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Characterization and classification of soils from Bankanahalli micro-watershed in the semi-arid tropics of Karnataka

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Abstract

A comprehensive soil resource inventory was conducted in the Bankanahalli micro-watershed of Mandya district, Karnataka, to characterize, classify, and evaluate soils across distinct agro-climatic and topographic gradients. The micro-watershed, situated in the semi-arid tropics, presents diverse pedogenic formations primarily derived from granitic gneiss. Nine pedons representing varied landscape positions (upland, mid-land, and lowland) were evaluated for their morphological, physical, and chemical properties. The findings revealed that soil depth, texture, and structural development are heavily governed by micro-relief. Upland soils (Chikkasavanur and Hatti series) were shallow to moderately shallow, exhibiting coarse textures (sandy loam to loamy sand) with high permeability but severely restricted moisture retention. Conversely, sub-surface layers in mid-land and lowland areas demonstrated advanced pedogenesis with well-developed argillic (Bt) horizons marked by pronounced clay illuviation, frequently exceeding 40% clay. Chemically, the soils proved to be non-saline, with soil reaction spanning from slightly acidic (pH 5.41) in specific surface horizons to strongly alkaline (pH 10.43) in deeper layers, a consequence of subsurface carbonate accumulation. Organic carbon was highest in the surface epipedons (up to 0.84%) but depleted rapidly with depth, reflecting the intense oxidation prevalent in semi-arid environments. Based on pedogenic development and analytical data, the soils were classified into *Alfisols* (*Typic Rhodustalfs*, *Rhodic Paleustalfs*, *Typic Paleustalfs*, *Typic Haplustalfs*) and *Inceptisols* (*Typic Haplustepts*). The study emphasizes the critical role of topography in semi-arid pedogenesis and provides a foundational land resource inventory to guide site-specific, climate-resilient agronomic interventions.

Keywords: Soil characterization, micro-watershed

1. Introduction

To enhance or at least maintain the present level of agricultural productivity, the management of land resources on scientific principles is paramount. Soil resource inventory provides the indispensable information required to understand the potential and limitations of land relative to optimum utilization. This requires a profound understanding of the properties and pedogenic processes of different soils in a given area, allowing for accurate mapping, characterization, and the implementation of sustainable management practices.

The study of soils within a micro-watershed framework has been increasingly adopted, as it encapsulates the diverse soil formations driven by local topographic and hydrological variations (Bhattacharyya *et al.*, 2024) ^[1]. In semi-arid tropical regions, the interplay of erratic rainfall, frequent droughts, and varying degrees of land degradation poses severe challenges to agricultural sustainability. The Bankanahalli micro-watershed, located in the Mandya district of Karnataka, presents a quintessential semi-arid landscape characterized by undulating topography and a mix of rainfed and protective irrigation agricultural systems. Topography significantly influences soil depth, drainage, and texture. Shallower, eroded soils typically dominate uplands, while deeper, fine-textured soils accumulate in valleys due to prolonged deposition and pedogenesis. Previous studies in similar landscapes across Karnataka have demonstrated the profound impact of agro-climatic zones and relief on soil morphology, fertility gradients, and taxonomic classification (Prabhavati *et al.*, 2017; Prathibha *et al.*, 2018; Patil *et al.*, 2017b) ^[9, 10, 7].

Therefore, this study was undertaken to systematically characterize and classify the soils of the Bankanahalli micro-watershed across its toposequence. The resulting physical and chemical data are critical for devising effective, climate-resilient soil and water conservation strategies and ensuring sustainable agricultural intensification.

2. Materials and Methods

2.1 Site Description

The Bankanahalli micro-watershed is situated between 12° 35' 6.86" to 12° 36' 56.68" N latitude and 76° 45' 13.14" to 76° 46'

23.72" E longitude, covering a geographic area of 489 hectares. It spans multiple villages including Gerahalli, Bevakallu, Billenahalli, Bankanahalli, Kulikoppalu, Nallahalli, and Hulikere within the Mandya district of Karnataka, India. The area falls under the Agro Ecological Sub Region (AESR) 8.2, characterized as a hot, moist, semi-arid eco-sub region within the southern plateau and hill region. It is categorized under Agro-climatic Zone 6 (Southern Dry Zone of Karnataka). The underlying geological formations range from Archaean granitic gneiss to Dharwar schists, providing the primary parent material for local pedogenesis.

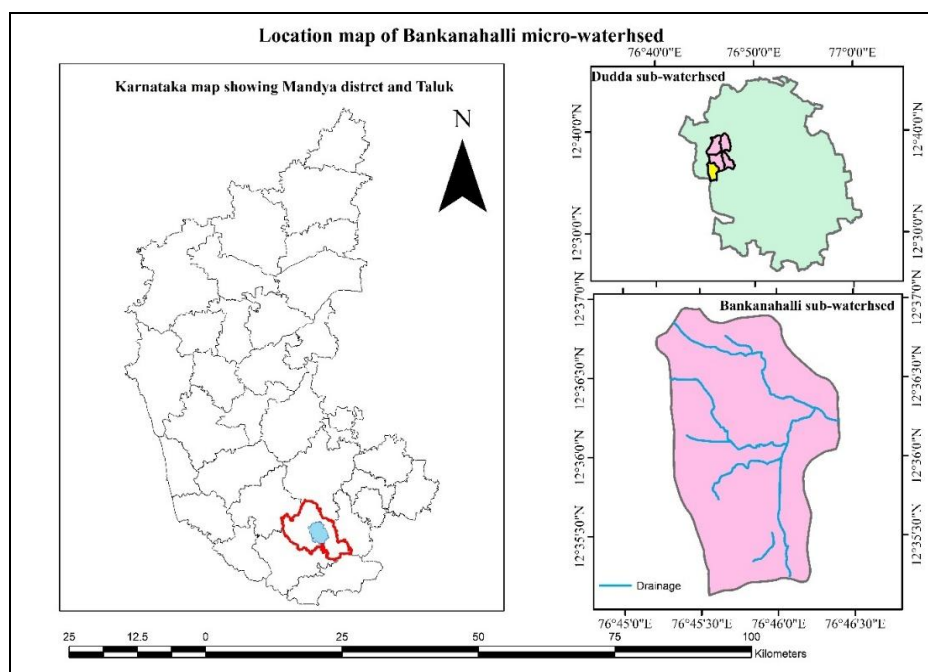


Fig 1: Showing the location map of the field in the Bankanahalli micro-watershed

Climatically, the region experiences three distinct seasons: Kharif, Rabi, and Summer. The average annual precipitation is 565.7 mm, predominantly concentrated during the south-west monsoon months (June to September). The daily mean maximum temperature reaches approximately 28.50°C, while the daily mean minimum temperature drops to 20.17°C. The natural vegetation is sparse, comprising dry deciduous species and grasses, which are heavily influenced by grazing and human interference.

2.2 Soil Profile Study and Field Sampling

A detailed traverse of the micro-watershed was conducted, and nine representative soil profiles were excavated across distinct physiographic positions—encompassing uplands, mid-lands, and lowlands. The horizons in each profile were delineated and described in situ for their morphological features, including depth, boundary distinctness, colour, texture, structure, consistency, root distribution, and effervescence, following standard USDA and ICAR-NBSS&LUP Soil Survey Manual protocols. Horizon-wise soil samples were collected, air-dried in the shade, gently crushed using a wooden mortar and pestle, and passed through a 2 mm sieve to prepare for comprehensive laboratory analysis.

2.3 Laboratory Analytical Procedures

The processed soil samples were analyzed for a suite of physical and chemical properties using standard analytical protocols. Particle size distribution (sand, silt, and clay fractions) was

estimated using the international pipette method following dispersion with sodium hexametaphosphate (Piper, 2002) [8]. Bulk density and maximum water holding capacity (MWHC) were determined utilizing the Keen's cup method. Soil reaction (pH) and electrical conductivity (EC) were measured in a 1:2.5 soil-to-water suspension. Organic carbon (OC) content was determined using the Walkley and Black wet oxidation method (Walkley and Black, 1934) [14]. Free calcium carbonate equivalent was estimated via the rapid titration method (Black, 1965) [2]. Cation exchange capacity (CEC) was determined by saturating the soil with 1 N sodium acetate (pH 8.2) and displacing it with neutral normal ammonium acetate (Thomas, 1982) [13]. Exchangeable bases (Ca, Mg, Na, K) were extracted using 1 N neutral ammonium acetate; sodium and potassium were quantified via flame photometry, while calcium and magnesium were determined via complexometric Versenate titration (Jackson, 1973) [3].

3. Results and Discussion

3.1 Mechanical Composition and Physical Pedogenesis

The mechanical composition of the soils across the Bankanahalli micro-watershed revealed significant spatial and vertical differentiation, heavily influenced by landscape position and active pedogenic processes. The particle-size distribution and coarse fragment data indicate a definitive textural progression from the surface to the subsurface horizons across all depth categories, as detailed in Table 1.

Table 1: Mechanical composition of identified soil series in the micro-watershed

Horizon	Depth (cm)	Coarse fragment (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class
Shallow (25-50cm)						
Chikkasavanur (CSR)						
Ap	0 - 12	10	68.90	10.83	19.50	sandy loam
Bt1	12 - 28	0	65.06	10.55	23.75	sandy clay loam
Bt2	28 - 45	10	64.80	11.98	22.25	sandy clay loam
Moderately Shallow (50-75cm)						
Hatti (HTI)						
Ap	0 - 14	10	79.98	5.05	14.45	Loamy sand
Bt1	14 - 40	-	60.96	4.60	33.95	sandy clay loam
Bt2	40 - 65	50	58.37	4.48	36.73	Sandy clay
Mukhadalli (MKH)						
Ap	0 - 10	30	67.59	9.28	22.37	sandy clay loam
Bt1	10 - 24	30	55.72	6.51	37.14	Sandy clay
Bt2	24 - 58	40	53.74	7.26	38.56	Sandy clay
Moderately Deep (75-100 cm)						
Bisaralli (BSR)						
Ap	0 - 13	-	68.66	13.20	17.35	sandy loam
Bt1	13 - 33	-	56.59	7.84	35.16	sandy clay
Bt2	33 - 54	40	54.78	8.28	36.57	sandy clay
Bt3	54 - 80	10	53.37	9.07	37.04	sandy clay loam
Gollarahalli (GHT)						
Ap	0 - 15	10	77.02	7.08	15.48	sandy loam
Bt1	15 - 32	30	69.58	7.50	22.40	sandy clay loam
Bt2	32 - 63	40	68.80	7.80	22.88	sandy clay loam
Bt3	63 - 79	10	66.26	8.20	25.15	sandy clay loam
Deep (100-150 cm)						
Kumchalli (KMH)						
Ap	0 - 15	-	62.43	7.25	19.53	Sandy loam
Bt1	15 - 40	-	51.48	5.23	42.80	Sandy clay
Bt2	40 - 61	-	50.63	5.55	43.43	Sandy clay
Bt3	61 - 83	20	49.74	6.23	43.63	Sandy clay
Bt4	83 - 95	20	49.23	6.25	44.18	Sandy clay
Shyanadrahalli (SNH)						
Ap	0 - 14	10	56.84	13.88	28.35	sandy clay loam
Bw1	14 - 42	0	43.57	15.31	40.37	clay
Bw2	42 - 67	0	42.48	15.88	41.09	clay
Bw3	67 - 94	30	42.04	15.19	42.24	clay
Bw4	94 - 122	60	40.71	15.02	43.79	clay
Bw5	122 - 145	60	59.67	16.14	23.81	clay
Very Deep (>150 cm)						
Santemarahalli (SMH)						
Ap	0 - 14	10	56.84	13.88	28.35	sandy clay loam
Bt1	14 - 42	0	43.57	15.31	40.37	clay
Bt2	42 - 67	0	42.48	15.88	41.09	clay
Bt3	67 - 94	30	42.04	15.19	42.24	clay
Bt4	94 - 122	60	40.71	15.02	43.79	clay
Bt5	122 - 145	60	59.67	16.14	23.81	clay
Bidarakatte (BDK)						
Ap	0 - 13	10	64.78	5.18	29.35	sandy clay loam
Bt1	13 - 40	30	58.42	5.55	35.53	sandy clay
Bt2	40 - 71	40	57.44	5.65	36.45	sandy clay
Bt3	71 - 94	40	56.96	5.58	36.98	sandy clay
Bt4	94 - 108	40	56.17	5.90	37.63	sandy clay
Bt5	108 - 139	40	55.59	6.43	37.80	sandy clay

Shallow soils, predominantly found in the upper landscape positions, are characterized by coarse surface textures. The Chikkasavanur (CSR) series exhibits a sandy loam surface (Ap) containing 68.90% sand and 19.50% clay, transitioning slightly to a sandy clay loam in the subsoil. Similarly, the moderately shallow Hatti (HTI) series displays an extreme textural gradient, beginning as a highly permeable loamy sand at the surface (79.98% sand, 14.45% clay) and abruptly transitioning to a sandy clay in the Bt2 horizon (36.73% clay). This vertical

transition is a classic hallmark of clay illuviation. While the coarse surface textures promote rapid infiltration and ease of mechanical tillage, they severely restrict moisture retention, rendering these upland soils highly susceptible to drought stress during dry spells.

Conversely, deep and very deep pedons (e.g., Kumchahalli, Shyanadrahalli, Santemarahalli, and Bidarakatte series) situated in the mid-lands and lowlands exhibit extensive argillic development. The KMH series, for instance, progresses from a

sandy loam (19.53% clay) to a dense sandy clay containing 44.18% clay in the Bt4 horizon. Both the SNH and SMH series present sandy clay loam surfaces that transition into heavy clay horizons, peaking at 43.79% clay at depths of 94-122 cm. The continuous and significant vertical increase in clay content confirms active illuviation and the maturation of argillic (Bt) horizons under semi-arid conditions (Kanwar, 1982) [4]. Although these dense clay accumulations provide superior nutrient and water-holding capacities—making them ideal for intensive cropping—they simultaneously present risks of restricted internal drainage and potential waterlogging during intense monsoonal rains.

Structural development aligned closely with this textural gradient. The surface horizons (Ap) generally exhibited very friable to friable granular or sub-angular blocky structures, facilitated by regular cultivation and lower clay contents. However, the subsurface argillic horizons displayed moderate to

strong sub-angular blocky structures. In the deepest, clay-dense profiles (e.g., SMH, BDK), firm, angular blocky structures with pressure faces were observed, indicating vertic shrink-swell tendencies. Coarse fragments played a crucial mitigating role in these deep pedons. The subsurface coarse fragment content reached up to 60% in the SMH and SNH series, and 40% in the BDK series. This high proportion of coarse fragments within the dense clay matrices improves subsoil aeration, assists in root penetration, and reduces the overall compaction risks that typically plague heavy clay soils.

3.2 Chemical Characterization and Fertility Dynamics

The chemical properties across the identified soil series highlight diverse fertility potentials and localized constraints directly linked to profile depth, leaching regimes, and clay mineralogy. Detailed chemical attributes of the soil horizons are presented in Table 2.

Table 2: Chemical characterization of identified soil series in the micro-watershed

Horizon	Depth (cm)	pH (1:2.5)	EC (1:2.5) (dSm ⁻¹)	OC (%)	Ca	Mg	Na	K	CEC	Base Saturation	ESP (%)
					(c.mol (+1) kg ⁻¹)					(%)	
Shallow (25-50cm)											
Chikkasavanur (CSR)											
Ap	0 - 12	6.57	0.08	0.66	4.00	2.50	0.21	0.19	10.19	67.71	2.06
Bt1	12 - 28	6.83	0.09	0.30	5.00	2.50	0.24	0.07	11.52	67.80	2.08
Bt2	28 - 45	6.93	0.13	0.24	4.50	2.50	0.32	0.06	11.00	67.09	2.91
Moderately Shallow (50-75cm)											
Hatti (HTI)											
Ap	0 - 14	6.71	0.06	0.27	2.50	1.50	0.16	0.46	7.53	61.35	2.12
Bt1	14 - 40	6.87	0.08	0.42	4.00	2.50	0.23	0.21	11.56	60.03	1.99
Bt2	40 - 65	7.01	0.13	0.30	6.00	3.00	0.31	0.15	12.33	76.72	2.51
Mukhadalli (MKH)											
Ap	0 - 10	6.64	0.13	0.60	3.50	1.50	0.07	0.19	8.44	62.32	0.83
Bt1	10 - 24	7.15	0.24	0.45	5.50	3.00	0.13	0.09	11.32	77.03	1.15
Bt2	24 - 58	7.33	0.44	0.30	6.00	3.00	0.31	0.08	12.09	77.67	2.56
Moderately Deep (75-100 cm)											
Bisaralli (BSR)											
Ap	0 - 13	7.35	0.1	0.54	5.50	2.50	0.12	0.17	12.19	68.01	0.98
Bt1	13 - 33	7.4	0.11	0.45	8.00	4.00	0.17	0.15	15.11	81.54	1.13
Bt2	33 - 54	7.54	0.11	0.36	8.50	4.00	0.17	0.12	15.75	81.21	1.08
Bt3	54 - 80	7.61	0.12	0.30	9.00	4.00	0.17	0.12	16.32	81.43	1.04
Gollarahatti (GHT)											
Ap	0 - 15	6.20	0.05	0.39	2.00	1.00	0.25	0.07	6.02	55.15	4.15
Bt1	15 - 32	6.29	0.06	0.36	3.00	1.50	0.27	0.08	7.56	64.15	3.57
Bt2	32 - 63	6.54	0.07	0.33	4.00	2.00	0.29	0.10	8.48	75.35	3.42
Bt3	63 - 79	6.71	0.08	0.30	4.50	2.00	0.30	0.07	8.92	77.02	3.36
Deep (100-150 cm)											
Kumchahalli (KMH)											
Ap	0 - 15	5.41	0.05	0.57	3.50	2.00	0.25	0.11	9.12	64.25	2.74
Bt1	15 - 40	5.77	0.06	0.45	5.00	2.50	0.30	0.09	10.91	72.32	2.75
Bt2	40 - 61	5.88	0.07	0.39	5.50	2.50	0.41	0.10	11.63	73.17	3.53
Bt3	61 - 83	6.71	0.08	0.36	6.00	2.50	0.37	0.16	11.77	76.72	3.14
Bt4	83 - 95	7.04	0.09	0.30	5.50	2.50	0.34	0.13	11.85	71.48	2.87
Shyanadrahalli (SNH)											
Ap	0 - 14	7.26	0.29	0.57	12.50	6.00	1.29	1.20	23.47	89.43	5.50
Bw1	14 - 42	8.23	0.29	0.51	12.00	6.00	1.39	1.20	22.89	89.95	6.07
Bw2	42 - 67	8.31	0.33	0.36	12.00	5.50	2.64	0.53	22.32	92.61	11.83
Bw3	67 - 94	8.36	0.35	0.30	12.50	5.00	3.26	0.48	21.84	97.25	14.93
Bw4	94 - 122	8.63	0.46	0.24	12.50	4.50	3.38	0.50	21.71	96.18	15.57
Bw5	122 - 145	8.94	0.59	0.15	12.50	4.00	3.25	0.67	21.37	95.55	15.21
Very Deep (>150 cm)											
Santemarahalli (SMH)											
Ap	0 - 14	9.02	0.38	0.84	3.50	1.50	1.62	0.24	8.91	76.99	18.18
Bt1	14 - 42	9.54	0.45	0.36	6.00	3.00	1.66	0.15	12.75	84.78	13.02
Bt2	42 - 67	10.36	0.56	0.15	7.00	3.00	1.70	0.14	13.42	88.23	12.67
Bt3	67 - 94	10.38	0.66	0.15	7.00	3.50	1.74	0.14	14.02	88.30	12.41

Bt4	94 - 122	10.39	0.94	0.15	7.00	3.50	1.75	0.12	13.97	88.55	12.53
Bt5	122 - 145	10.43	1.14	0.15	6.50	3.00	1.86	0.09	12.30	93.09	15.12
Bidarakatte (BDK)											
Ap	0 - 13	6.87	0.08	0.54	6.50	3.00	0.40	0.52	13.55	76.90	2.95
Bt1	13 - 40	6.95	0.1	0.42	7.50	3.00	0.34	0.14	13.98	78.54	2.43
Bt2	40 - 71	7.02	0.14	0.33	8.00	3.00	0.40	0.11	14.32	80.38	2.79
Bt3	71 - 94	7.08	0.16	0.3	8.00	3.50	0.55	0.09	14.79	82.08	3.72
Bt4	94 - 108	7.51	0.22	0.21	8.50	3.50	0.63	0.10	14.91	85.38	4.23
Bt5	108 - 139	7.58	0.34	0.15	8.50	4.00	0.47	0.09	15.42	84.70	3.05

Note: Base cations (Ca, Mg, Na, K) and CEC are expressed in $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Selected representative horizons are shown for brevity.

Soil reaction (pH) across the micro-watershed spanned a remarkably broad spectrum, reflecting differential weathering, leaching, and depositional environments (Patil *et al.*, 2017a) [6]. The surface horizons of the Kumchahalli (KMH) series are strongly acidic (pH 5.41), favoring the solubility and availability of most micronutrients but potentially limiting basic cations. Conversely, the deeper soils, particularly in the lowland Santemarahalli (SMH) and Shyanadrahalli (SNH) series, exhibit progressive alkalization. The pH peaks at a strongly alkaline 10.43 in the SMH Bt5 horizon (122-145 cm). This rising alkalinity is a direct consequence of the accumulation of calcium carbonates and basic cations in the subsoil, a phenomenon driven by the limited leaching capacity of the semi-arid climate. Despite the high pH in specific subsoils, the Electrical Conductivity (EC) remains universally low throughout the watershed, ranging from 0.05 dS/m to a maximum of 1.14 dS/m (SMH Bt5). This confirms that the entire micro-watershed is non-saline, thus posing no osmotic stress limitations for standard crop cultivation.

The distribution of organic carbon (OC) follows a strict and expected depth-dependent decline. Surface horizons (Ap) demonstrated moderate biological activity and organic input, with OC peaking at 0.84% in the SMH series, 0.66% in the CSR series, and 0.60% in the MKH series. However, OC rapidly depletes in the subsurface layers, plummeting to as low as 0.15% in the deeper Bt horizons of the SMH and BDK series. This sharp vertical decline underscores the rapid oxidation and mineralization of organic matter in hot, semi-arid environments. The intrinsically low subsoil organic carbon highlights the necessity for agricultural management practices that incorporate organic amendments, such as mulching and green manuring, to build sustainable carbon pools.

Cation Exchange Capacity (CEC) varies significantly across the pedons, closely mirroring the clay distribution pattern. It ranges from a low of 6.02 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in coarse, sandy surface soils to a robust 23.47 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in the SNH Ap horizon, extending deeply into the argillic profiles. Exchangeable calcium is the overwhelmingly dominant basic cation across all series, contributing to a strong Base Saturation (BS). BS remains consistently high, ranging from a minimum of 55.15% to an optimal 97.25% in the SNH Bw3 horizon. This indicates that the exchange complex is predominantly occupied by nutrient bases, affording the soils a high capacity for nutrient retention and supply.

While the soils are generally non-saline and exhibit high base saturation, the Exchangeable Sodium Percentage (ESP) data reveals critical localized sodicity risks that require immediate attention. In the shallow to moderately deep series (CSR, HTI, MKH, BSR, GHT), ESP is well-controlled, generally remaining below 4.15%. However, in specific horizons of the deep and very deep series, sodium accumulation is pronounced. The ESP reaches 15.57% in the SNH Bw4 horizon and spikes to a concerning 18.18% in the SMH Ap horizon. These elevated ESP

values (>15%) cross the threshold for sodicity, signifying a distinct risk of soil dispersion. Sodic dispersion compromises aggregate stability, severely restricts subsoil permeability, induces surface crusting, and negatively impacts root proliferation. Ameliorative measures, such as the application of gypsum combined with deep-rooted cover cropping, are essential to displace exchangeable sodium and restore structural integrity in these affected zones.

3.3 Taxonomic Classification

Based on the integration of pedogenic properties, horizonation, base saturation, and moisture regimes, the soils of the Bankanahalli micro-watershed were classified into two dominant taxonomic orders under the USDA Soil Taxonomy framework (Soil Survey Staff, 2022; Nayak *et al.*, 2002) [12, 5]: *Alfisols* and *Inceptisols*.

Alfisols constitute the predominant soil order, characterized by the illuviation of silicate clays leading to distinct argillic (Bt) horizons. The Mukhadalli and Bisarahalli series exhibit extensive clay accumulation and reddish hues driven by iron oxide weathering; they are classified at the subgroup level as *Typic Rhodustalfs*. The deeply weathered profiles of the Kumchahalli series, featuring prolonged pedogenesis and intense red colors, are classified as *Rhodic Paleustalfs*. The Bidarakatte series, similarly deep but lacking the distinct rhodic color requirements, is grouped under *Typic Paleustalfs*. The relatively younger, fine-loamy, moderately weathered upland profiles of the Chikkasavanur and Hatti series are classified as *Typic Haplustalfs*.

Inceptisols were identified in specific midland and lowland positions where soil development is progressive but lacks complete argillic expression (Sireesha and Naidu, 2013) [11]. The Shyanadrahalli (SNH) series is characterized by a developing cambic (Bw) subsurface horizon. This cambic horizon displays moderate structural development (blocky structure) and slight clay accumulation relative to the overlying ochric epipedon, indicating active but incomplete pedogenesis. Consequently, the SNH series is classified as fine, isohyperthermic *Typic Haplustepts*. The transition from highly leached, permeable upland *Typic Haplustalfs* to dense, clay-rich lowland *Paleustalfs* and *Haplustepts* perfectly encapsulates the profound influence of topography and localized hydrology on semi-arid soil formation.

4. Conclusion

The comprehensive pedological characterization of the Bankanahalli micro-watershed reveals a highly diverse landscape where soil formation is intrinsically linked to topography, drainage, and semi-arid climatic forcing. The soils, primarily derived from granitic gneiss, range from shallow, highly permeable upland soils to very deep, clay-rich lowland profiles. Upland soils suffer from severe physical constraints, notably restricted moisture retention and shallow rooting depths, which heighten vulnerability to drought. Conversely, the

lowland Alfisols and Inceptisols offer substantial fertility potentials driven by high cation exchange capacity, active clay illuviation, and high base saturation. However, these deep soils face distinct chemical and physical constraints, notably localized strong alkalinity and marginal sodicity (ESP up to 18.18%) in subsurface horizons. These conditions can impede permeability, induce soil dispersion, and restrict micronutrient availability. The classification of these soils into *Typic Rhodustalfs*, *Paleustalfs*, *Haplustalfs*, and *Haplustepts* provides a precise taxonomic framework reflecting their weathering intensity. The findings underscore the necessity of abandoning generalized agricultural practices in favor of site-specific, climate-resilient agronomic interventions. Practices such as organic mulching, the incorporation of green manure, and contour farming are highly recommended. These interventions will mitigate the specific constraints of moisture loss and erosion in the uplands, and structural degradation in the lowlands, ultimately fostering enhanced soil organic carbon sequestration and ensuring long-term agricultural sustainability in the semi-arid tropics.

Authors' contribution

Ashwarya Golshetti: Carried out the study including collection of samples and analysis of relevant properties of soil and water, structured the manuscript, S B Yogananda: Supervised the research work and monitored preparation of the manuscript; Carried out the study including collection of samples and analysis of relevant properties of soil and water, structured the manuscript; M A Ananthakumar M N Thimmegowda and P Thimmegowda: supervised the research work and monitored preparation of the manuscript; K. Shivashanakar: helped in preparing the map and also helped in preparing the maps.

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