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Land suitability assessment through soil profile study in the Siruvani foothills of the Western Ghats of Tamil Nadu, India

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Abstract

The aim of this study was to investigate the morphological, physical, and chemical characteristics of soils occurring in the North Farm of Karunya Campus, located in the Coimbatore district of Tamil Nadu, within the Coimbatore Plateau physiographic region. Three representative soil profiles were excavated and analysed to assess soil development, classification, and agricultural suitability. The study area is underlain by deep Quaternary alluvium deposits exceeding 30 meters, with soils found on gently sloping terrain (1–3%). Five distinct horizons were identified in the profiles: Ap, Bw, Bwk1, Bwk2, and Bwk3. The presence of calcium carbonate ($CaCO_3$) nodules in the Bwk horizons confirmed secondary carbonate accumulation. The soil texture was predominantly sandy clay loam, with increasing clay and silt content at depth. The soil structure ranged from angular and subangular blocky in the surface layers to massive and single-grain in the deeper horizons. The soils were well-drained, slightly to moderately alkaline (pH 7.9–9.1), and non-saline (EC < 1 dS m^{-1}). The total organic carbon (TOC) content was higher in the surface layer and decreased gradually with depth. Available nitrogen, phosphorus, and potassium were also concentrated in the surface horizon. Cation exchange capacity ranged from 10.7 to 18.3 cmol (P^+) kg^{-1}, and base saturation increased with depth. The soils were classified as fine-loamy, mixed, isohyperthermic, Typic Calciustepts (Inceptisols) according to the USDA Soil Taxonomy, and as Calcic Cambisol (Loamic) based on the World Reference Base for Soil Resources. The soils were rated as Class II under the Land Capability Classification (LCC), indicating cultivable land with minor limitations, and as S2 under the Land Suitability Classification (LSC), reflecting moderate constraints for crop production. The Storie index value ranged between 59 and 66%, with a mean of 62.2%, placing the soil in the "good" category, which highlights its potential for productive agriculture with appropriate management interventions.

1. Introduction

Modern soil science traces its origins to the pioneering work of Dokuchaev, who introduced foundational concepts about soil profiles in Russia, and later contributions by Hilgard and Joffe in the United States (Brevik and Hartemink, 2010). These early studies emphasized the significance of soil horizons in comprehending pedogenesis and soil formation, laying the groundwork for classification systems that are still widely used (IUSS Working Group WRB, 2015). A soil profile serves as an essential framework to examine soil development, processes, and attributes (Churchward, 1961). These profiles are segmented into layers, or horizons, typically aligned with the soil surface (Simonson, 1959; Shaw, 1928). Each horizon possesses distinct physical, chemical, and biological properties, shaped by environmental influences and human activities (Brevik et al., 2016). The term "horizon" is preferred over "layer" as the latter often denotes geological strata rather than changes brought about by soil-forming processes. The deposition of new materials through geological activity plays a crucial role in the formation of soil horizons, transforming a uniform (isotropic) soil profile derived from a single parent material into varied (anisotropic) segments (Jenny, 1941; Johnson et al., 1987).

Soil horizons form the foundation of soil classification systems and are essential for developing effective land management practices. A comprehensive understanding of their variability, supported by robust analytical methods and adaptive management strategies, is critical for optimizing soil functions and ensuring the long-term sustainability of land use (Hartemink et al., 2019). The formation and development of soil horizons over time, driven by various pedogenic processes, play a crucial role in understanding and interpreting soil profiles. These horizons offer valuable insights into soil genesis, support accurate soil classification, and guide sustainable land-use planning and management.

Advancements in soil science have significantly enhanced our understanding of the complex variability observed within soil horizons, both spatially and temporally. This growing body of knowledge emphasizes the importance of adopting advanced methodologies to effectively study and manage such variability (Hartemink et al., 2019). This study focuses on exploring the variability of soil horizons, identifying the key factors influencing their development, and examining the broader implications for soil classification and sustainable soil management.

Addressing variability within and between soil horizons has long been a challenge in soil science. This variability stems from natural factors, such as climate, topography, and diversity in parent material, as well as human-induced influences, including agricultural practices and land management (Minasny et al., 2016). Current research focuses on measuring this variability to improve soil classification systems and land-use practices. For example, differences in soil texture and landscape position significantly affect the variability of soil organic carbon (SOC) within horizons. Additionally, agricultural activities impact horizon thickness and boundary characteristics, highlighting the need for adaptive management strategies (Hartemink et al., 2020).

Understanding variability in soil horizons is integral to soil classification and management. Classification frameworks, such as the IUSS Working Group World Reference Base for Soil Resources (WRB) and Soil Taxonomy, rely on horizon features to group soils into functional categories (IUSS Working Group WRB, 2022; Soil Survey Manual, 2018). However, the variability inherent in horizons poses challenges for these systems. Moreover, horizon variability affects soil functions and ecosystem services. For instance, nutrient distribution and SOC within horizons play key roles in soil fertility, water retention, and plant growth (Fedenko et al., 2024). Characteristics such as horizon thickness and boundary definition significantly influence critical agricultural and forestry processes, including water infiltration and root penetration (Hartemink et al., 2020). Anthropogenic modifications, including fertilization and tillage, further alter horizon properties, necessitating the development of tailored management strategies to counteract potential negative impacts (Bockheim et al., 2020).

In recent years, researchers have made significant advances in understanding and addressing soil horizon variability. Variations in soil SOC were assessed about soil texture and topographic position. Similarly, research into agricultural impacts has indicated changes in horizon boundaries and thickness, emphasizing the importance of adaptive soil management practices (Hartemink et al., 2020). These findings highlight the need for novel techniques to account for the dynamic geographical and temporal structure of soil horizons (Hartemink et al., 2019).

The evaluation of land suitability is crucial to sustainable land management because it serves as the foundation for scheduling and managing land resources (Kýlýç et al., 2022). The authors suggest that land assessment determines whether resources are improving or declining over time. Several land factors, such as soil types, topography, hydrology, and basic geology, have a direct impact on land capabilities and productivity (Abdel Rahman et al., 2016). These variables limit or increase the land's potential for various purposes. Land capability classification aims to predict the agricultural potential of land development units, ultimately informing decisions on the most suitable land uses. Land suitability evaluation is thus critical for optimal land use planning (Girmay et al., 2018).

Land suitability assessments are used to analyze a property's potential for different uses based on the unique needs and preferences of each land use type. Such assessments combine qualitative and quantitative methods. Climate, hydrology, terrain, vegetation, and soil qualities are all considered while evaluating land suitability qualitatively (Halder et al., 2013). This technique is frequently the initial stage in agricultural land use planning, determining whether a specific land use type is appropriate for a given area. Several known approaches are used to assess land suitability. The Storie Index, for example, gives a numerical representation of a soil's relative appropriateness for agricultural use. It assesses soil productivity using variables such as soil surface, depth, texture, slope, and controllable parameters like drainage and salinity. Furthermore, the Sys Rating System was created utilizing the structure of the FAO Framework for Land Evaluation (2007), which provides a systematic approach to assessing land suitability (Bagherzadeh et al., 2011).

2. Materials and methods

2.1. Study area

The soil profiles were excavated from the North farm of Karunya campus, situated in the Coimbatore district of Tamil Nadu at coordinates 10°56'56"N and 76°45'13"E, within the Coimbatore plateau physiographic region (Fig. 1). This area lies within the Noyyal river basin, characterized by an extensive system of irrigation tanks replenished by both river flow and seasonal rainfall. Geologically, the western part of the district is dominated by Proterozoic-aged Maruthamalai granite, while the Siruvani valley is underlain by thick Quaternary alluvium deposits exceeding 30 meters. The study site receives an average annual rainfall of 730 mm and experiences a mean annual temperature of 25.2°C. The major crops cultivated in the region include bananas, onions, coconuts, and tomatoes. The landform consists of gently sloping terrain with gradients ranging from 1% to 3%, and minimal signs of erosion were observed. No rock outcrops were present at the site, and the soils were well-drained. Soil profiles were excavated to dimensions of 2 meters in length, 1 meter in width, and 2 meters in depth, with the profile face oriented along the north-south axis. A representative image of the soil profiles is shown in Fig. 2.

2.2. Details of analytical procedures

Soil samples were collected from each identified horizon and subjected to standard laboratory analyses to determine their physical and chemical properties. Soil colour was recorded using the Munsell Soil Colour Chart (Soil Survey Staff, 2014), and texture was determined by the International Pipette Method (Piper, 1966). Soil structure was assessed in the field, while bulk density, particle density, and total porosity were measured using the Measuring Cylinder Method (Tan, 1998). Soil pH and electrical conductivity (EC) were measured in a 1:2.5 soil-water suspension using potentiometry and conductometry, respectively, following the method described by Jackson (1973). Total organic

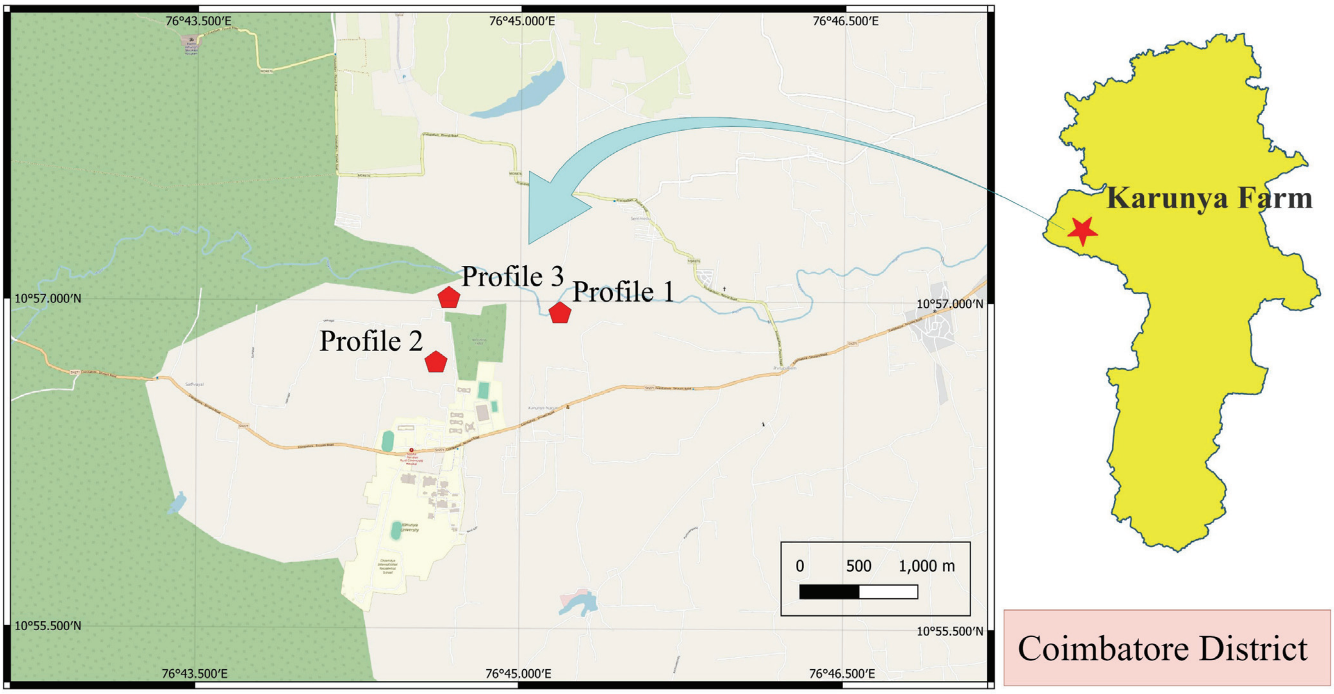
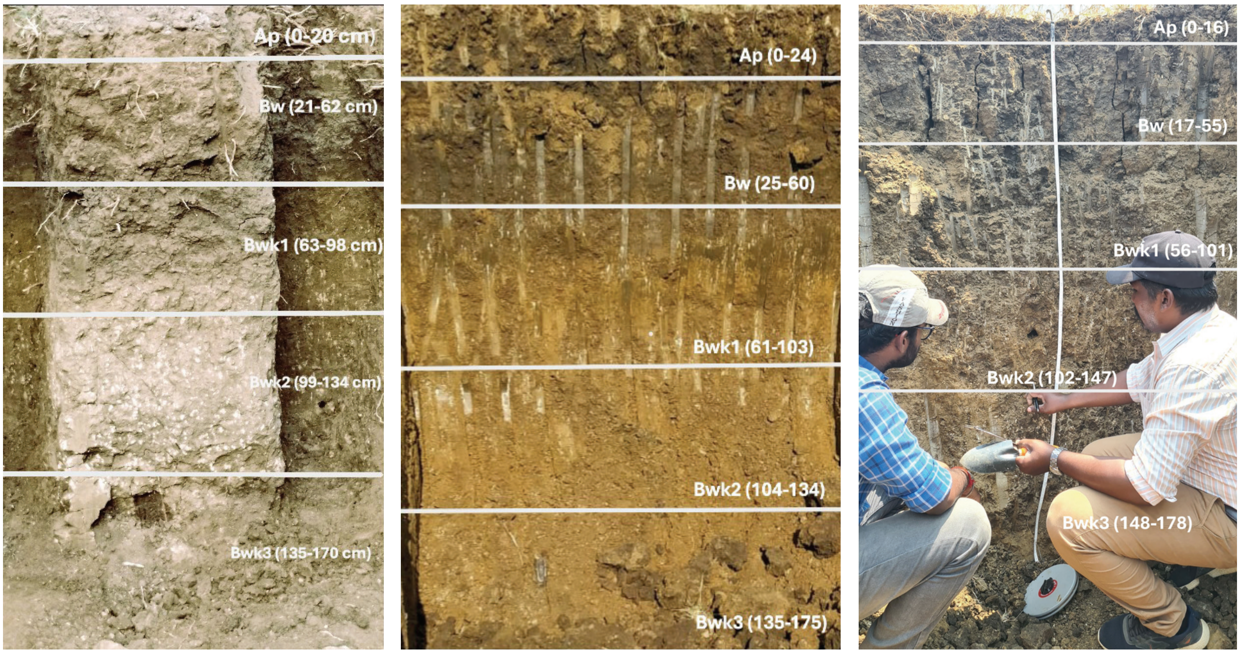


Fig. 1. Location of the soil profile in the North farm of Karunya campus



Profile 1 **Profile 2** **Profile 3**

Fig. 2. Morphological features of soil profiles showing distinct horizons

carbon content was estimated using the Chromic acid wet digestion method (Walkley and Black, 1936). Available nitrogen was determined by the alkaline permanganate method (Subbiah and Asija, 1956), while available phosphorus was estimated colorimetrically (Olsen, 1954). Exchangeable potassium and sodium were measured using flame photometry (Toth and Prince, 1949), and exchangeable calcium and magnesium were quantified by Versenate titration (Jackson, 1973). The available sulphur content was analyzed through turbidimetry (Steinbergs, 1955), and free calcium carbonate was estimated using the Rapid Titration method (Piper, 1966). Cation exchange capacity (CEC) was determined using Neutral normal ammonium acetate extraction (Jackson, 1973). The tables 7–13 present the results of each soil profile separately.

2.3. Soil classification

Considering the morphological and analytical characteristics of the studied soil profiles, taxonomic classification was conducted using the USDA Soil Taxonomy and the IUSS Working Group World Reference Base for Soil Resources (WRB) to ensure a globally recognized interpretation of its properties. Additionally, land capability (Tables 1 and 2) and land suitability (Tables 3 and 4) evaluation criteria were performed following the guidelines of the Food and Agriculture Organization (1976), along with the Storie Index evaluation (Tables 5 and 6) (Storie, 1978), to assess the agricultural potential of the soil.

Table 1
Land capability classes

Class	Features
I	Excellent cultivable, deep, nearly level, productive land. Soils have no limitations that restrict their use
II	Good cultivable land on almost level plain or on gentle slopes. Soils have moderate limitations that reduce the choice of crops or that require moderate conservation practices. (Soil depth, salinity, texture, drainage, erosion
III	Moderately Good cultivable land. Soils have severe limitations that reduce the choice of plants, require special conservation practices or both. Limitations are moderate erosion, soil depth, soil salinity, texture, drainage. Unsuitable for vegetable cultivation
IV	Fairly good land with moderate steep slopes. Soils have very severe limitations that reduce the choice of plants, require very careful management or both. With such limitations the lands are fit for cultivation only occasionally. Limitations are strong salinity, shallow soil depth, strong erosion, fine soil texture, poor drainage
V	Land is not suitable for arable farming. Soils are not likely to erode, but have other limitations impractical to remove, that limit their use largely to pasture and woodland.
VI	Non arable land, well suited for grazing and pasture, but not cultivable. Severe limitations such as steep slope, severe erosion, limiting soil depth, strongly gypsiferous, stony or sandy
VII	Fairly well suited for grazing or forestry, but not cultivable. Severe limitations are steeply sloping, very shallow depth, not enough available moisture for
VIII	Non-arable, extremely rough, rocky arid, wet or extremely saline, suitable for only wild life or recreation. Very severe limitations of very steeply slope, highly eroded, barren mountain

Table 2
Land capability class rating criteria

Characteristics	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Topography								
Slope (%)	0–1	1 to 3	3 to 8	8 to 15	Up to 3	15 to 30	30 to 50	30 to 50
Erosion	Nil	Slight	Moderate	Severe	Nil	Severe	Very Severe	Extremely rugged and rocky
Wetness								
Flooding	Nil	Almost Nil	Slight	Moderate	Moderate to severe	Nil, Severe	Nil, very severe	–
Drainage	Well	Moderate	Imperfect	Poor	Very poor	Excessive	Excessive	Excessive
Permeability	Moderate	moderately rapid	rapid, slow	Very rapid, very slow	–	–	–	–
Infiltration rate (cm hr^{-1})	2 to 3.5	1 to 2, 3.5 to 5	0.5 to 1, 5 to 10	<0.5 to > 10	–	–	–	–
Physical soil condition								
Surface texture	Loam	Silt and clay	Silty loam and clay	Silty clay loam	Silt and clay	Silty loam and clay loam	Silty loam, silt and clay	Silty loam, silt and clay
Soil depth (cm)	>150	150 to 100	100 to 50	50 to 25	50 to 150+	25 to 10	<10	Nil
Fertility (f)								
CEC	40 to 16	16 to 12	16 to 12	12 to 8	–	–	–	–
Base Saturation %	80+	80+	80 to 50	50 to 35	50 to 35	35 to 15	<15	–
OC %	>1	0.75 to 1	0.5 to 0.75	0.3 to 0.5	<0.3	–	–	–
Salinity EC	<1	1 to 2	2 to 4	4 to 8	8 to 15	15 to 35	35+	–

Table 3
Land Suitability Classes

Classes	Rating	Results	Features
Class 1	S1	Highly Suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Class 2	S2	Moderately Suitable	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
Class 3	S3	Marginally Suitable	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
Class 1	N1	Currently not suitable	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Class 2	N2	Permanently not suitable	Land having limitations which appear so severe as to preclude any possibilities Of successful sustained use of the land in the given manner.

Table 4
Land suitability class rating criteria

Characteristics	Degree of limitation and suitability class				
	0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (Very severe)
	S1	S2	S3	N1	N2
Climatic (under irrigated conditions)					
Rainfall (summer dominant) (mm)	>1500	1000 to 1500	750 to 1000	<750	–
During the growing period	>750	550 to 750	450 to 550	<450	–
Topographic (slope %)					
Plain, irrigated	0 to 1	1 to 3	3 to 8	>8	Others
Hilly, unirrigated, but terraced	<3	3 to 8	8 to 15	15 to 30	>30
Wetness					
Flooding	Moderate	Strong	Severe	–	–
Drainage class	Imperfect	Moderate, well,	Poor, excessive	Excessive	–
Soil					
Textural class	Silty clay	Silty clay	Loam, silty loam, silt	Silty loam	Silty clay
Silt + clay %	>80	50 to 80	30 to 50	<30	–
Depth (cm)	>80	50 to 80	25 to 50	<25	–
$CaCO_3$ %	3 to 15	15 to 25	25 to 50	50 to 75	–
Gypsum %	0.3 to 2	2 to 5	5 to 10	10 to 25	>25
Stoniness (Volume %)					
Surface	<3	3 to 15	15 to 40	40 to 75	>75
Subsurface	<15	15 to 40	40 to 75	-	-
Soil fertility					
NPK rating	HHH	MMM	MLL	LLL	-
CEC (cmol (p^+) kg^{-1})	>16	16 to 10	10 to 5	<5	-
Base saturation %	>80	80 to 50	0 to 35	<35	-
Soil salinity (1 m soil) dS m^{-1}					
Fine, moderately fine texture with high and brackish ground water (within 1 m)	<2	2 to 4	4 to 8	8 to 15	>15
Coarse, medium textured with low good quality ground water table (below 1 m)	<4	4 to 8	8 to 15	15 to 25	>25
Sodicity (ESP)					
Coarse, medium texture	<15	15 to 25	25 to 40	>40	-
Fine texture	<8	8 to 15	15 to 25	25 to 40	>40

Table 5
Rating criteria for Storie Index

Grade	Percentage	Category
1	80 to 100	Excellent
2	60 to 79	Good
3	40 to 59	Fair
4	20 to 39	Poor
5	10 to 19	Very poor
6	<10	Extremely poor

Table 6
Criteria for Storie Index

Description	Sub-category / Detail	Rating
Profile Characteristics	Soils on recent alluvial plains	100
	Shallow phases 0.6 m deep	50–60
	Shallow phases 0.9 m deep	70
	Extremely gravelly sub soils	80–95
	Stratified clay sub soils	90–95
	Soils on young alluvial flooded plains	50–60
	Shallow phases 0.6 m deep	70
	Shallow phases 0.9 m deep	80–95
	Extremely gravelly sub soils	80–95
	Stratified clay sub soils	90–95
	Soils on older alluvial plains	–
	Shallow phases 0.6 m deep	40–60
	Shallow phases 0.9 m deep	60–90
	Extremely gravelly sub soils	60–90
	Stratified clay sub soils	90–95
	Soils on older plains or terraces	40–80
	Soils on upland over hard rock (less than 0.3 m)	10–30
	0.3 to 0.6 m	30–50
	0.6 to 0.9 m	50–70
	0.9 to 1.2 m	70–80
	1.2 to 1.8 m	80–100
	More than 1.8 m	100
	Soils on upland over soft material (less than 0.3 m)	20–40
	0.3 to 0.6 m	40–60
	0.6 to 0.9 m	60–80
	0.9 to 1.2 m	80–90
	1.2 to 1.8 m	90–100
	More than 1.8 m	100

Table 6 – continue

Description	Sub-category / Detail	Rating
Soil Texture – Medium	Fine sandy loam	100
	Loam	100
	Silt loam	100
	Sandy loam	95
	Silty clay loam – Calcareous	95
	Silty clay loam – Non calcareous	90
	Clay loam – Calcareous	95
	Clay loam – Non calcareous	85–90
Soil Texture –Fine	Silty clay – Highly calcareous	70–90
	Silty clay – Non calcareous	60–70
	Clay – Highly calcareous	70–80
	Clay – Non calcareous	50–70
Soil Texture – Light/Coarse	Coarse sandy loam	90
	Loamy sand	80
	Very fine sand	80
	Fine sand	65
	Sand	60
	Coarse sand	–
Soil Texture – Gravelly	Gravelly fine sandy loam	70–80
	Gravelly loam	60–80
	Gravelly silty loam	60–80
	Gravelly sandy loam	50–70
	Gravelly clay loam	60–80
	Gravelly clay	40–70
	Gravelly sand	–
Soil Texture – Stony	Stony fine sandy loam	70–80
	Stony loam	60–80
	Stony silty loam	60–80
	Stony sandy loam	50–70
	Stony clay loam	50–80
	Stony clay	40–70
	Stony sand	10–40

Table 6 – continue

Description	Sub-category / Detail	Rating
Slope	Nearly level (0–2%)	100
	Gently undulating (0–2%)	95–100
	Gently sloping (3–8%)	85–100
	Undulating (3–8%)	80–95
	Moderately sloping (9–15%)	80–95
	Rolling (9–15%)	80–95
	Strongly sloping (16–30%)	70–80
	Hilly (9–15%)	70–80
	Steep (30–45%)	30–50
	Very steep (45% and over)	5–80
Other – Drainage	Well drained	100
	Fairly well drained	80–90
	Moderately water logged	40–80
	Badly waterlogged	10–40
	Subject to overflow	Variable
Alkali	Alkali free	60–95
	Slightly affected	30–60
	Moderately affected	15–30
	Moderately to strongly affected	5–15
	Strongly affected	–
Nutrient level (Fertility)	High	95–100
	Fair	80–95
	Poor	60–80
	Very poor	40–60
	Acidity	–
Erosion	None to slight	95–100
	Detrimental deposition	75–95
	Moderate sheet erosion	80–95
	Occasional shallow gullies	70–90
	Moderate sheet erosion with shallow gullies	60–80
	Deep gullies	10–70
	Moderate sheet erosion with deep gullies	10–60
	Severe sheet erosion	50–80
	Severe sheet erosion with shallow gullies	40–60
	Severe sheet erosion with deep gullies	10–40
	Very severe erosion	10–40
	Moderate wind erosion	20–60
	Severe wind erosion	80–95
Micro relief	Smooth	100
	Channels	–
	Hog wallows	60–95
	Low hummocks	60–95
	High hummocks	80–95
	Dunes	10–40 / 20–60

3. Results and Discussion

3.1. Differentiation of soil horizons

Horizon boundaries were delineated using a two-meter measuring tape, guided by observable morphological and physical characteristics. Across all three soil profiles, parent material was not encountered, indicating that soil development occurred entirely within Quaternary alluvial deposits. This observation aligns with the District Survey Report for Granite, Coimbatore District (2019), which notes that alluvium in this region, particularly in the Chinnathadagam and Siruvani valleys, can exceed 30 meters in thickness. As a result, no C horizon was present, and the profiles were dominated by surface and subsurface horizons.

According to the morphological features, five distinct genetic horizons were identified down to a depth of 170 cm, classifying the profiles as deep (greater than 100 cm). The surface horizon, designated as Ap, exhibited evidence of anthropogenic disturbance resulting from past plowing. Beneath this, the profile comprised sequential B horizons labelled as Bw, Bwk1, Bwk2, and Bwk3, with horizon designations informed by differences in colour and structure due to pedogenic processes, as per the IUSS Working Group WRB (2022). The 'w' suffix in horizon naming reflects these structural and colour variations, while the 'k' denotes the presence of calcium carbonate accumulations. Diffusely distributed $CaCO_3$ nodules were observed in the Bwk horizons, indicating secondary carbonate enrichment within the subsoil.

3.2. Morphological characteristics of the soil profile

Variation in the distinctness of the horizon boundary was observed across the soil profile. The Ap and Bw horizons exhibited gradual transitions, whereas the boundary at the Bwk1 horizon was clearly defined, consistent with observations reported by Jimenez et al. (2024). In contrast, the Bwk2 and Bwk3 horizons displayed diffuse and less discernible boundaries. These findings align with those of Wang et al. (2015), who noted that horizon topography is often irregular and wavy, except in the Bwk1 horizon, which demonstrated a distinctly wavy demarcation.

The structural grade of the profile also varied by depth. Strong structural development was recorded in the Bw and Bwk1 horizons, while the Bwk2 and Bwk3 horizons were characterized by weaker structures. In terms of particle size distribution, the Bwk1 horizon predominantly contained coarser particles, whereas finer textures were observed in the Ap, Bw, and Bwk2 horizons. Root distribution showed a marked decline with depth; the Ap and Bw horizons harboured more than 40% of the total root biomass, while deeper layers contained less than 20% (Table 7), a trend corroborated by Długosz et al. (2022) in comparable soil profiles. Pore size distribution also varied with depth. The Ap horizon exhibited finer pores, likely due to plowing, higher organic matter content, and finer aggregate formation. In contrast, medium-sized pores were more prevalent in the subsurface horizons, attributed to reduced anthropogenic influence and natural pedogenic development.

Table 7
Morphological characteristics of soil horizons of different soil profiles

Horizon	Depth	Distinctness	Topography	Size of the rock fragments	Grade of Soil	Size of Soil	Roots	Size of Roots	Location of Roots
Profile 1									
Ap	0–20	Gradual	Irregular	Fine gravel	Moderate	Fine	Many	Fine	Throughout
Bw	21–62	Gradual	Irregular	Fine gravel	Moderate	Fine	Common	Medium	Throughout
Bwk1	63–98	Clear	Wavy	Fine gravel	Strong	Very Coarse	Common	Medium	Throughout
Bwk2	99–134	Diffuse	Irregular	Fine gravel	Weak	Fine	Nil	Nil	Nil
Bwk3	135–170	Diffuse	Irregular	Fine gravel	Weak	Medium	Nil	Nil	Nil
Profile 2									
Ap	0–24	Gradual	Irregular	Fine gravel	Moderate	Fine	Many	Fine	Throughout
Bw	25–60	Gradual	Wavy	coarse gravel	Strong	Fine	Common	Medium	Throughout
Bwk1	61–103	Clear	Wavy	Fine gravel	Strong	Very Coarse	Few	Medium	Throughout
Bwk2	104–134	Diffuse	Irregular	Fine gravel	Weak	Fine	Common	Medium	Throughout
Bwk3	135–175	Diffuse	Irregular	Fine gravel	Weak	Medium	Nil	Nil	Nil
Profile 3									
Ap	0–16	Gradual	Irregular	Fine gravel	Moderate	Fine	Many	Fine	Throughout
Bw	17–55	Clear	Wavy	Fine gravel	Moderate	Medium	Many	Medium	Throughout
Bwk1	56–101	Clear	Irregular	coarse gravel	Strong	Very Coarse	Few	Medium	Throughout
Bwk2	102–147	Diffuse	Irregular	Fine gravel	Weak	Medium	Few	Nil	Nil
Bwk3	148–178	Diffuse	Irregular	Fine gravel	Weak	Medium	Nil	Nil	Nil

3.3. Soil physical properties

The physical characteristics of the genetic horizons were described in accordance with the USDA soil description guidelines (Soil Survey Division Staff, 2014). The results of the soil physical properties are summarized in Table 8.

Soil colour showed clear variability across horizons and profiles under both dry and moist conditions. In profile 1, the surface Ap horizon exhibited a dark greyish brown (2.5Y 4/2) in the dry state, transitioning to brown (10YR 5/3) in the Bw3 horizon. Under moist conditions, colours ranged from very dark greyish brown (10YR 3/2) in the Ap horizon to dark brown (10YR 3/3) in the Bwk3 horizon. Similar transitions were observed in profile 2, where the Ap horizon was initially dark brown (10YR 3/3, dry) and then shifted to brown (10YR 2/2) and finally to dark brown (10YR 3/3). In profile 3, the Ap horizon began as dark greyish brown (10YR 4/2, dry) and gradually changed to brown (10YR 5/3) in the Bwk3 horizon. Moist colour transitions in this profile followed a similar trend. These colour patterns reflect differences in organic matter distribution and horizon development, consistent with the findings by Yang et al. (2022).

Calcium carbonate nodules were detected in the Bwk horizons across all three profiles. Free $CaCO_3$ content ranged from 0.48–0.52% in the Ap horizons to 15–16% in the Bwk2 horizons, with slightly reduced values in the Bwk3 horizons (12–13%). The pedogenic formation of $CaCO_3$ occurs through the dissolution of CO_2 and alkaline earth-bearing minerals, the movement of dissolved calcium ions with percolating water, and the subsequent precipitation of carbonates under favourable geochemical conditions (Zamanian et al., 2016). Depending on the direction of soil water movement, carbonate accumulation can occur via perdescendum (downward movement), perascendum (capillary rise), in-situ precipitation, or biologically mediated pathways (Chendev et al., 2014; Wang et al., 2015; Khalidy et al., 2022; Durand et al., 2018). Effervescence testing with 1:1 HCl indicated strong reactions in the Bw, Bwk1, and Bwk3 horizons, and violent effervescence in the Bwk2 horizon in all the profiles, suggesting elevated carbonate content. However, the presence of $CaCO_3$ did not alter the mineralogical composition of the clay, which remained a consistent mixture, as also reported by Kowalska et al. (2021).

Soil texture varied distinctly among the horizons. Across the three profiles, most horizons showed the same texture, except for the Bwk1 horizon in profile 2, which was classified as silty clay loam, while the others were clay loam. Sandy clay loam occurred in the Ap and Bw horizons, whereas the Bwk2 and Bwk3 horizons were characterized as silt loam. With increasing depth, the contents of sand and silt gradually decreased, while the clay content remained relatively uniform. Slightly higher clay concentrations were observed in the Bw and Bwk1 horizons, resulting in a denser texture. These patterns align with the observations of Weerasekara et al. (2024), who noted maximum clay accumulation in the B horizons.

Soil structural types also varied with depth. In profile 1, the Ap and Bw horizons displayed angular to sub-angular blocky structures, while the Bwk1 horizon showed massive

Table 8
Physical properties of soil horizons of different soil profiles

Horizon	Depth	Soil Colour (Dry)	Soil Colour (Moist)	Soil structure	Soil Textural Class	Bulk Density ($Mg\ m^{-3}$)	Particle Density ($Mg\ m^{-3}$)	Pore Space (%)	Free $CaCO_3$ (%)	Effervescence
Profile 1										
Ap	0–20	Dark greyish brown (2.5Y 4/2)	Very dark greyish brown (10YR 3/2)	Angular blocky	Sandy clay loam	1.27	2.87	55.7	0.52	Slight
Bw	21–62	Very dark greyish brown (2.5Y 3/2)	Very dark greyish brown (10YR 3/2)	Sub angular blocky	Sandy clay loam	1.20	2.48	51.6	1.48	Strong
Bwk1	63–98	Very dark brown (7.5YR 2.5/2)	Very dark greyish brown (2.5Y 3/2)	Massive	Clay loam	1.05	2.31	54.5	4.70	Strong
Bwk2	99–134	Olive brown (2.5Y 4/4)	Olive brown (2.5Y 4/4)	Single grain	Silt loam	1.08	2.47	56.2	15.5	Violent
Bwk3	135–170	Brown (10YR 5/3)	Dark Brown (10YR 3/3)	Angular blocky	Silt loam	1.10	2.76	60.1	12.9	Strong
Profile 2										
Ap	0–24	Dark brown (10YR 3/3)	Very dark brown (10YR 2/2)	Angular blocky	Sandy clay loam	1.16	2.64	56.0	0.48	Slight
Bw	25–60	Very dark greyish brown (2.5Y 3/2)	Dark greyish brown (10YR 3/3)	Angular blocky	Sandy clay loam	1.28	2.53	49.4	1.52	Strong
Bwk1	61–103	Dark brown (7.5YR 3/2)	Very dark brown (7.5YR 2.5/2)	Granular	Silty clay loam	1.02	2.22	54.0	4.46	Strong
Bwk2	104–134	Olive brown (2.5Y 4/4)	Olive brown (2.5Y 4/4)	Single grain	Silt loam	1.14	2.52	54.7	15.6	Violent
Bwk3	135–175	Brown (10YR 5/3)	Dark Brown (10YR 3/3)	Angular blocky	Silt loam	1.07	2.71	60.5	13.0	Strong
Profile 3										
Ap	0–16	Dark greyish brown (10YR 4/2)	Very dark greyish brown (10YR 3/2)	Angular blocky	Sandy clay loam	1.24	2.59	52.1	0.51	Slight
Bw	17–55	Very dark brown (7.5YR 2.5/2)	Very dark brown (7.5YR 2.5/2)	Sub angular blocky	Sandy clay loam	1.19	2.50	52.4	1.51	Strong
Bwk1	56–101	Very dark brown (7.5YR 2.5/2)	Very dark brown (7.5YR 2.5/2)	Massive	Clay loam	1.06	2.38	55.4	4.35	Strong
Bwk2	102–147	Dark Brown (10YR 3/3)	Dark Brown (10YR 3/3)	Granular	Silt loam	1.21	2.69	55.0	15.3	Violent
Bwk3	148–178	Brown (10YR 5/3)	Dark Brown (10YR 3/3)	Angular blocky	Silt loam	1.10	2.81	60.8	13.0	Strong

structure, the Bwk2 horizon was single grain, and the Bwk3 horizon reverted to angular blocky. Profile 2 displayed similar trends, but with a granular structure in Bwk1, instead of massive, followed by a single grain in Bwk2 and an angular blocky structure in Bwk3. Profile 3 also maintained the same structures in the Ap and Bw horizons as profile 1, with massive structures in Bwk1, granular structures in Bwk2, and angular blocky structures in Bwk3. Overall, while Ap and Bw horizons were consistently angular to subangular blocky across profiles, variations were observed in Bwk1, indicating the influence of carbonate accumulations. These results align with the findings of Warhade et al. (2022).

Bulk density and particle density values were within the expected range. Across the three profiles, bulk density ranged between 1.02 Mg m^{-3} (Bwk1 in profile 2) and 1.28 Mg m^{-3} (Bw in profile 2). Particle density values ranged from 2.22 Mg m^{-3} (Bwk1 in profile 2) and 2.87 Mg m^{-3} (Ap in profile 1). Pore space varied between 49.4% (Bw in profile 2) and 60.8% (Bwk3 in profile 3) (Fig. 3). These results indicate compaction in Bw horizons and relatively greater porosity in deeper silt loam horizons. Overall, the profile showed uniform physical properties, indicating consistent pedogenic processes throughout the soil profiles.

3.4. Soil chemical properties

The chemical properties of the soil profile are presented in Table 9. Soil pH ranged from 7.95 to 9.15 across the horizons, indicating slightly to moderately alkaline conditions. The lowest pH (7.95) was observed in the Ap horizon of profile 3, while the highest (9.15) occurred in the Bwk3 horizon of profile 2. In all profiles, pH increased with depth, particularly in the carbonate-enriched Bwk horizons due to the presence of free $CaCO_3$ in subsoil layers, which reacts with water and carbon dioxide to produce bicarbonate, thereby increasing alkalinity. These findings are similar to those of Sujatha et al. (2021), who reported slightly alkaline pH values in the Bwk and Bwk1 horizons of soils from the Pinneru river basin in Andhra Pradesh. Lower pH values were noted in horizons lacking calcium carbonate.

Electrical conductivity (EC) values were low to moderate (0.11 to 0.47 dS m^{-1}) across profiles, indicating negligible salinity hazard. The maximum EC (0.47 dS m^{-1}) was recorded in the Bwk3 horizon of profile 2. In profiles 1 and 3, EC values generally increased with depth; however, in profile 1, the Ap horizon showed a relatively higher EC, followed by a decline. These trends are consistent with the findings of Jimenez et al. (2024). Overall, the values indicate low salinity throughout the profile, suggesting minimal accumulation of soluble salts.

Available nitrogen ranged from 368.4 to 485.1 kg ha^{-1} across the profiles. Profile 2 exhibited the lowest surface N (368.4 kg ha^{-1}), while profile 3 had the highest subsurface value (485.1 kg ha^{-1}) in the Bwk2 horizon. A general increase in N with depth was noted in all profiles, contrasting with the decline of other nutrients. Available phosphorus showed a decreasing trend with depth in all profiles, ranging from 53.7 kg ha^{-1} in the Ap horizon of profile 3 to as low as 7.2 kg ha^{-1} in the Bwk1 horizon of profile 1. Profile 1 consistently had the lowest P in subsurface layers, while profile 3 maintained relatively higher surface concentrations. A similar depth-wise declining pattern was observed for available potassium (K), the highest available K (656.9 kg ha^{-1}) was observed in the Ap horizon of profile 3, whereas the lowest (84.0 kg ha^{-1}) occurred in the Bwk1 horizon of the same profile. In all three profiles, available K was concentrated in the surface and dropped significantly in deeper horizons (Fig. 4). These trends align with the findings of Sujatha et al. (2021), who reported that available P and K are typically concentrated in surface horizons and decline with depth.

Total organic carbon content declined markedly with depth in all profiles (Fig. 5). Surface Ap horizons recorded the highest OC content (7.6–8.8 g kg^{-1}), while subsurface Bwk1 horizons had the lowest (5.3–7.1 g kg^{-1}), and Bwk2 and Bwk3 horizons

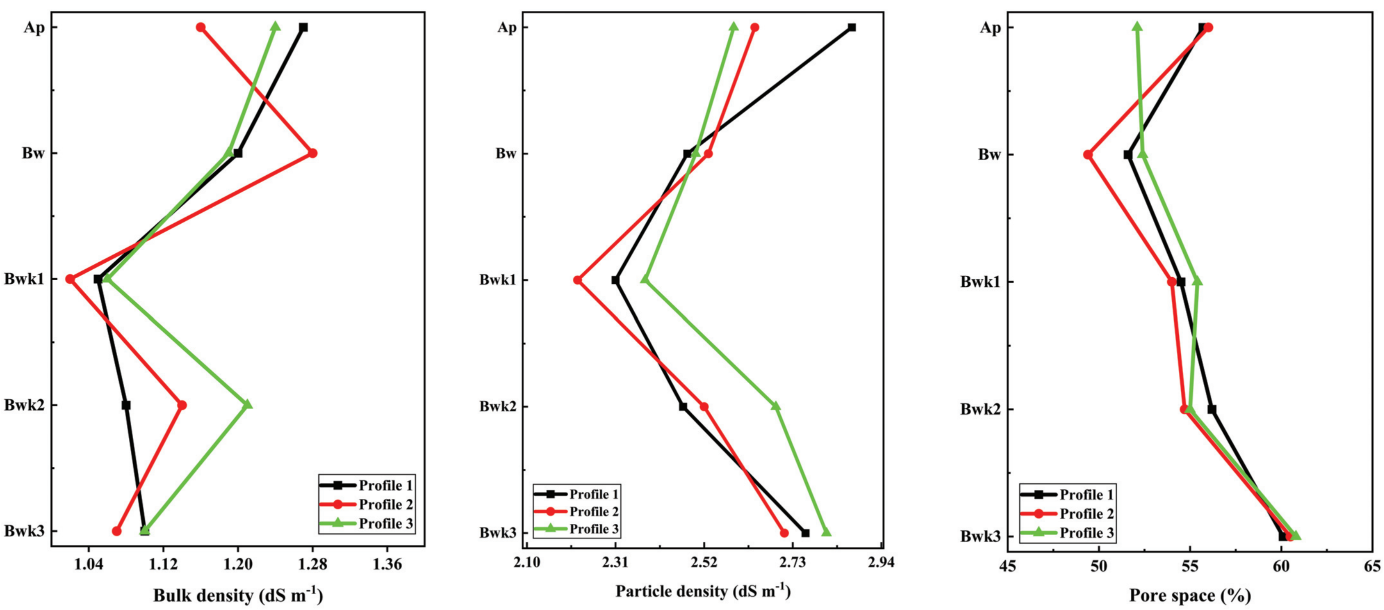


Fig. 3. Status of physical properties of soil horizons of different soil profiles

Table 9
Chemical properties of soil horizons of different soil profiles

Horizon	Depth	pH	EC (d Sm⁻¹)	N (kg ha⁻¹)	P (kg ha⁻¹)	K (kg ha⁻¹)	OC (g kg⁻¹)	Ca (Cmol (P⁺) kg⁻¹)	Mg	Na	Ex. K	BS (%)	CEC (Cmol (P⁺) kg⁻¹)
Profile 1													
Ap	0–20	8.25	0.11	380.3	53.2	568.2	8.22	4.46	1.72	0.11	0.69	62.3	11.2
Bw	21–62	8.41	0.14	399.4	21.3	249.3	8.18	6.07	2.61	0.15	0.91	77.3	12.6
Bwk1	63–98	8.74	0.17	427.3	7.21	84.60	5.26	7.14	2.38	0.42	0.65	59.2	17.9
Bwk2	99–134	9.01	0.27	467.9	15.2	141.2	7.67	12.0	3.22	0.75	0.30	93.5	17.4
Bwk3	135–170	9.09	0.30	462.2	11.5	131.1	7.74	11.0	2.84	0.92	0.28	85.9	17.5
Profile 2													
Ap	0–24	8.64	0.38	368.4	40.6	468.3	7.59	5.39	2.17	0.26	0.72	66.7	12.8
Bw	25–60	8.26	0.27	378.6	27.3	226.0	8.24	7.17	2.39	0.48	0.83	74.5	14.6
Bwk1	61–103	8.64	0.29	416.8	14.2	116.3	7.06	9.38	3.17	0.59	0.72	75.7	18.3
Bwk2	104–134	8.78	0.38	446.3	9.05	163.9	8.11	13.8	3.98	0.81	0.46	110.8	17.2
Bwk3	135–175	9.15	0.47	471.2	12.3	148.0	8.39	13.4	2.72	0.86	0.15	101.4	16.9
Profile 3													
Ap	0–16	7.95	0.13	399.1	57.3	656.9	8.79	3.05	1.12	0.17	0.79	47.9	10.7
Bw	17–55	8.90	0.17	412.3	19.7	288.3	8.16	4.53	3.13	0.32	0.90	74.6	11.9
Bwk1	56–101	8.66	0.26	433.5	7.80	84.00	5.36	7.12	2.29	0.40	0.64	60.1	17.4
Bwk2	102–147	9.04	0.27	485.1	16.2	130.5	7.63	11.0	2.17	0.79	0.30	79.2	18.0
Bwk3	148–178	8.93	0.34	463.6	11.9	136.7	7.66	10.5	2.98	0.93	0.37	83.5	17.7

exhibited moderate OC levels. Profile 3 had the highest surface OC (8.79 g kg⁻¹). The higher OC concentration in surface horizons is attributed to the accumulation of plant residues, organic amendments, and microbial activity. The moderate OC levels in subsurface layers may result from the downward movement of organic matter through bioturbation and pedogenic processes. Similar vertical OC trends were observed by Kome et al. (2021), who reported a decrease in total organic carbon content with depth, attributed to reduced organic input in lower layers.

Exchangeable calcium (Ca^{2+}) concentrations ranged from 3.05 to 13.8 cmol (P^+) kg⁻¹, with values generally increasing in subsurface horizons. Profile 2 recorded the highest Ca^{2+} concentration (13.8 cmol (P^+) kg⁻¹) in the Bwk2 horizon, while the lowest was noted in the Ap horizon of profile 3. This trend suggests

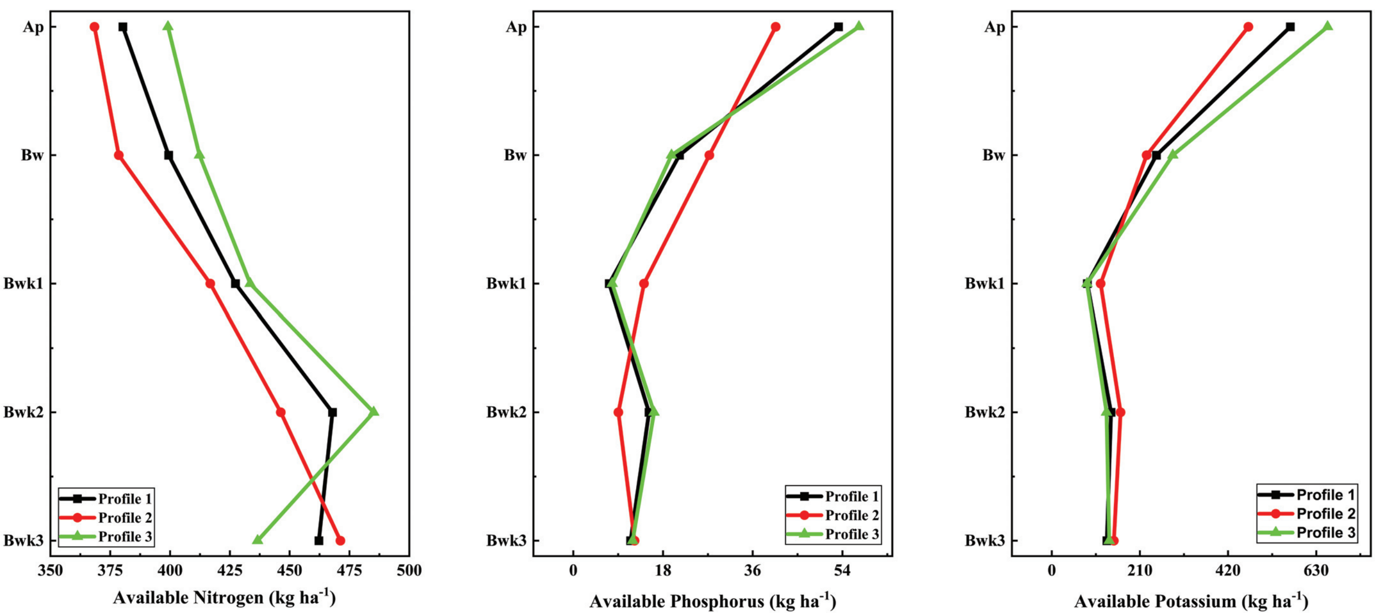


Fig. 4. Status of available nitrogen, phosphorus, and potassium in soil horizons of different soil profiles

downward leaching and accumulation of calcium carbonate in lower horizons, as supported by morphological observations of CaCO3 nodules in the Bwk2 and Bwk3 horizons, which are consistent with Khalidy et al. (2022). Exchangeable magnesium (Mg^{2+}) varied from 1.12 to 3.98 cmol (P^+) kg^{-1}, with the highest values in the Bwk1, Bwk2, and Bwk3 horizons, whereas the surface Ap horizons recorded the lowest Mg^{2+} values across the profiles. Values below 2 cmol (P^+) kg^{-1} may limit the growth of magnesium-demanding crops. The increase in Mg^{2+} mirrored the trend in Ca^{2+}, reflecting their shared geochemical behaviour.

Exchangeable sodium (Na^+) increased with depth across all profiles, ranging from 0.11 in to 0.93 cmol (P^+) kg^{-1} in Ap and Bwk3 horizons, respectively. These values are low and do not pose sodicity risks. Exchangeable potassium (K^+) declined with depth, ranging from 0.91 cmol (P^+) kg^{-1} in the Bw horizon to 0.15 cmol (P^+) kg^{-1} in the Bwk3 horizon, consistent with the findings of Alaboz et al. (2022). Across the profiles, sodium (Na^+) content showed an increasing trend, whereas potassium (K^+) exhibited a decreasing trend. Adequate K^+ in surface layers supports crop growth, while lower levels in subsoil may limit nutrient uptake by deep-rooted crops.

Cation exchange capacity (CEC) values ranged from 10.7 to 18.3 cmol (P^+) kg^{-1}. Higher CEC was observed in the Bwk1, Bwk2, and Bwk3 horizons (> 15 cmol (P^+) kg^{-1}), while the Ap and Bw horizons recorded lower values (< 15 cmol (P^+) kg^{-1}). This is due to increased clay content (Ayam et al., 2020) in the subsurface horizons, which might have contributed to the higher CEC values. Base Saturation (BS) ranged from 47.9% in the Ap horizon of profile 3 to 110.8% in the Bwk2 horizon of profile 2. Profiles 2 and 3 generally exhibited higher BS values in subsurface horizons (Bwk2 and Bwk3) (Fig. 5). Surwase et al. (2023) noted that soils in lowland plains often show higher base saturation compared to those in escarpments, which supports the elevated BS observed in the Siruvani foothill soils. Overall, the combination of higher CEC and BS in lower horizons suggests improved fertility status at depth in this profile.

3.5. Derived soil chemical properties

The derived chemical properties of three soil profiles are presented in Table 10. A progressive increase in sodicity with depth was observed across all profiles, as indicated by the rising Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR). In general, surface horizons (Ap) of all profiles exhibited low ESP (< 2.1) and moderate SAR (6.3–13.4), suggesting minimal sodicity hazard and favourable conditions for crop growth. However, deeper horizons, particularly the Bwk2 and Bwk3, showed marked increases in sodicity. In profile 1, ESP increased from 0.98 in the Ap horizon to 5.26 in the Bwk3 horizon, while SAR rose from 6.26 to 35.0. A similar pattern was noted in profile 2, where ESP rose from 2.03 in the surface to 5.09 in the Bwk3 horizon, accompanied by SAR values increasing from 13.4 to 30.3. The highest sodicity was recorded in profile 3, where ESP reached 5.25, and SAR peaked at 35.8 in the Bwk3 horizon. These results confirm the tendency of sodium accumulation in deeper horizons, consistent with the findings of Warhade et al. (2022).

The marked elevation in ESP and SAR with depth suggests that the lower horizons are becoming increasingly sodic. Excess sodium in these layers may degrade soil permeability, hinder root water uptake, and reduce nutrient availability, particularly affecting deep-rooted crops. Changes in the Sodium Ratio (NaR) and Magnesium Adsorption Ratio (MAR) further reflect shifts in soil chemistry that may influence both plant health and structural stability. Sodium ratio values were low across all profiles (0.07), though a gradual increase with depth was evident. In profile 1, NaR rose from 0.02 in the Ap horizon to 0.07 in the Bwk3 horizon, whereas in profiles 2 and 3, NaR values remained moderate but consistently higher in subsoil horizons (0.05–0.07). The

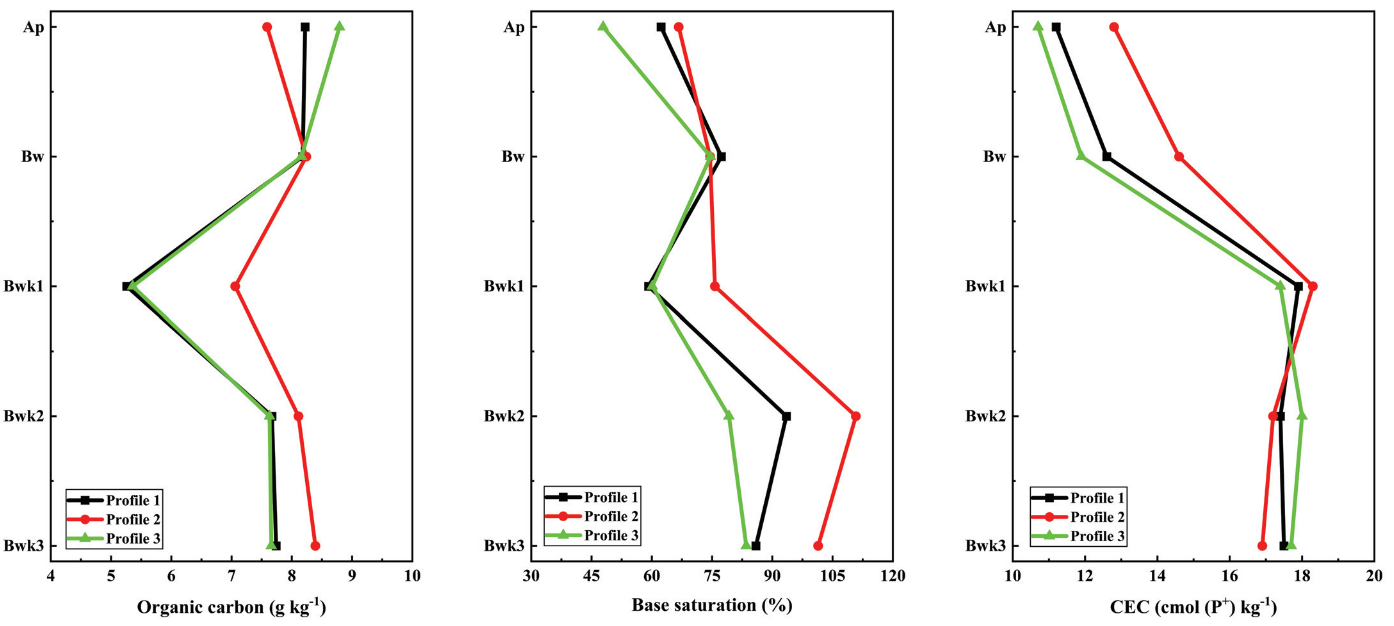


Fig. 5. Status of Total organic carbon, base saturation, and cation exchange capacity of soil horizons of different soil profiles

Table 10
Derived chemical parameters of Soil horizons of different soil profiles

Horizon	Depth	ESP (%)	SAR	SSP (%)	Sodium Ratio	Magnesium Adsorption Ratio	Total cations	TSS (mg L^{-1})	TDS (mg L^{-1})
Profile 1									
Ap	0–20	0.98	6.26	1.58	0.02	0.28	1.1	70	172
Bw	21–62	1.19	7.20	1.54	0.02	0.30	1.4	90	219
Bwk1	63–98	2.35	19.3	3.97	0.04	0.25	1.7	109	266
Bwk2	99–134	4.31	27.2	4.61	0.05	0.21	2.7	173	422
Bwk3	135–170	5.26	35.0	6.12	0.07	0.21	3.0	192	469
Profile 2									
Ap	0–24	2.03	13.4	3.04	0.03	0.29	3.8	243	594
Bw	25–60	3.29	22.0	4.42	0.05	0.25	2.7	173	422
Bwk1	61–103	3.22	23.6	4.26	0.05	0.25	2.9	186	453
Bwk2	104–134	4.71	27.2	4.25	0.05	0.22	3.8	243	594
Bwk3	135–175	5.09	30.3	5.02	0.05	0.17	4.7	301	734
Profile 3									
Ap	0–16	1.59	11.8	3.31	0.04	0.27	1.3	83	203
Bw	17–55	2.69	16.4	3.60	0.04	0.41	1.7	109	266
Bwk1	56–101	2.30	18.4	3.83	0.04	0.24	2.6	166	406
Bwk2	102–147	4.39	30.8	5.54	0.06	0.16	2.7	173	422
Bwk3	148–178	5.25	35.8	6.29	0.07	0.22	3.4	218	531

Magnesium Adsorption Ratio (MAR) varied inversely, with relatively higher values in surface horizons (0.28–0.41) and lower values in deeper horizons (<0.22). Notably, profile 3 exhibited the highest MAR in the Bw horizon (0.41), reflecting enhanced magnesium dominance, while profiles 1 and 2 showed steady declines with depth. This inverse relationship between NaR and MAR highlights the gradual shift from magnesium dominance in the surface to sodium dominance at depth, with potential implications for soil aggregation and nutrient availability.

Salinity indicators, including total soluble salts (TSS), total dissolved salts (TDS), and total cations, also increased consistently with depth in all profiles. In profile 1, TDS increased from 172 mg L^{-1} in the Ap horizon to 469 mg L^{-1} in the Bwk3 horizon, while total cations rose from 1.1 to 3.0 cmol (P$^+$) kg^{-1}. In profile 2, significantly higher values were recorded, with TDS reaching 734 mg L^{-1} in the Bwk3 horizon and total cations peaking at 4.7 cmol (P+) kg^{-1}, indicating substantial salt accumulation. Profile 3 displayed intermediate values, with TDS increasing from 203 mg L^{-1} in the surface to 531 mg L^{-1} in the Bwk3 horizon. And total cations rising from 1.3 to 3.4 cmol (P$^+$) kg^{-1}. The higher TSS and TDS values in profile 2 suggest salt enrichment, which may limit plant-available water and impose salinity stress on crops, compared to the relatively lower salt load in profiles 1 and 3.

3.6. Soil classification

According to the USDA Soil Taxonomy, the soil is classified based on several key factors, including texture, mineralogy, temperature, and moisture regimes, as well as calcium carbonate accumulation. Based on analytical data and field observations of three soil profiles, the particle size analysis confirms a loamy texture, characterized by adequate proportions of fine particles, including silt and clay. Since no single mineral type dominates the composition, the soil falls under the category of mixed mineralogy.

The mean annual soil temperature in the Siruvani foothills consistently exceeds 22°C, with seasonal variations of less than 6°C between summer and winter. This places the soil within the isohyperthermic temperature regime. The soil profile exhibits limited horizon development, lacking C and R horizons, and features significant calcium carbonate accumulation, including visible $CaCO_3$ nodules. These characteristics are typical of soils formed in semi-arid to sub-humid tropical regions under an ustic moisture regime.

Taken together, these features support classification within the Inceptisol order, specifically the Calciustept suborder. Therefore, the complete taxonomic classification is Fine-loamy, mixed, isohyperthermic, Typic Calciustept.

According to the IUSS Working Group World Reference Base for Soil Resources (WRB), the soil is classified as a Calcic Cambisol (Loamic). Here, Calcic is the principal qualifier, indicating the presence of a calcic horizon with notable accumulation of calcium carbonate. Cambisol is the Reference Soil Group (RSG), describing soils with weakly developed horizons, and loamic is a supplementary qualifier that provides additional information about the soil's loamy texture.

3.6.1. Land capability classification (LCC)

Based on the land capability classification, the three profiles exhibit predominantly favourable conditions for agricultural use (Table 11). All profiles exhibit gently sloping land (class II), slight erosion (class II), well-drained soils (class I), a loamy texture (class I), and adequate profile depth (>170 cm, class I), which collectively support good root penetration and water retention. Flooding is a common constraint across the profiles, rated as class IV, requiring attention to drainage management.

Permeability and infiltration rates are classified as class II, reflecting moderate but manageable conditions for water movement. Chemical properties exhibit moderate limitations: the cation exchange capacity (CEC) is consistently classified as class III across the profiles, while total organic carbon ranges between classes II and III, and base saturation (BS) varies from classes II to III. Electrical conductivity (EC) values are favourable (class I), indicating no salinity hazard. Despite these constraints, the majority of the soil characteristics support a Class II rating overall, which corresponds to cultivable land on nearly level or gently sloping terrain. Although certain limitations may influence crop selection or require conservation measures, the land holds strong potential for sustainable agricultural productivity.

3.6.2. Land suitability classification (LSC)

The Land Suitability Classification (LSC) of the three profiles indicates that the land is moderately to highly suitable for agriculture, though certain limitations must be addressed (Table 12). The annual rainfall of 730 mm is categorized as N1, signifying that it is inadequate for rainfed cultivation, and thus irrigation is essential for reliable crop production. The topography, characterized by a gentle slope of 1–3%, is classified as S2, indicating moderate suitability. It poses minimal erosion risk and is manageable for cultivation. Flooding, rated as S1, indicates that the area is suitable for farming, provided that effective drainage systems are in place to manage occasional water accumulation. Similarly, soil drainage falls under S2, indicating moderate suitability, with some areas potentially requiring improved drainage infrastructure to prevent waterlogging.

The loamy soil texture in all three profiles is rated S3, meaning it is marginally suitable while loamy soils are generally advantageous, they may need soil amendments to enhance fertility and structure over time. In contrast, the soil depth of 170 cm or more is rated S1 in all three profiles, indicating excellent suitability and offering ample depth for root development. The calcium carbonate and gypsum content are consistently rated S1 in all profiles, suggesting no significant limitations. Stoniness, both surface (4–6) and subsurface (15–19), is rated S2, indicating moderate limitations, as excessive stones may hinder tillage and root development.

Nutrient availability (N, P, K) places all profiles in S2, reflecting moderate fertility. Profile 3, however, shows slightly higher phosphorus content (22.5 kg ha^{-1}) compared to the others. Cation Exchange Capacity (15.1–15.9 cmol (P^+) kg^{-1}) is consistently rated S2, while Base Saturation shows variation: Profile 2 is S1 (85.8%), whereas Profiles 1 (75.6%) and 3 (69.0%) fall under S2, reflecting a moderate nutrient holding capacity and suggesting the need for occasional nutrient supplementation. Electrical conductivity values (0.19–0.35 dS m^{-1}) are uniformly rated S1, indicating no salinity hazard. Similarly, ESP values (2.81–3.66%) are rated S1, confirming that salinity and sodicity are not limiting factors, thus making the land suitable for most crops.

Overall, the majority of the land characteristics of three profiles are moderately suitable for agriculture (S2), indicating minor constraints that may reduce productivity unless managed properly. As emphasized by Vasu et al. (2018), with proper irrigation, balanced fertilization, and ongoing soil improvement practices, the land holds strong potential for sustainable agriculture.

Table 11
Land Capability Classification (LCC) of the soil parameters of different soil profiles

		Profile 1		Profile 2		Profile 3	
S.No	Characteristics	Result	Class	Result	Class	Result	Class
1.	Slope (%)	2	II	2	II	2	II
2	Erosion	Slight	II	Slight	II	Slight	II
3.	Flooding	Moderate	IV	Moderate	IV	Moderate	IV
4.	Drainage	Well drainage	I	Well drainage	I	Well drainage	I
5.	Permeability	Moderately rapid	II	Moderately rapid	II	Moderately rapid	II
6.	Infiltration (cm hr^{-1})	1.5	II	1.8	II	1.6	II
7.	Texture	Loamy	I	Loamy	I	Loamy	I
8.	Depth (cm)	170	I	175	I	178	I
9.	CEC (Cmol (p^+) kg^{-1})	15.3	III	15.9	III	15.1	III
10.	OC (g kg^{-1})	7.41	III	7.87	II	7.52	II
11.	BS (%)	75.6	III	85.8	II	69.0	III
12.	EC (dS m^{-1})	0.19	I	0.35	I	0.23	□

Table 12
Land Suitability Classification (LSC) of the soil parameters of different soil profiles

S.No	Characteristics	Profile 1	Class	Profile 2	Class	Profile 3	Class
1.	Rainfall (mm)	730	N_1	730	N_1	730	N_1
2	Topography (%)	1 to 3	S_2	1 to 3	S_2	1 to 3	S_2
3.	Flooding	Moderate	S_1	Moderate	S_1	Moderate	S_1
4.	Drainage	Moderate	S_2	Moderate	S_2	Moderate	S_2
5.	Texture	Loamy	S_3	Loamy	S_3	Loamy	S_3
6.	Soil Depth (cm)	170	S_1	175	S_1	178	S_1
7.	$CaCO_3$ (%)	6.9	S_1	8.2	S_1	5.1	S_1
8.	Gypsum (%)	1.0	S_1	1.2	S_1	1.2	S_1
9.	Stoniness (Surface) Stoniness (Subsurface)	4 15	S_2 S_2	6 16	S_2 S_2	4 19	S_2 S_2
10.	Available N (kg ha^{-1}) Available P (kg ha^{-1}) Available K (kg ha^{-1})	427.4 (Medium) 21.6 (Medium) 234.8 (Medium)	S_2	416.2 (Medium) 20.6 (Medium) 224.5 (Medium)	S_2	433.3 (Medium) 22.5 (High) 259.2 (Medium)	S_2
11.	CEC (Cmol (p^+) kg^{-1})	15.3	S_2	15.9	S_2	15.1	S_2
12.	BS (%)	75.6	S_2	85.8	S_1	69.0	S_2
13.	EC (dS m^{-1})	0.19	S_1	0.35	S_1	0.23	S_1
14.	ESP (%)	2.81	S_1	3.66	S_1	3.24	S_1

3.6.3. Storie index (SI)

The Storie Index, a quantitative measure of land productivity, assigns high scores (≥ 90) for slope, soil fertility, and micro-relief across all profiles, highlighting the land's strong potential for agricultural use (Table 13). Moderate scores for erosion (90) and soil profile (80) suggest some risks and opportunities for improvement in these areas. Based on the evaluation, the soils in the study area recorded Storie Index values of 61.7% for profile 1, 59.0% for profile 2, and 65.8% for profile 3, with an overall score of 62.2%, which reflects a high agricultural potential (good: 60–79). To fully realize this potential and support sustainable long-term cultivation, minor management interventions such as erosion control, drainage improvements, supplemental irrigation, and nutrient management are recommended.

Table 13
The Storie Index (SI) of the soil parameters of different soil profiles

Characteristics	Rating (Out of 100)		
	Profile 1	Profile 2	Profile 3
Profile	80	85	85
Texture	95	95	95
Slope	100	100	100
Alkali	95	95	95
Fertility	90	90	95
Erosion	95	95	95
Micro relief	100	90	95

Storie Index:

Profile 1 = (80/100) × (95/100) × (100/100) × (95/100) × (90/100) × × (95/100) × (100/100) × 100 = 61.7%

Profile 2 = (85/100) × (95/100) × (100/100) × (95/100) × (90/100) × × (95/100) × (90/100) × 100 = 59.0%

Profile 3 = (85/100) × (95/100) × (100/100) × (95/100) × (95/100) × × (95/100) × (95/100) × 100 = 65.8%

4. Conclusions

The study of the soil profiles from the Siruvani foothills of the Coimbatore district revealed distinct morphological, physical, and chemical characteristics influenced by the region's topography, parent material, and semi-arid climatic conditions. The soils exhibited a weakly developed horizon sequence (Ap–Bw–Bwk), light yellowish-brown coloration, moderate structure, and coarse texture, indicating moderate pedogenic development. The particle size analysis confirmed the dominance of sandy loam textures in the surfaces and silty loam at depth, contributing to high drainage potential and low water-holding capacity. The soil pH ranged from slightly to moderately alkaline, accompanied by an increase in electrical conductivity and calcium carbonate content with depth, suggesting limited leaching and calcic accumulation. Total organic carbon and available N, P, K were medium in fertility, indicating a need for soil fertility enhancement strategies. From the land evaluation perspective, Land Capability Classification (LCC) falls under class II, indicates minor limitations related to slope and nutrient availability. Land Suitability Classification

(LSC) ranks them in the moderately suitable (S2) category due to constraints in moisture and fertility. The Storie Index (SI), places them in a "good" category for productive agriculture. Overall, the study emphasizes the importance of site-specific soil assessment for land use planning and sustainable soil management in the Siruvani foothills. These findings provide a scientific basis for enhancing nutrient management and guiding future soil conservation efforts in the region.

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Conflict of Interest

The authors declared that there is no conflict of interest.

Author Contributions

Balaganesh Balashanmugavel – Conceptualization, Investigation, Methodology, Supervision, Writing – review and editing. **Kamalakannan Sendilkumar** – Funding acquisition, Investigation, Visualization, Writing original draft. Both authors read and approved the final manuscript.

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