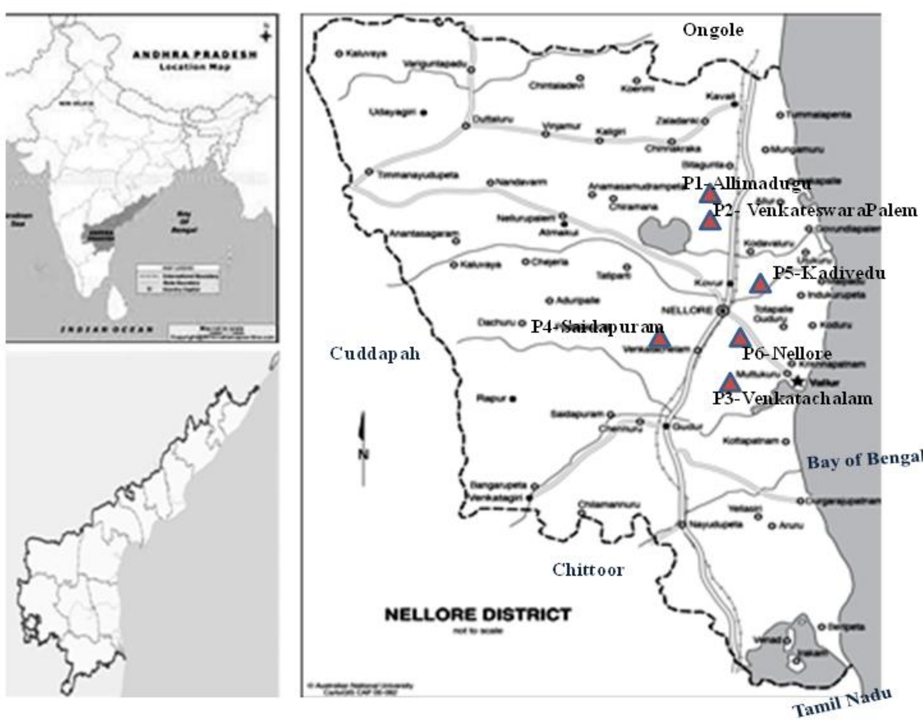

Figure 1 Location map with soil profile sites

The normal rainfall of the district is 1080.5 mm but received 758.9 mm during 2013-2014. The North East monsoon is recorded 369.6 mm. The area receives 61 per cent of total normal rainfall (1080mm) during north east monsoon, 31 per cent from south west monsoon with decrease of total amount of rainfall to 848mm during 2013 and 758mm during 2014mm [20]. Based on the previous literatures and geological framework of the laterite tract of Nellore district, the hard crust of gravelly laterite is partly eroded by rills and gullies with two distinct layers of pisolitic nodules are identified – (1) loose and less compacted gravelly iron concreted zone (10 to 25 cm thick) and (2) compacted and hard layer composed of regularly spaced nodules cemented by red clayey matrix with its uncertain spatial relation with coastal laterite of Miocene – Pliocene surface [22,25]. Six representative laterite associated soils from Allimadugu (P1), Venkateshswarapalem (P2), Venkatachalam (P3), Saidapuram (P4), Kadivedu (P5) and Nellore (P6) were selected for this study.

Morphology of soils

All pedons have hue 10YR to 2.5YR with mosit value 3 to 5 and dry value 4 to 6 and chroma of 3 to 8. These soils have distinct dark yellowish to red matrix with hue 7.5YR in Ap horizons except in Allimadugu (PI) with 10YR and in Venkateswara Palem (P2) with hue 2.5YR. The variations in colour is due to differences in local relief and consequent transport of weathered material. The increasing redness with depth indicates presence of hematite and well drained conditions [25]. The maximum clay enriched argillic horizonation in Venkateshswara Palem (P2) is observed beyond 38cm with notation of Bt1, Bt2 and Bt3. The presence of cambic horizons is noticed in Venkatachalam (P3), Saidapuram (P4), Kadivedu (P5) and lack of horizonation in Allimadugu (P1) and Nellore (P6). The red to reddish brown profiles are well oxidized with iron oxides which produces deep red subsoils in P2 and P3.

Laboratory Analysis

Horizon wise soil samples for each soil series were collected and passed through 2mm sieve after air drying. Bulk samples were air-dried, homogenized, and sieved to < 2 mm to remove coarse fragments. The Munsell soil colour chart was used to describe the soil colors. Particle size distribution was determined by the sieve and pipette method, following pre-treatment with H_2O_2 to remove organic matter, followed by dispersion by shaking with sodium hexameta phosphate [26]. Undisturbed cores were taken from the soil horizons to estimate bulk density [27, 28]. The pH (1:2.5), Organic carbon (OC, Walkley Black), Cation exchange capacity (CEC) and exchangeable bases (ammonium acteate) and percent base saturation was estimated as sum of bases/CEC*100 [29, 30]. Free iron compounds (Fed), including poor and well crystalline forms, were extracted with dithionate - citrate - bicarbonate (DCB) solution [31]. Elemental analysis was carried out using 1mm soil fraction by Na_2CO_3 fusion for all elements except sodium in triacid digestion and estimated by Atomic absorption spectrophotometer (Hitachi model) [32]. Molar concentrations were estimated by dividing the elemental concentrations with atomic weight of the elements. In this work, the following indicators of weathering were analyzed:

The Parker's indicator [33], based on interrelations between alkaline elements and alkaline earths as well as the strength of their binding with oxygen:

$$\text{Parker's index} = \frac{2Na2O}{0.35} + \frac{MgO}{0.90} + \frac{2K2O}{0.25} + \frac{CaO}{0.70}\ X\ 100$$

The numerical value of the indicator should decrease with the increase of rock weathering from >100 to 0. The Parker's indicator is an appropriate indicator for studying of the mobility of alkali metals and alkaline earths in soil profiles.

Indicator of potential erosion (Modified Potential Weathering Index):

$$\text{MPWI} = \frac{Na2\ O + K2\ O + CaO + MgO}{Na2O + K2O + CaO + MgO + SiO2 + Al2O3 + Fe2O3} X100$$

modified by Vogel [34], is calculated from the mole relationships of individual elements and it determines the relationship of the mobile and non-mobile elements. The obtained numerical value decreases with the intensity of the weathering processes.

Chemical Index of Alteration (CIA) introduced by Nesbitt and Young [10] is based on the mole relationship of the non-mobile aluminum to the mobile alkali metals and alkaline earths. The Ca, Na, and K content, together with the intensity of weathering processes, decreases in a given environment, while the numerical value of the indicator increases:

$$CIA = \frac{Al2O3X100}{Al2O3+CaO+K2O+Na2O}$$

Chemical Index of Weathering (CIW) by Harnois [11] is calculated from the mole relationships of the elements in equation:

$$CIW = \frac{Al2O3X100}{Al2O3+CaO+Na2O}$$

The indicator is based on the non-mobility of aluminum and the mobility of Ca and Na. The numerical value increases with the intensity of weathering processes.

Indicator of Kronberg, A and B, [10] is based on the mole relationships of the analyzed elements:

$$A = \frac{SiO2+CaO+K2O+Na2O}{Al2O3+SiO2+CaO+Na2O+K2O} \qquad B = \frac{CaO+Na2O+K2O}{Al2O3+CaO+Na2O+K2O}$$

The indicators illustrate the degree of hydrolysis of silicones and the accumulation of aluminum sesquioxides and silica with the simultaneous release of alkali metals and alkaline earths. This process links the transformation of easily weathering primary materials with the creation of new products and the accumulation of residual oxides during the weathering processes. The numerical values of both indicators decrease during the development of soils. Indicators A and B can be used for grouping of soil horizons or profiles. For the direct comparison of individual indicators of weathering, part of them was normalized in relation to the percent content Fe_d to Fe_t.

WI – (*Weathering Index)* – [35] the coefficient expressed in weight proportions, calculated by the following formula:

$$WI = \frac{(Al2O3+Fe2O3)}{(Na2O+K2O)}$$

Losses and gains of major elements

The Geochemical mass balance estimates chemical gains and losses of elements in a soil sample as compared to the bedrock. The volumetric change was predicted from the strain εi,w, i.e., the ratio of volume change during weathering and soil formation to the initial volume [36, 37, 38]. Positive strain values reveal dilation of the soil mass and element depletion, while negative values reflect collapse and residual enrichment of the element. Soil strain was estimated using the following equation:

$$\varepsilon i,w = (\rho pCi,p/\rho wCi,w) - 1$$

where, ρ=dry bulk density in g cm^{-3} for soil sample,(ρw) and parent material (ρp), Ci= the concentration of the immobile element i in the soil sample (Ci,w) and parent material (Ci,p).

The chemical mass loss or gain of element j through the soil profile as an open system (τj,w) was calculated as follows:

$$\tau\, j,w = (\rho wCj;w/\rho pCj,p)(\varepsilon i,w + 1) -1 \quad (2)$$

Positive value of τj,w reflect net gain or residual enrichment by precipitation or sorption, while negative values of mass transport throughout the profile indicate that element j has net loss and if τj, w is -1, element j has completely leached from the system. A real calculation of mass transport in open systems such as soil needs volumetric changes estimation with these conditions: an element as immobile component and a homogeneous parent material [38].

Results and Discussion

Particle size distribution and bulk density of soils

The particle size distribution shows that these soils have high amounts of mean coarse sand (40.5%) and clay (24.8%) and low amounts of fine sand (21.2%) and silt (13.5%) indicating the predominance of quartz and feldspars. The per cent of coefficient of variation of particle distribution is 41.3% for silt, 32 for clay, 29 for fine sand and 22.8 for coarse sand. In Venkateshswara Palem profile (P2) the presence of argillic horizon is confirmed with clay increase of >1.2 times from Ap to Bt horizons. The clay content is 31 to 41 per cent in the subsoils of Venkateshswara Palem (P2) and Venkatachalam (P3) whereas 20 to 28 per cent in Allimadugu (P1), Saidapuram (P4) and Kadivedu (P5) and of 11 to 13 per cent in Nellore soil (P6), The silt content varies from 4.44 per cent to 27.71 per cent with increasing trends in the profile 1,3,5 and 6 (**Table 1**). The Nellore soil (P6) registered more than 50% of coarse sand with increasing depth but decreasing trend in P3 and P5. The bulk density varies from 1.22 to 1.67 $Mgm^{-3}$with slight variations with depth. The uniform bulk densities in different horizons indicate uniform weathering rates with depth. Similar kind of bulk densities were reported in soils of east coast laterite occurring in Tamil Nadu [39]. The decreasing bulk density from 1.61 to 1.59Mgm^{-3} in the profiles of P5 and P6 is in agreement with the earlier observations of Maignien [40]. The silt/clay ratio is ranged from 0.11-2.25. Van Wambeke [41] reported that old parent materials usually have a silt/clay ratio below 0.15 while silt/clay ratios above 0.15 are indicative of “young” parent materials. Results of this study shows that most of the soils have silt/clay ratio above 0.15 indicating that the soil are relatively young with high degree of weathering potential. Silt/clay ratios are relatively higher in the surface horizon and decrease with increase depth in the pedons. The decrease in silt/clay ratio with depth is an indication that sub-soils horizons are more weathered than surface horizons.

Table 1 Particle size distribution and bulk density of soils

Soil series	Horizon	Depth (cm)	Particle size distribution (<2mm, %)				Bulk density (Mgm-3)
			coarse sand	fine sand	silt	clay	
Allimadugu	Ap	0-9	43.11	23.96	10.95	21.98	1.22
	A21	9-21	43.68	20.65	12.88	22.79	1.67
	A22	21-38	50.33	17.28	12.13	20.26	1.63
Venkateswarapalem	Ap	0-15	23.09	34.76	16.07	26.08	1.35
	B21t	15-31	34.61	16.70	12.56	36.13	1.32
	B22t	31-53	32.00	14.30	12.00	41.70	1.42
	B31	53-68	30.77	9.87	27.71	31.65	1.48
	B32	68-92	28.57	14.19	24.33	32.91	1.53
Venkachalam	A	0-10	54.13	26.88	4.44	14.55	1.47
	B21	10-22	46.64	23.58	9.30	20.48	1.64
	B22	22-42	36.14	12.88	16.25	34.73	1.45
Saidapuram	A	0-11	40.04	20.28	18.26	21.42	1.57
	B2	11-26	37.93	22.85	15.32	23.9	1.61
	B3	26-35	41.93	23.98	9.32	24.77	1.52
Kadivedu	A	0-13	44.15	24.37	10.69	20.79	1.61
	B	13-46	31.74	26.61	13.57	28.08	1.59
Nellore	A21	0-10	54.43	28.91	5.42	11.24	1.65
	A22	10-39	56.27	18.11	12.41	13.21	1.56

Chemical properties of soils

These soils are slightly acid (pH-6.3) to neutral (pH - 7.0) in reaction with low organic carbon (0.05 to 0.47 %) and cation exchange capacity (CEC) of 3.62 to 11.6 cmol(p+)kg^{-1} with increasing depth. The CEC of 11.6cmol/kg^{-1} is recorded in Bw horizon of P5 but value of 3.62 cmol/kg in A horizons of P3 (**Table 2**). The total nitrogen content varies from 0.022 to 0.067 per cent with decreasing depth trends those results in narrow C/N ratio’s from 5.56 to 11.08 in P1, P3 and P4 while remaining soils have values in between 2.06 and 5.53. Among exchangeable cations, Ca is dominant followed by Mg, Na and K. The exchangeable Ca varies from 1.24 (P3) to 5.26cmol/kg (P5). Next to Ca, Mg dominant with values varying from 0.64 to 4.28cmol/kg. All pedons shows increasing trend with depth except in P2 where Mg shows irregular depth trends. These soils have 0.13 to 0.92 cmol/kg exchangeable sodium and 0.03 to 0.23cmol/kg potassium. The base saturation is more than 60% with decreasing trends in P1, P2 and increasing depth trends in other soils. The Ca to Mg ratio < 3 in these soils means that uptake of P may be inhibited [42].In addition to that there is possibility of deterioration of structural stability with the consequent surface sealing, decreased infiltration, increased runoff and erosion in the events of rainfall [43]. This is due to hydration energy and radius of

Mg greater than Ca [44] and large separation distance between clay layers resulting flocculation and low structural stability. These soils have low exchangeable Ca (< 2 cmol/kg) in surface horizons of all soils but moderate in subsoil horizons. The exchangeable Mg is high (>1cmol/kg) with low (< 0.15cmol/kg) to moderate (0.15 -0.3cmol/kg) amounts of exchangeable K and low amounts of Na (<0.1cmol/kg). The studied soils have low organic matter content. Similar values of C/N ratios in these eroded soils are related to similar properties of these soils (soil texture, soil reaction).

Table 2 Chemical properties of soils

Soil series	Depth (cm)	p^H 1:2 soil water	p^H 1NKCl	Organic carbon (%)	Total nitrogen (%)	C/N	CEC	Exchangeable bases cmol(p+)kg-1 Ca^{2+}	Mg^{2+}	Na^+	K^+	Base saturation (%)
Allimadugu	0-9	6.5	4.7	0.402	0.054	7.37	7.04	1.44	1.48	0.313	0.076	75.4
	9-021	6.3	4.6	0.341	0.044	7.66	7.93	3.68	1.83	0.313	0.066	74.26
	21-38	6.5	4.8	0.256	0.04	6.40	8.92	3.16	3.04	0.295	0.143	74.41
Venkateswara Palem	0-15	6.8	5.4	0.286	0.051	5.53	6.78	2.16	2.46	0.043	0.417	74.92
	15-31	6.9	5.6	0.170	0.046	3.69	10.48	3.16	4.28	0.076	0.279	74.37
	31-53	6.8	5.5	0.219	0.046	4.75	11.22	3.23	4.08	0.117	0.295	68.82
	53-68	6.5	5.6	0.219	0.043	5.05	10.22	2.74	1.85	0.128	0.921	55.17
	68-92	6.7	5.6	0.134	0.035	3.83	9.98	3.64	1.52	0.082	0.73	59.83
Venkachalam	0-10	6.7	5.3	0.414	0.063	6.58	3.62	1.24	0.64	0.056	0.313	62.12
	10-22	6.9	5.2	0.347	0.040	8.56	6.64	2.64	1.68	0.123	0.395	63.82
	22-42	6.8	5	0.341	0.030	11.0	9.71	3.58	2.34	0.123	0.378	66.12
Saidapuram	0-11	6.7	5	0.469	0.067	6.98	5.52	2.32	0.96	0.030	0.133	62.38
	11-26	7	5.4	0.493	0.054	9.04	9.96	3.76	2.96	0.082	0.208	70.38
	26-35	7	5.7	0.463	0.042	11.0	11.06	4.28	3.46	0.232	0.330	75.06
Kadivedu	0-13	7	4.8	0.213	0.064	3.31	7.39	3.12	1.66	0.102	0.295	70.05
	13-46	6.9	5.2	0.152	0.043	3.51	11.56	5.26	2.88	0.128	0.452	75.43
Nellore	0-10	6.7	4.6	0.054	0.026	2.06	4.63	1.86	0.68	0.066	0.347	63.77
	10-39	6.4	4.7	0.054	0.022	2.44	7.24	2.48	1.64	0.117	0.382	63.79

Elemental composition of soils

The chemical weathering processes of rocks lead to products whose chemical composition is changed in relation to the final material. Chesworth [45] (1973) classifies the main elements into three groups based on their behavior in the environment: (a) the least mobile: Si, Al, Fe, and Ti, which remain in place, (b) elements with the medium mobility of alkaline earths: Ca, Mg, removed as acidic carbonates and settled repeatedly as carbonates, and (c) the most mobile, alkaline metals: Na and K, which are generally formed in water solutions to the point of precipitation in the evaporation process. The SiO_2 content varies from 57.36 to 76.50 per cent with more than 60 per cent in the profiles of 1,2 and 6 with decreasing depth trends while irregular trends in P3 and P4. The Al_2O_3 content is 12.71 to 26.51 % with increasing depth trends in P4, P5 and P6. These soils have 9.75 to 15.75 % of Fe_2O_3 contents with increasing depth trends. The medium mobility of alkaline elements in these soils varies from 0.15 to 0.84 % of CaO and 0.12 to 0.96% of MgO. The profile distribution of these oxides shows increasing trend with depth in P1, P2, P4 and P6. These soils registered less than 0.4% of K_2O content with increasing depth trend but its content is relatively low 0.093 to 0.006% in P2 (**Table 3**). The Na_2O content is 0.47 to 4.57 % with irregular depth trends in P1, P2 and increasing trends in other soils. The distribution of MnO is varied from 0.02 to 0.70 % with increasing depth trends in P1, P3 and P4. Similar trends are recorded for free Fe_2O_3 (3.44 to 7.84%), 60 to 930mg/kg CuO. According to Hallberg [46], high Cu/Zn ratios indicate reducing depositional conditions, while low Cu/Zn ratios suggest oxidising conditions. Thus, the low average values of Cu/Zn (3.19) indicate that the soils were developed in well-oxidizing environment. In the upper horizons, at least, a strong leaching of Cu, and Zn go with the pedogenesis evolution (**Table 3**).The concentration of these elements is very low in the pale-coloured soil but is nearly the same as that of the parent rock (except partially leached Zn) in the red powdery soil. In lateritic soils Cu and Zn are correlated

Laterite is the reddish – brown coloured product of intense tropical weathering made up of mineral assemblages that may include iron or aluminum oxides, oxyhydroxides or hydroxides, kaolinite and quartz, characterized by a ratio

SiO_2 : R_2O_3 (where $R_2O_3 = Al_2O_3 + Fe_2O_3$) and subjected to hardening up on exposure to alternate wetting and drying [47]. It is suggested that materials having Fe_2O_3 : Al_2O_3 ratio more than 1 and SiO_2 : Fe_2O_3 ratio less than 1.33 be termed as 'ferruginous laterite'; while those with Fe_2O_3 : Al_2O_3 ratio less than1 and SiO_2 : Fe_2O_3 less than 1.33 as 'aluminous laterite' [48]. The depth functions of molar ratio's are irregular trends in all soils except in Venkateswara Palem (P2) soil with gradational decrease of SiO_2 / R_2O_3(5.24 to 3.92, **Table 4**), and SiO_2 / Al_2O_3 (8.06 to 5.16). These soils have molar ratio of Fe_2O_3 / Al_2O_3 more than 1 but SiO_2 to Fe_2O_3 is more than 10 but to define it as ferruginous laterite as corroborated with field morphological observations.

Table 3 Elemental composition of soils

Soil series	Depth (cm)	Elemental composition											Loss on ignition (%)
		SiO_2 (%)	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	Free Fe_2O_3	CuO mgkg^{-1}	ZnO	
Allimadugu	0-9	71.5	15.6	10.25	0.15	0.12	0.68	1.23	0.035	3.64	150	20	5.24
	9-21	76.5	12.7	9.75	0.49	0.76	0.44	1.35	0.037	3.44	150	22	6.32
	21-38	73.2	13.9	10.75	0.61	0.96	0.11	0.98	0.040	4.26	180	22	6.62
Venkateswar apalem	0-15	70.4	14.8	12.5	0.56	0.62	0.006	0.76	0.022	4.77	60	15	4.32
	15-31	73.7	15.0	9.75	0.47	0.67	0.008	0.67	0.031	4.79	80	22	6.78
	31-53	69.8	14.9	13.5	0.53	0.79	0.009	0.94	0.035	4.28	90	25	7.34
	53-68	67.1	16.8	12.75	0.64	0.58	0.085	0.47	0.021	3.96	850	35	7.23
	68-92	66.7	21.9	11	0.65	0.5	0.093	0.56	0.037	3.63	930	55	6.87
Venkachalam	0-10	59.4	26.5	10.25	0.84	0.46	0.19	2.35	0.035	4.83	80	25	8.23
	10-22	57.3	24.3	14.5	0.33	0.38	0.25	3.46	0.054	4.69	900	60	8.34
	22-42	63.5	16.1	15.5	0.19	0.37	0.29	4.57	0.039	5.31	600	50	9.26
Saidapuram	0-11	61.8	16.5	9.75	0.36	0.34	0.21	1.98	0.020	4.76	510	50	7.35
	11-26	64.3	17.6	14.25	0.23	0.33	0.23	2.34	0.072	7.69	760	50	9.64
	26-35	60.3	20.8	15.75	0.4	0.36	0.26	3.42	0.061	7.84	630	65	12.37
Kadivedu	0-13	66.3	15.9	14.75	0.39	0.62	0.12	2.11	0.062	5.46	920	50	18.48
	13-46	64.5	23.0	10.25	0.32	0.53	0.18	3.45	0.060	6.98	890	60	12.56
Nellore	0-10	72.8	13.8	12.25	0.23	0.38	0.2	0.78	0.020	6.20	110	60	15.66
	10-39	60.5	16.73	12.5	0.25	0.43	0.21	0.56	0.017	7.04	120	42	13.38

Weathering indices

Chemical weathering indices useful in pedogenesis or other geological applications are commonly used for characterizing weathering profiles by incorporating bulk major element oxide chemistry into a single metric for each sample. Weathering information and investigate stage of soil evolution is as well important for agricultural and environmental researches. Among the weathering indices that monitor the decomposition of an unstable mineral include the Chemical Index of Alteration (CIA) [10]; that logically predicts the extent of conversion of feldspar minerals and that feldspars are the most abundant rock-forming mineral group in the Earth's crust, this index has been widely employed in studies [9]. The Values of CIA (69.5 to 91.0) indicated high rates of weathering with serious losses of bases. The indices CIA is perhaps more suitable for the study of early stages of rock weathering rather than for well-developed tropical soils [49]. Weathering index of Parker (WIP) can be used to identify the initial and lateral products of weathering which can be tracked at the same time. WIP is a suitable index to investigate the mobility of alkaline and alkaline-earth metals [9]. The other indices also shows similar trends of indicating intensive weathering of these laterite soils with values of 2.12 to 6.35 for MPWI, more than 75 of Kronberg A, 8.04 to 30.5 for Kronberg B indices and 8.79 to 37.41 for parker indices (**Table 4**).

For soils studied, the CIA values showed a strong and positive correlation with pedogenic iron index (r^2= 0.84**) and clay content (r^2= 0.86**). These relationships indicate that CIA could be a useful weathering index for assessing weathering intensity in the area studied. For Schwertmann [50], rapid release of Fe and low concentration of organic compound favors hematite formation while high concentration of organic compounds favours goethite.

Table 4 Molar ratios and Weathering indices of soils

Soil series	Depth (cm)	molar ratios				Weathering indices						Fed/Ft* 100
		SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3	MPWI	CIA	A	B	PI	WI	
Allimadugu	0-9	5.48	7.77	18.59	2.39	2.57	83.87	87.08	16.13	21.94	13.45	35.51
	9-21	6.86	10.24	20.81	2.3	3.71	79.34	89.87	20.66	22.18	12.75	35.28
	21-38	5.96	8.89	18.05	2.02	3.48	84.98	88.49	15.02	14.83	22.66	39.63
Weighted mean		6.13	9.05	19.05	2.20	3.34	82.84	88.59	17.06	18.84	17.35	37.28
Venkateswarapalem	0-15	5.24	8.06	15	1.85	2.56	88.53	87.37	11.47	10.22	35.69	38.16
	15-31	5.86	8.29	20	2.4	2.38	90.03	87.71	9.97	9.33	36.51	49.13
	31-53	5.04	7.94	13.9	1.72	3.01	87.51	87.23	12.49	12.31	29.95	31.70
	53-68	4.59	6.72	14.1	2.08	2.43	90.53	85.29	9.47	8.79	53.36	31.06
	68-92	3.92	5.16	16.32	3.16	2.35	91.96	81.64	8.04	9.54	50.42	33.00
Weighted mean		4.85	7.10	15.80	2.29	2.56	89.77	85.56	10.22	10.15	41.38	36.02
Venkachalam	0-10	3.02	3.76	15.31	4.06	4.71	84.55	77.23	15.45	27.81	14.47	47.12
	10-22	2.89	3.99	10.55	2.64	5.36	81.04	78.28	18.96	37.41	10.46	32.34
	22-42	4.11	6.64	10.82	1.62	6.35	69.50	85.84	30.50	47.85	6.51	34.26
Weighted mean		3.50	5.20	11.81	2.49	5.68	76.38	81.63	23.26	40.10	9.53	36.77
Saidapuram	0-11	4.59	6.33	16.72	2.63	3.77	81.97	84.81	18.03	23.14	11.97	48.82
	11-26	4.06	6.16	11.91	1.93	3.79	81.67	84.47	18.33	26.39	12.40	53.96
	26-35	3.31	4.9	10.2	2.08	5.30	78.33	81.56	21.67	37.30	9.94	49.78
Weighted mean		4.03	5.89	12.98	2.19	4.17	80.91	83.63	19.09	28.17	11.63	51.27
Kadivedu	0-13	4.43	7.05	11.93	1.69	4.04	81.11	86.07	18.89	23.89	13.76	37.02
	13-46	3.7	4.75	16.71	3.51	5.22	80.55	80.94	19.45	36.67	9.16	68.10
Weighted mean		3.91	5.40	15.36	3.00	4.89	80.71	82.39	19.29	33.06	10.46	59.31
Nellore	0-10	5.7	8.89	15.92	1.78	2.00	88.76	88.47	11.24	11.73	26.58	50.61
	10-39	4.66	6.89	14.4	2.1	2.12	91.83	84.02	8.17	10.03	37.96	56.32
Weighted mean		4.93	7.40	14.79	2.02	2.09	91.04	85.16	8.96	10.47	35.46	54.86

Losses and gains of elements in soils

The losses and gains of six major elements viz., Al_2O_3, Fe_2O_3, CaO, MgO, K_2O and MnO in each soil profile shows considerable gains of Al_2O_3 and Fe_2O_3 except in Allimadugu (P1) and Fe_2O_3 in Kadivedu (P5) with substantial losses of CaO, MgO, K_2O and MnO (**Table 5**). The gains of Al_2O_3 and Fe_2O_3 amounts to 37.95 kgm^{-2} in Venkachalam (P3) and 5.12 kgm^{-2} in Saidapuram (P4)where as a total loss of Al_2O_3 is 2.58kgm^{-2} in Allimadugu (P1) and net loss of Fe_2O_3 0f 1.1kgm^{-2} in Kadivedu (P5).The differential rates of Al_2O_3 in genetic horizons of Venkateswara Palem (P2) and in surface horizons of Nellore (P6) / Saidapuram (P4) indicate contrasting pedogenic processes such as vertical migration and lateral movement under existing semiarid climate. The serious losses of CaO, MgO and K_2O accounts to 13.4kgm^{-2}in P2, 12kgm^{-2}in P1 and 9.2kgm^{-2} in P5 due to dealkalisation and partial desilication of primary minerals. These soils show serious loss of K_2O making infertile with poor K reserves and subjected to erosion in the event of intense rains.

The pedogenic characteristics of ferruginous soils at study sites are considered to determine thresholds as: (i) the ratio of total Al to total Fe; (ii) pH; (iii) base saturation; (iv) the weathering indices of CIA, CIW, PIA and VR. The ratio of total Al to total Fe in soils is more than unit value indicating consistently increasing to the sites with considerable decrease in base saturation (< 20%) in argillic B horizons. The loss of base cations is due to drop in pH towards acidity and the increased Al that competes with base cations for the exchange sites. These soils have neutral, kaolinitic materials but small amount of inherited 2/1 Phyllites (like illite) can be found; clay-illuviated weakly structured B [51, 52]. This pH range under study area within a relatively narrow range of climate window, represents a threshold transition from an exchange complex dominated by Al, hydroxyl Al species and H^+ [53]. The area comes under hot humid to perhumid climate with length of growing period 210-270 days and greater leaching intensity of low base saturation (less than 30 per cent) and acid environment even under small changes of rainfall at sites under study. The soil profiles show only minor differences in base saturation and pH because they all are being buffered by Al hydrolysis. It is pertinent to say that current weathering rates in soil profiles (high values CIA, CIW and PIA) at the high rainfall may actually operating at slower rate because of the depletion of primary minerals [54].

Table 5 Major elemental losses and gains (kg/m^2)

Soil series	Depth (cm)	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	MnO	Total
Allimadugu	0-9	+1.79	+0.78	-0.75	-1.12	-0.86	-0.06	-0.22
	09-021	-3.85	-0.77	-0.92	-1.02	-2.21	-0.13	-8.9
	21-38	-0.52	+2.46	-0.82	-0.74	-3.57	-0.16	03.35
	total	-2.58	+2.47	-2.49	-2.88	-6.64	-0.36	-12.47
Venkateswarapalem	0-15	-0.38	+1.86	-0.29	-1.16	-2.24	-0.55	-2.76
	15-31	-1.55	-4.53	-0.54	-0.37	-2.33	-0.56	-9.88
	31-53	+0.15	+5.93	-0.50	-0.05	-3.19	-0.75	+1.59
	53-68	+5.26	+3.66	-0.08	-0.39	-0.47	-0.54	+7.44
	68-92	+24.86	+0.09	-0.10	-0.90	-0.77	-0.82	+22.36
	total	+22.44	+7.01	-1.51	-2.87	-9.00	-3.22	+18.76
Venkachalam	0-10	+13.04	+2.12	+0.05	-0.21	-0.45	-0.18	+14.37
	10-22	+11.39	+8.32	-0.62	-0.31	-0.37	-0.17	+18.24
	22-42	-1.99	+9.43	-1.00	-0.45	-0.42	-0.23	+5.34
	total	+22.44	+19.87	-1.57	-0.97	-0.97	-0.58	+37.95
Saidapuram	0-11	+0.85	-3.03	-0.91	-0.34	-0.97	-0.54	-4.94
	11-26	+1.78	+3.54	-0.96	-0.45	-1.13	-0.56	+2.22
	26-35	-5.08	+4.17	-0.34	-0.19	-0.57	-0.31	+7.84
	total	-2.45	+4.68	-2.21	-0.98	-2.67	-1.41	+5.12
Kadivedu	0-13	+2.58	+4.47	-0.80	-1.07	-0.92	-0.54	+3.72
	13-46	+33.57	-5.57	-1.99	-2.62	-1.79	-1.18	+20.52
	total	+36.25	-1.10	-2.79	-3.69	-2.71	-1.72	+24.24
Nellore	0-10	-0.66	+0.84	-0.28	-0.21	-0.49	-0.29	-1.09
	10-39	+11.96	+5.35	-0.52	-0.21	-1.03	-0.65	+14.90
	total	+11.30	+6.19	-0.80	-0.42	-1.52	-0.94	+13.81

It is interesting to mention here that the top soils of these profiles meet the criteria to define as modic that display characteristics like incompletely mineralized OM (intensive rubber growing area and frequent additions of leaf) and an OC content of >0.6 percent, blackish brownish in the hue of 5YR with base saturation < 10 per cent and pH <5.0 [55]. The occurrence of modic topsoils in ferruginous soils of Shillong plateau were reported and proposed to use modic at subgroup level for Sombrihumults in Shillong plateau [56]. The difficulties in identifying the clay skins in argillic horizons in soils of Kerala and in Northen states was very well expressed in review of red ferruginous soils of India [57] and made them to place some soils in the subgroups of Dystrudepts. In the study sites, Al:Fe ratio ranges from 10.97 (P1) to 0.94(P2) with maximum values in between 2.0 to 3.0 in genetic horizons. This threshold reflects the onset of anaerobiosis leading to iron reduction [58]. The CIA values more than 90 in P3 and P4 indicates intense chemical weathering correspond to pH values less than 4.5 whereas CIA values less than 75 in P1and P2 indicates less intensely weathered with a corresponding pH more than 4.7. The assumption that Ca, Na and K decrease as weathering intensity increases and that Al stays mostly immobile is valid here. These results are in accordance with observations in other weathering studies and theoretical considerations of the element behavior, suggesting that K release is small compared to the Na release. This is due to stronger weathering resistance of K phases such as K-feldspar and due to the fixation of K on clay minerals [59, 60]. Moreover, high CIA values, suggest derivation from a stable terrain (autochthonous in nature) and the plagioclases in parent rock displayed increasing chemical weathering with steadily decreasing contents of plagioclases and enriched in secondary aluminous clay minerals [61]. Iiron oxides constituted 26-39% of Fet, which indicated low and medium degree of weathering of mineral substrates. Vertical variability in Fed /Fet ratios suggested slight displacement of iron or/and variable intensity of weathering at different depths. The high content of free iron oxides in parent materials was the characteristic feature of the studied soils as compared to solum. Crystalline forms of iron predominated over amorphous.

Conclusions

Six representative profiles of Somasila – Telugu ganga project area in Nellore district, Andhra Pradesh located on gently rolling peneplains of Archean age schists showed the presence of hard and compact laterite or ferruginous layer. Generally these soils have dark yellowish brown to red sandy loam to loam texture with an increasing intensity of redness, clay maxima and iron illuviation in B horizons. These soils are slightly acid to neutral in reaction with low water holding capacity, poor organic carbon and CEC. These soils were severely eroded as evidenced by decreasing trends of silt to clay ratio and structural stability indices. The non lateritic nature was confirmed with the value of SiO_2/R_2O_3 greater than 2. The chemical balance sheets were constructed with silica as invariant and showed considerable gains of Fe_2O_3 and Al_2O_3 and substantial losses of bases such as CaO, MgO and K_2O in genetic horizons of all soils. These soils were classified in the subgroups of Alfisols, Inceptisols and Entisols. These soils were poor in fertility status (available NPK) because of paradoxical situation prevailed under semiarid monsoonic climate that did not permit sufficient weathering to release nutrients and subjected to serious erosional process in the event of high intensity rainfall in the east coast of Andhra Pradesh.

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