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Landform - Based Soil Variability and Water Regime Implications in the KRP Dam Catchment, Tamil Nadu, India

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ABSTRACT

Hydropedology studies soil and water processes across landscapes. This research characterized the soils in the Krishnagiri Reservoir Project (KRP) Dam catchment, Tamil Nadu, India, to identify pedological indicators of water regimes and the effects of land management. A (2020-2023) soil survey at a 1:10,000 scale provided data for the 12,483 ha catchment. Five soil series from various landforms were classified, and drainage classes were estimated based on soil features without direct hydrological monitoring. Soil properties varied by landform, from shallow (<50 cm) to deep (100-150 cm), with drainage from well to poorly drained. Colors ranged from dark reddish-brown to black; textures ranged from loamy sand to clay. Structure ranged from massive to subangular blocky; pH from neutral to moderately alkaline (6.74-9.19), electrical conductivity from non-saline to slightly saline (0.04-1.64 dS m^{-1}), organic carbon from low to high (0.15-2.17%), and cation exchange capacity from 4.43 to 54.0 cmol (p^+) kg^{-1}. The soil exchange complex held Ca > Mg > K > Na. Soil classes included Alfisols (NGH & MLD series - uplands), Inceptisols (STP & SDK series - lowlands), and Entisols (KLV series - lowlands). Soils with periodic saturation (KLV, STP, SDK) had higher clay, CEC, and nutrients than well-drained uplands (NGH, MLD). Correlation analysis (n=45) showed strong positive relationships between clay, CEC, and exchangeable bases, with sand negatively correlating. Upland soils exhibited erosion and nutrient loss with low water-holding capacity (5.44-7.99%). Lowland soils had higher available water (11.89-22.39%) but signs of drainage issues and salt buildup. This study provides a baseline for soil features in the KRP Dam catchment. Water regime inferences need validation via direct hydrological monitoring, including water table, soil moisture, and hydraulic testing. Conservation strategies for uplands (erosion, organic matter) and lowlands (drainage, salinity) should be field-tested before implementation. This baseline supports future integrated research for sustainable crop management in dam-affected regions.

1 | INTRODUCTION

Hydropedology connects pedology, soil physics, and hydrology to bridge scales and convert soil survey data into soil hydraulic information (Kutilek & Nielsen, 2007). In this case, pedotransfer functions connect simpler soil characteristics, such as morphological features, to more intricate variables, such as soil hydraulic properties, which are difficult to measure (Lin *et al.*, 2006; Bouma, 2024). Determining the relationship between soil water regime and soil morphology thus requires an understanding of redox reactions in soil and their impact on the development of redoximorphic color patterns (Rabenhorst & Parikh, 2000). It is a helpful tool for monitoring and assessing climate change and for integrating soil and water data into land use systems (Daniel Filho & Barretto de Figueiredo, 2025). Additionally, hydropedology has a significant impact on formulating environmental policies from a global to a local level (Bouma, 2006). Soil survey databases provide a wealth of information that can be utilized to predict the fate of water and contaminants in the landscape (Henry Lin, 2011). Wilding and Lin (2006) also assert that the focus of Pedology is transitioning from classification and inventory to the comprehension and quantification of spatial and temporal processes that are essential to the water cycle and ecosystem. Current knowledge deficits include the quantification of soil hydro morphology and modeling, predictions of soil and hydrological properties and processes, and data-bridging through pedotransfer functions (Lin *et al.,* 2006; Ma *et al.,* 2017; Kaur & Kumari, 2024). It is necessary to gain a better understanding of how water flow patterns affect soil processes and soil formation across the landscape. Quantification of soil variation, spatial and temporal, is essential for the effective modelling of hydraulic processes in the landscape (Zacharias *et al.,* 2009)

Before the construction of dams, the main land uses were betel vines and mango, which were based on a canal irrigation system that covered a small area. After the dam was built, the uplands were transformed into a paddy-based land-use system and coconut plantations (Srinivasan *et al.,* 2019; Srinivasan *et al.,* 2023). The transformation of well-drained soil into a layer saturated with water alters the soil systems hydro morphological and physical characteristics. Significant issues with soil physical and chemical deterioration, poor water management, monocropping systems, and their effects on inadequate ecosystem management (Srinivasan *et al.,* 2022). It is anticipated that hydropedology will increase our understanding of the environment, ecology, agriculture, and natural resources of the KRP Dam catchment. Mapping soil-water and soil-landscape at farm scales is made easier by measurements of soil hydro-morphology, soil structure, and their effects on water flow and movement across diverse landscapes, as well as their implications for crop management (Lin, 2003). These include nutrient cycling, precision agriculture, climate change, ecosystem functions, water and soil quality and landscape processes and management. Therefore, a case study was conducted in the KRP dam catchment to assess soil, water, and responses to crop and ecosystem management.

HIGHLIGHTS

- Detailed soil survey (1:10,000 scale) characterized five major soil series across landforms in a dam catchment in semi-arid tropical India.
- Upland Alfisols showed well-drained characteristics with erosion evidence, while lowland Inceptisols and Entisols exhibited morphological features suggesting periodic saturation.
- Strong correlations between clay content, cation exchange capacity, and nutrient retention demonstrate texture's role in soil fertility management.
- Soils with morphological indicators of seasonal saturation had higher clay content (42-58%), available water capacity (11-22%), and nutrient availability than well-drained upland soils.

2 | MATERIALS AND METHODS

2.1 | Study Area

Krishnagiri Dam, known as Krishnagiri Reservoir Project (KRP) Dam, was built across the Thenpennai River fall in Dhuduganahalli village, Krishnagiri district. The study area, which is located between latitudes 21°29′37.44″ N and longitudes 78°10′41.51″ E, is part of the agroecological sub-region (AESR) of 8.2. It covers 12483 ha (Fig. 1), of which 8477 ha (67.94%) are majorly covering five soil series. The remaining area comprises minor soils and permanent features such as roads, waterbodies, and other features. This reservoir provides direct irrigation benefits to sixteen (16) villages. Successful cultural operations are guaranteed by a water supply from the reservoir for ten (10) months of the year. During the 150–180-day growing period, the northeast monsoon (October–December) receives 60–70% of the mean annual rainfall, which ranges from 750 to 900 mm (LGP). During the summer, the average high temperature is 37°C, while the average low temperature is 25.5°C. The soil temperature class is hyperthermic. It is a hot, semi-arid ecoregion with mixed red loamy soils and the "ustic" moisture regime. There are a significant number of forests at the top of the mountains and hillocks. The primary crop grown in the dam catchment is paddy, but there are also significant amounts of coconut, jasmine, ragi, mango, and legumes. Site characteristics are given in (Table 1).

2.2 | Field Studies

The base map was prepared using geological data, a survey of India Toposheet (1:50,000scale), and remote sensing data from IRS-P6 LISS IV (5.8 m of resolution). Different physiographic regions, landscapes, landforms, and land use/land cover were identified by visually interpreting the satellite image based on tone/color, texture, pattern, and shape, among other factors. In the KRP dam catchment, a thorough soil study at a 1:10,000 scale was carried out between 2020 and 2023. Satellite image interpretation, ground-truth observation (soil survey fieldwork), laboratory analysis, and GIS mapping comprise the four tiers of the detailed soil survey methodology. Given the variability, random observations were made throughout the slope, encompassing all landform units. Soil profiles (vertical cuts and arrangements of soil layers/horizons) excavated to a depth of 1.5 to 2 m, or until they reached rock or hard substratum/parent materials, were used to study soil morphological properties (Soil Survey Staff, 2003). A portable global positioning system (GPS) was used to record the latitude, longitude, and elevation at each sampling location. In the KRP dam catchment, ninety-two (92) soil profiles were examined. The KRP dam catchment was divided into ten (10) soil series (homogeneous units with similar responses for level management) based on the soil characteristics. Of these, five major soil series were used to assess the hydropedology in the area: Kalveli (KLV), Santhapuram (STP), and Sundekuppam (SDK) are lowland, and Nagojanahalli (NGH) and Malayandahalli (MLD) are upland (Table 2). The soil profiles from each landform were comprehensively analyzed to characterize morphological attributes and assess key soil parameters, including slope, depth, and physicochemical properties (Soil Survey Staff, 2003). Topography-soil-hydrology sequences in the KRP Dam catchment are given in (Fig. 2).

2.3 | Soil Analysis

Major soil parameters were analyzed by systematically collecting horizon-wise soil samples, air-drying, processing, and sieving them through a 2 mm mesh. Particle-size distribution was determined using the international pipette method (Day, 1965). Soil pH and electrical conductivity (EC) were measured according to the standard procedures described by Page *et al.* (1982). Soil organic carbon content was estimated by the moist oxidation method of Walkley & Black (1934). To determine soil moisture-retention characteristics, disturbed soil samples were saturated for 48 hours, followed by pressure application at 0.03, 0.05, 0.1, and 1.5 MPa in a pressure plate extractor until drainage ceased. The samples were then oven-dried at 105°C for 24 hours, and the difference in water retained between 0.03 and 1.5 MPa suctions was used to compute the available water capacity (AWC) (Klute, 1986). Cation exchange capacity (CEC) was determined using neutral normal ammonium acetate at pH 7.0, and base saturation was calculated as the percentage ratio of the sum of exchangeable bases to CEC. Exchangeable calcium (Ca) and magnesium (Mg) were extracted with the same solution and quantified using an atomic absorption spectrophotometer (AAS) (Jackson, 1973). Available phosphorus was estimated via the ascorbic acid reduction method (Bray & Kurtz, 1945), while available potassium was extracted using neutral normal ammonium acetate (pH 7.0) and determined by flame photometry. Accessible sulfur was extracted with 0.15% $CaCl_2$, and sulfate concentration was measured by the turbidimetric method (Jackson, 1973). Available boron was quantified using the Azomethine-H reagent (Jackson, 1973). Micronutrient availability (Fe, Mn, Cu, and Zn) was assessed through DTPA extraction followed by analysis with an atomic absorption spectrophotometer (Lindsay & Norvell, 1978). Finally, soil classification was performed in accordance with the criteria outlined in Keys to Soil Taxonomy (Soil Survey Staff, 2014).

TABLE 1 Site characteristics of the study area

S.No	Landform	Series	Elevation MSL (m)	Slope %	Erosion	Major crops	Management
P1	Gently sloping Upland	Nagojanahalli (NGH)	615	1-3	Moderate	Mango, Sorghum	Moderate
P2	Gently sloping Upland	Malayandahalli (MLD)	479	1-3	Moderate	Mango, Pulses, Groundnut	Moderate
P3	Nearly level Lowland	Kalveli (KLV)	450	0-1	Very slight	Paddy, Coconut	Moderate
P4	Nearly level Lowland	Santhapuram (STP)	426	0-1	Slight	Paddy, Coconut	Good
P5	Nearly level Lowland	Sundekuppam (SDK)	418	0-1	Very slight	Paddy, Jasmine, Coconut	Good

TABLE 2 Soil characteristics and classification in the KRP Dam catchment

Landforms	Soil Series	Soil landform relationship	Area (ha)	% of TGA
Upland	Nagojanahalli (NGH)	Moderately deep, well-drained, dark reddish-brown to reddish-brown, sandy clay loam texture in series control section (37-90 cm) on very gently sloping (1-3%) upland with loamy sand surface texture and moderate erosion. (*Fine-loamy, mixed, isohyperthermic, Typic Haplustalfs*)	1334.3	10.69
	Malayandahalli (MLD)	Deep, well-drained, dark reddish-brown to dark red, sandy clay to sandy clay loam texture in series control section (23-109 cm) on very gently sloping (1-3%) upland with sandy loam surface texture and moderate erosion. (*Fine-loamy, mixed, isohyperthermic, Rhodic Palustalfs*)	481.0	3.85
	Kalveli (KLV)	Deep, moderately well-drained, dark gray to brown, sandy clay loam to sandy loam texture in series control section (14-137 cm) on nearly level sloping (0-1%) low land with sandy clay loam surface texture and very slight erosion. (*Sandy, mixed, isohyperthermic (Calcarious), Typic Ustifluvents*)	1639.2	13.14
Lowland	Santhapuram (STP)	Shallow, moderately well-drained, dark yellowish-brown to brown, sandy clay loam texture in series control section (21-48 cm) on nearly level sloping (0-1%) lowland land with sandy loam surface texture and slight erosion. (*Fine-loamy, mixed, isohyperthermic (Cal), Typic Haplustepts*)	4035.0	32.35
	Sundekuppam (SDK)	Deep, somewhat poorly drained, dark brown to dark grayish brown, sandy clay to sandy clay loam texture in series control section (20-150 cm) on nearly level sloping (0-1%) lowland land with sandy clay surface texture and very slight erosion. (*Fine-loamy, mixed, isohyperthermic, Fluevntic Haplustepts*)	987.6	7.91
		Total	8477	67.94

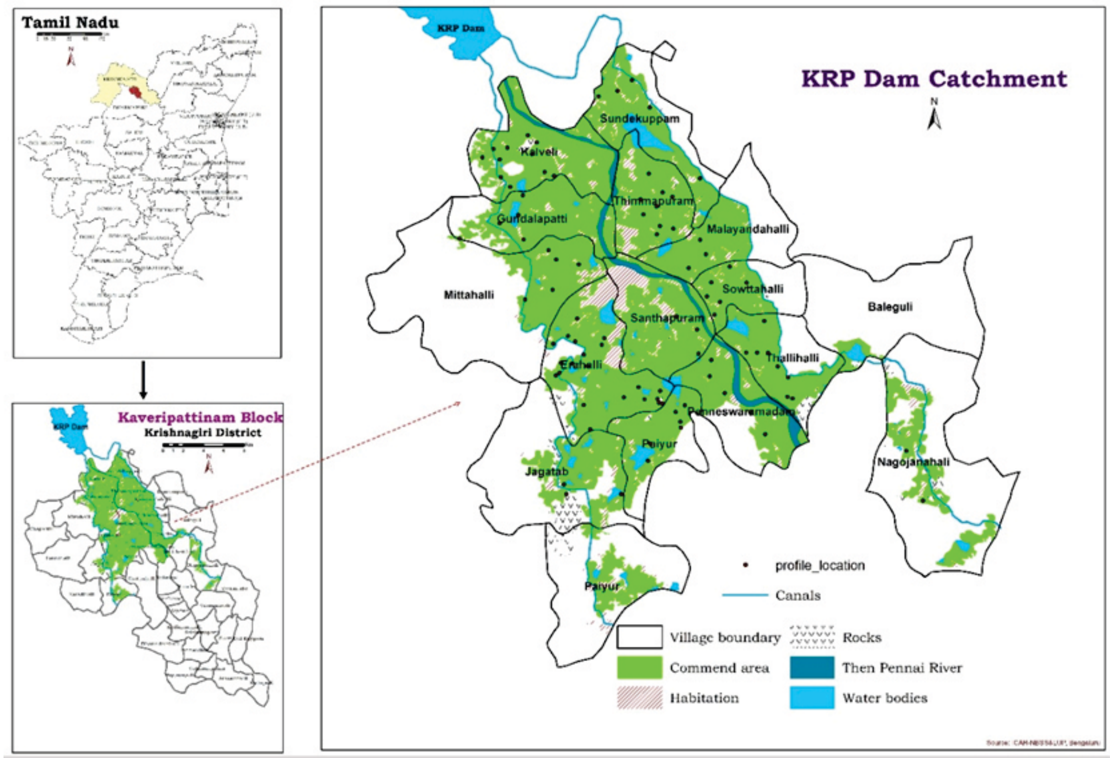

FIGURE 1 Location map of the Study area

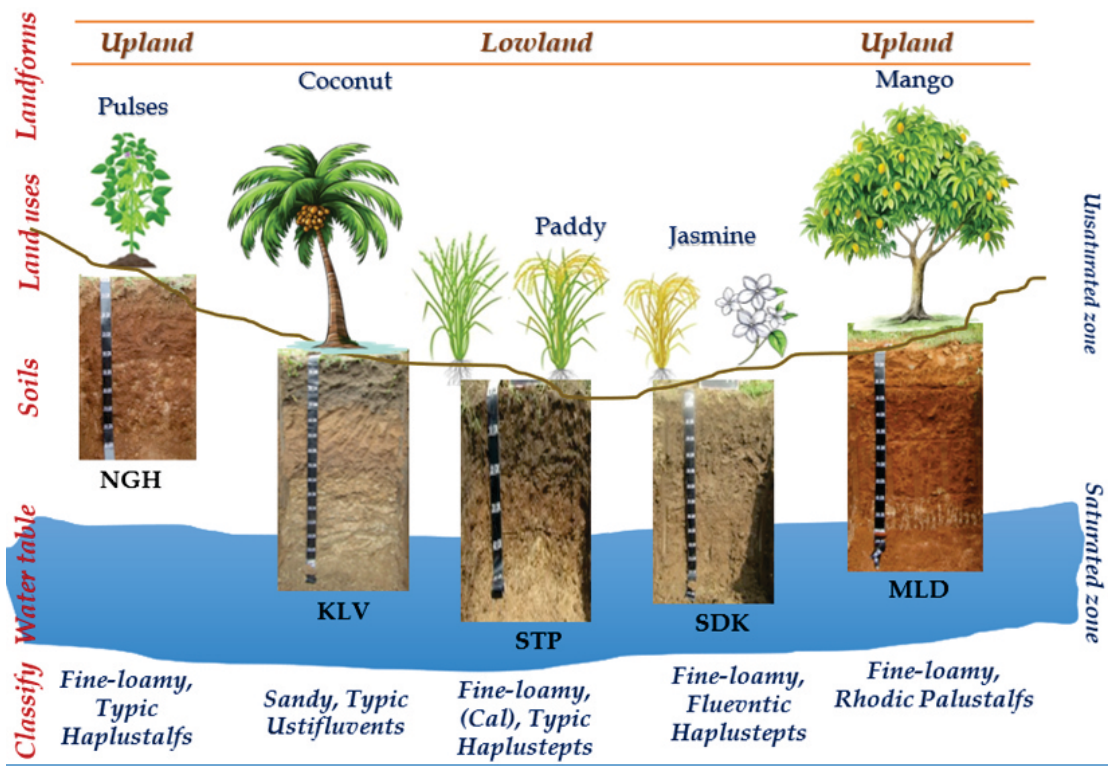

FIGURE 2 Topography-soil-hydrology sequences in KRP Dam catchment (*"*Water table positions inferred from soil morphology; direct measurements not available". Include scale and clearer labels)*

2.4 | Statistical Analysis

The correlation coefficient was evaluated for various soil characteristics in the KRP Dam catchment to determine the influence on soil and water. A network map visualization was carried out using R software, and the Q graph package involves plotting nodes (variables or items) and edges (relationships, usually correlations or partial correlations) for interpretations.

2.5 | Study Limitations and Scope

This study details soil characteristics for the KRP Dam catchment, but faces limitations. Soil drainage was assigned based on morphological criteria without hydrological validation. Hydraulic properties were limited to available water capacity; other parameters were not measured. Soil sampling was conducted only once during (2020-2023), without seasonal monitoring. Water quality analysis was absent, impeding the assessment of water's influence on soil chemistry. These findings are preliminary and need further hydrological validation.

3 | RESULTS AND DISCUSSION

3.1 | Morphological Characteristics and Inferred Drainage Classes

(Table 3) shows brief morphological features of the pedons. Soil depth ranged from shallow (<50 cm) to deep (100-150 cm). Upland soils (NGH, MLD series) were moderately deep to deep (90-109 cm), while lowland soils varied from shallow (STP: 48 cm) to deep (KLV: 137 cm; SDK: 150 cm). Drainage classes were assigned based on soil color, structure, landscape, and land use, following standard procedures (Soil Survey Staff, 2003). Upland soils were well drained and aerobic, while lowland soils showed moderately well to poorly drained conditions, suggesting periodic saturation. These classifications are based on morphological criteria; direct water table or seasonal soil moisture data were not collected.

3.1.1 | Soil Color Patterns

Surface soil colors in upland areas ranged from dark reddish brown (5YR 3/3 in NGH) to dark reddish brown (2.5YR 3/4 in MLD). Subsurface horizons exhibited colors from dark reddish brown (2.5YR 3/3) to reddish brown (2.5YR 4/4). The consistent reddish hues (2.5YR to 5YR) throughout upland profiles, with no gray tones or strong mottling, indicate well-oxidized soils and align with well-drained conditions. Lowland soils showed darker shades: surface horizons varied from very dark gray (10YR 3/1 in STP and SDK) to dark gray (10YR 4/1 in KLV), while subsurface horizons ranged from brown (7.5YR 4/2-4/3) to black (10YR 2/1). These darker colors in lowland soils may stem from several factors, including: (a) organic matter buildup during saturation periods under anaerobic conditions; (b) formation of reduced iron compounds (ferrous iron) producing gray to black shades; or (c) accumulation of organic-rich sediments from upslope erosion. Oxidation-reduction (redox) processes influence soil color development, especially in soils with alternating aerobic and anaerobic conditions (Tiruneh *et al.*, 2024). However, this survey did not systematically document redoximorphic features (iron/manganese concentrations and depletions), limiting precise assessment of saturation duration and timing.

3.1.2 | Soil Texture

The gravel content varied across soil series and with depth. The NGH series had 15-40% coarse fragments, reaching a maximum of 40% in the surface horizon. MLD and STP series mainly accumulated gravel in lower horizons (30-60%), while KLV and SDK series were mostly free of gravel throughout. The presence of coarse fragments in upland soils can limit rooting depth, reduce water retention, and impact tillage. Surface textures ranged from loamy sand in NGH to clay in SDK. Upland soils had loamy sand to sandy loam surfaces (NGH: loamy sand; MLD: sandy loam), while lowland soils ranged from sandy loam (STP) to sandy clay loam (KLV) and clay (SDK). Subsurface textures generally contained more clay: sandy loam to sandy clay in uplands and sandy clay loam to clay in lowlands. The increasing clay content with depth in upland Alfisols aligns with translocation processes (illuviation) that create argillic horizons. In lowland soils, higher clay levels may result from: (a) depositional processes moving fine particles from upslope areas; (b) in-situ weathering under different moisture conditions; and (c) textural stratification in alluvial parent materials (Srinivasan *et al.*, 2024).

3.1.3 | Soil Structure

The soil structure ranged from massive to subangular blocky forms. Upland soils consistently showed fine to medium, weak to moderate, subangular blocky structures throughout the profile. In contrast, lowland soils exhibited notable structural differences: the surface horizons of the STP and SDK series were massive, a result of repeated puddling during paddy cultivation. Puddling—wet tillage under saturated conditions—disrupts natural soil aggregates, leading to particle rearrangement and destruction of structural units in the topsoil. This process creates a compacted plough pan in the subsoil that can hinder water percolation and root penetration (Ye *et al.*, 2024). Beneath the puddled zone, the lowland soils displayed fine to medium, weak to moderate, subangular blocky structures.

3.1.4 | Consistency

Dry consistency ranged from loose (NGH, MLD surface horizons) to slightly hard (KLV) to hard (MLD subsurface). Moist consistency varied from very friable to friable across most horizons. Wet consistency showed clear differences between soil series: upland soils ranged from non-sticky/non-plastic to moderately sticky/moderately plastic, while lowland clay-rich soils (particularly SDK) exhibited very sticky/very plastic consistency, affecting workability and tillage timing.

3.1.5 | Morphological Indicators of Water Regime

While drainage classes were assigned based on morphological features, observations suggest contrasting soil-water regimes warrant further investigation. Upland soils (NGH, MLD) showed uniform reddish colors, no gray mottling, reduction features, or horizon-specific color changes, indicating fluctuating water tables. Their structure and friability suggest aerobic, well-drained conditions, though confirmation requires water-table depth and hydraulic-conductivity tests. Lowland soils (KLV, STP, SDK) exhibited features such as darker colors, massive puddled surfaces, a sticky consistency when wet, and low-lying landscape positions, suggesting periodic saturation. However, the lack of gray mottling or iron/manganese concretions, common in poorly drained soils, indicates only brief or surface saturation from irrigation or flooding. Black colors in SDK horizons might show reduced iron or organic matter in young deposits. Massive structures may be anthropogenic. These ambiguities highlight the need for hydrological monitoring—installing water table wells, soil moisture sensors, and redox potential measurements—to validate drainage classifications.

3.2 | Physical Characteristics

Detailed physical properties are in (Table 3 and Table 4). Particle size varied by landform position and depth. Upland soils: In the NGH series, sand dominated (67.01%-85.95%), with clay (8.13%-20.62%) and low silt (5.92%-12.37%). The MLD series had lower sand (52.66%-76.88%) and higher clay (14.64%-38.33%), especially in the Bt2 horizon, indicating argillic horizon development. Silt ranged from 7.50 to 9.87%. The KLV series showed variable texture, with sand (58.76%-78.95%), clay (9.31%-22.98%), and silt (11.31%-20.98%), reflecting stratified alluvial parent material with lithological discontinuities (Zhang *et al.,* 2025). The STP series had a sandy loam surface (sand 76.4%, clay 12.2%) over sandy clay subsurface (sand 55.4%-60.3%, clay 37.3%-39.2%). The SDK series had the highest clay (42.15% surface to 58.26% in the deepest layer), decreasing sand with depth. Silt ranged from 25.0-29.18%, higher than in other series. Increasing clay with depth suggests clay illuviation forming argillic horizons in Alfisols, with clay translocated via percolating water over long profile development. Lowland soils exhibit more complex clay distributions due to depositional sorting, differential weathering, stratification, and limited pedogenic translocation. Silt patterns may indicate lithological discontinuities or variable parent material composition (Zhang *et al.*, 2025).

Most soils are dominated by sand (>50%) due to granite-gneiss weathering into quartz-rich sand. Available water capacity (AWC), calculated as the difference between gravimetric water at field capacity and permanent wilting point, ranged from 5.44% to 22.39% across horizons. The NGH series had the lowest AWC (5.44-6.77%), indicating minimal water storage, while the MLD series was slightly higher (5.91-7.99%). Low AWC in upland soils is due to coarser textures, coarse fragments (15-40% NGH, up to 30% MLD lower horizons), and lower organic matter (0.15-0.41%) compared to lowlands. The KLV series had intermediate AWC (8.09-13.34%), the highest in surface horizons. STP series showed AWC of 9.52-11.89%. The SDK series had the highest AWC (7.84-22.39%), with maximum water retention (22.39%) at 110-150 cm depth, associated with clay content (58.26%). Higher AWC in lowlands relates to more clay and silt, higher organic carbon (1.49-2.17%), and finer pore sizes that retain water. AWC offers a potential water storage index, but factors like effective rooting depth (soil depth, restrictive layers, gravel, barriers) influence the water accessible to plants. Drainage and water table dynamics affect actual water availability, with capillary rise or waterlogging either supplementing or reducing accessible water. Hydraulic conductivity impacts water infiltration, percolation, and redistribution, yet it was not measured here. Water retention measurements at only two points provide rough estimates; full profiles would offer better insights. Additionally, crop water use depends on atmospheric demand, crop stage, and management, making AWC one of many influencing factors.

The correlation analysis (Section 3.6, Fig. 3) shows expected links between particle sizes and water retention. Clay content strongly correlates positively with AWC, silt moderately, while sand strongly negatively correlates (see Figure 3 and Supplementary Table S1 for details). These relationships highlight texture's role in water capacity and underscore the importance of managing soil texture (preventing erosion of fine particles, maintaining organic matter). The AWC range (5.44-22.39%) across the catchment suggests different irrigation strategies. Upland soils with AWC <8% need: (a) frequent, light irrigations; (b) mulching; (c) organic matter to boost water retention. Lowland soils with higher AWC (11-22%) can: (a) be irrigated less often with larger depths; (b) buffer drought stress; but (c) need drainage management to avoid waterlogging. All implications remain hypothetical until validated by field trials, moisture monitoring, and crop performance assessments.

FIGURE 3 Pearson's correlation coefficients between different soil properties (*n* = *45*) Only statistically significant correlations ($p<0.05$) are displayed. Line color indicates direction (green=positive, red=negative), and thickness represents correlation strength.

TABLE 3 Morphological and physical characteristics of the KRP Dam soils

Depth (cm)	Horizon	Colour (moist)	Sand	Silt (%)	Clay	Texture	Coarse fragments (%)	Structure	Consistence		
									D	M	W
P1: Nagojanahalli (NGH) series											
0-16	Ap	5YR 3/3	85.95	5.92	8.13	ls	40	f 1 sbk	l	vfr	so/po
16-37	Bt1	2.5YR 3/4	71.84	7.63	20.53	scl	15	m 2 sbk	-	vfr	ms/mp
37-90	BC	2.5YR 4/3	67.01	12.37	20.62	scl	25	m 2 sbk	-	vfr	ms/mp
P2: Malayandahalli (MLD) series											
0-23	Ap	2.5YR 3/4	76.88	8.48	14.64	sl	-	m 2 sbk	h	fr	ss/sp
23-53	Bt1	2.5YR 4/4	52.66	9.48	37.86	sc	-	m 2 sbk	-	fr	ms/mp
53-88	Bt2	2.5YR 3/6	54.17	7.50	38.33	sc	-	m 2 sbkm	-	fr	ms/mp
88-109	BC	2.5YR 3/3	58.55	9.87	31.58	scl	30	m 1 sbk	-	fr	ms/mp
P3: Kalveli (KLV) series											
0-14	Ap	10YR 4/1	59.24	20.22	20.54	scl	-	m 2 sbk	sh	fr	ms/mp
14-28	A2	10YR 4/1	58.76	20.98	20.26	scl	-	m 2 sbk	-	fr	ms/mp
28-54	A3	7.5YR 4/3	78.95	11.74	9.31	sl	-	f 1 sbk	-	fr	ss/sp
54-78	A4	7.5YR 4/2	71.03	11.31	17.66	sl	-	f 2 sbk	-	fr	ss/sp
78-137	AC	10YR 5/3	64.24	12.78	22.98	scl	-	m 1 sbk	-	fr	ms/mp
P4: Santhapuram (STP) series											
0-21	Ap	10YR 3/1	76.4	11.4	12.2	sl	-	Puddled	-	fr	ss/sp
21-38	Bw1	10YR 4/4	55.4	5.40	39.2	sc	-	m 2 sbk	-	fi	ms/mp
38-48	BC	10YR 4/3	60.3	2.31	37.3	sc	60	m 1 sbk	-	fr	ms/mp
P5: Sundekuppam (SDK) series											
0-19	Ap	10YR 3/1	28.67	29.18	42.15	c	-	Puddled	l	l	vs/vp
19-49	Bw1	10YR 3/1	27.98	25.24	46.78	c	-	f 2 sbk	-	vfr	vs/vp
49-75	Bw2	10YR 3/1	24.21	26.47	49.32	c	-	f 2 sbk	-	vfr	vs/vp
75-110	Bw3	10YR 2/1	17.57	25.25	57.18	c	-	f 2 sbk	-	vfr	vs/vp
110-150	Bw4	10YR 2/1	16.74	25.00	58.26	c	-	f 2 sbk	-	vfr	vs/vp

Texture: ls- loamy sandy, sl- sandy loam, scl - sandy clay loam; sc - sandy clay; c - clay
Structure: Size (S) - vf - very fine, f - fine, m - medium, c - coarse; Grade (G) - 0 – structure less, 1- weak, 2 - moderate, 3 - strong; Type (T) cr - crumb, sg - single grain, abk - angular blocky, sbk - sub-angular blocky; *Consistence*: Dry: s - soft, 1- loose, sh - slightly hard, h - hard Moist: 1- loose, vfr- very friable, fr - friable, fi - firm, vfi - very firm; Wet: so - non-sticky, ss - slightly sticky, ms – moderately sticky; vs – very sticky; po - non-plastic, sp – slightly plastic, mp – moderately plastic; vp – very plastic

3.3 | Physico-Chemical Characteristics

Soil reaction in the lowland soils of the Dam catchment ranges from neutral to moderately alkaline, with pH values between 6.74 and 9.19 (Table 4). These soils exhibit slight to moderate alkalinity, attributed to regular water movement that enriches salt content. Electrical conductivity (EC) values range from 0.04 to 1.64 dS m^{-1}, indicating a generally non-saline condition; however, SDK soils show comparatively higher salt concentrations. The low EC values may result from the undulating terrain, which facilitates percolation and drainage, thereby leaching soil salts after rainfall (Nachshon, 2018). Organic carbon (OC) content varies from low to high, ranging from 0.36 to 2.17% in surface soils and 0.15 to 0.80% in sub-surface soils. Land use and management practices influence OC levels, with upland soils exhibiting lower content (~0.50%) compared to medium to high levels in lowland paddy soils. The generally low organic matter content is likely due to the predominance of tropical climates, which accelerate organic matter decomposition and reduce vegetation cover (Srinivasan *et al.,* 2020). A variety of intricate connections between hydropedology and soil biogeochemistry, frequently involving the temporal and geographic variation in water, nutrients, and carbon are varied in landform structure and vegetation (Ma *et al.,* 2017). Base saturation (BS) and cation exchange capacity (CEC) range from 80 to 100% and 4.43 to 54.0 cmol (p^+) kg^{-1}, respectively, reflecting variations in clay content, organic carbon, and clay mineralogy across soil strata. Exchangeable bases in all pedons follow the order $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ on the soil exchange complex. Elevated exchangeable calcium in surface soils may result from its redistribution by plant activities and water movement (Yang *et al.,* 2024). This increased Ca^{2+} occupancy on colloidal exchange sites likely accounts for the enhanced base saturation observed in all the soil series. The degree of leaching was assessed by variations in base saturation (Vasu *et al.,* 2016).

3.4 | Soil Nutrient Contents

Soil fertility indicates nutrient levels and contributes to plant growth and productivity (Table 5). The N estimation was avoided since the available N content was often low. The amount of nitrogen in Indian soils is minimal. This widespread deficit, which stunts plant growth and reduces crop yields, is partly due to low organic matter content, considerable leaching, and runoff losses (Dey & Sekhon, 2016). Tight cycling and minimal mineral N loss result from biotic processes that focus on competition for mineral N between microbes and plants (Kaye & Hart, 1997). The available P varied from 1.0 to 71 kg ha^{-1} in different soils in the Dam catchment. Very low level in upland soils, Overall P rated as low and surface soils of lowlands are rated medium to high (23- 57 Kg ha^{-1}). On the other hand, lower soil horizons showed decreasing order and the surface horizons showed the maximum accessible P concentration. In poor land conditions, the application of complex fertilizers and phosphate to paddy and jasmine crops is increasing the availability of P (Srinivasan *et al.,* 2019). The greatest amount of soil P mobility and availability is determined by crop residue and water movement (Misal *et al.,* 2022). Due to the fixation of released P by clay minerals and iron and aluminum oxides, subsurface horizons have a lower P concentration than surface horizons. Soil's available K content ranged from 44 to 638 kg ha^{-1}. K fertilizer application, upstream K translocation from deeper depths, and groundwater capillary rise in a paddy environment all usually demonstrated a falling tendency with depth, with the highest accessible K content found in the surface and subsoils of the Dam catchment (Das *et al.,* 2022). Except for MLD soils, which had less organic matter in the intermediate and lower layers, the accessible S in soils ranged from 4.16 to 106.3 mg kg^{-1} and was generally evaluated as high (>20 ppm). In soils, available B ranged from 0.04 to 0.56 mg kg^{-1}, which is considered poor. The distribution of clay and organic carbon over several strata is correlated with available S and B. The soil's DTPA-extractable zinc content varied from 0.02 to 3.30 mg kg^{-1}. There was little deep variation in the vertical distribution of zinc. The threshold level for accessible zinc in these soils was 0.60 mg kg^{-1}, with the exception of the KLV soils' surface layer (Lindsay & Norvell, 1978). High soil pH levels may have contributed to the restricted amount of zinc available by forming insoluble calcium zincate or Zn complexes in poorly drained low land condition (Rahman *et al.,* 2022).

Each Pedon had a sufficient amount of available Cu (0.34 to 2.70 mg kg^{-1}), and each value was far greater than the critical limit of 0.20 mg kg^{-1} in soils. The DTPA-extractable Fe concentration of the soils varied from 0.76 to 74.50 mg kg^{-1}. The critical limit of 4.5 mg kg^{-1} shows that there was sufficient accessible Iron (Fe) in the surface layers but not in the subsoils. The distribution of available Fe across all pedons showed no obvious pattern, yet it abruptly decreased. The buildup of organic carbon in the surface horizons could be the cause of the availability. Because of the increased organic C, surface horizons showed higher quantities of DTPA-extractable Fe. The soil's accessible Mn content ranged from 0.36 to 11.30 mg kg^{-1}. The crucial limit of 1.0 mg kg^{-1} for accessible Mn was met by the soils, and it almost decreased with depth. This could have been due to increased biological activity and organic C in the surface strata. The chelation of organic compounds created during the breakdown of organic sources provides the basis for micronutrient availability. Micronutrient availability is based on the chelation of organic compounds produced during the decomposition of organic matter (Dhaliwal *et al.,* 2019). By considering the relationships between soil structure, flow pathways, and hydrology, hydropedology may integrate ecological and hydrologic perspectives on nutrient cycle and biogeochemistry when assessing various nutrient transport and transformation (Castellano *et al.*, 2012).

3.5 | Soil Classification

Based on morphological characteristics, analytical properties, and moisture regime inference, the five major soil series were classified to the subgroup level according to USDA Keys to Soil Taxonomy (Soil Survey Staff, 2014). The classification, family designations, and area extent are presented in (Table 2 and Fig. 2).

3.5.1 | Upland Alfisols

Two soil series were identified: Nagojanahalli (NGH), classified as Typic Haplustalfs (Fine-loamy, mixed, isohyperthermic), characterized by an argillic horizon, ochric epipedon, ustic moisture regime, and isohyperthermic temperature, with minimal horizon development. The Malayandahalli (MLD), classified as Rhodic Palustalfs (Fine-loamy, mixed, isohyperthermic), features darker red coloration, presence of argillic horizons with clay accumulation, well-drained, and more developed profile features, placing these soils in the Alfisol order, typical of subhumid to semi-arid regions with seasonal moisture deficits.

3.5.2 | Lowland Inceptisols

The Santhapuram series (STP) is a Typic Haplustepts (Fine-loamy, mixed, isohyperthermic, calcareous) based on a Cambic horizon (Bw1, BC) with alteration but no clay accumulation, too shallow (48 cm) for Alfisol or Mollisol, with ustic moisture, throughout profile calcareous, and indicating simple profile development; the Sundekuppam series (SDK) is a Fluvaquentic Haplustepts (Fine-loamy, mixed, isohyperthermic) with Cambic horizons (Bw1-Bw4), features of fluvial parent material, periodic saturation near aquic conditions, a deep profile (150 cm), and isohyperthermic temperature. “Fluvaquentic" suggests occasional saturation, with dark colors indicating possible saturation or organic matter; future monitoring may lead to reclassification. Inclusion of the drainage class warrants re-evaluation if hydrological data contradict observed morphology. Inceptisols are young, minimally developed soils in recently saturated or periodically saturated materials.

TABLE 4 Physico-chemical characteristics of the KRP Dam soils

Depth (cm)	pH (1:2.5) H_2O	EC (dS m^{-1})	OC (%)	AWC (%)	Exchangeable cations Ca	Mg	Na	K	Sum of cations	CEC	BS (%)
					(1 N $NH_4$0Ac, pH 7.0) cmol (p^+) kg^{-1}						
P1: Nagojanahalli (NGH) series											
0-16	6.76	0.116	0.36	5.44	3.24	0.68	0.04	0.15	4.11	4.43	93
16-37	6.92	0.049	0.17	6.77	8.95	1.43	0.05	0.16	10.59	11.54	92
37-90	7.42	0.091	0.15	6.48	11.3	3.78	0.08	0.15	15.31	14.42	100
P2: Malayandahalli (MLD) series											
0-23	7.34	0.075	0.41	5.91	3.60	1.95	0.03	0.12	5.70	7.09	80
23-53	7.53	0.080	0.41	7.99	6.44	3.95	0.65	0.07	11.12	11.99	93
53-88	7.62	0.078	0.20	6.66	6.89	3.74	0.61	0.06	11.30	11.77	96
88-109	7.88	0.074	0.24	6.75	9.29	3.56	0.71	0.06	13.62	13.95	98
P3: Kalveli (KLV) series											
0.14	7.75	1.140	0.43	13.34	9.12	4.85	1.65	0.28	15.90	15.97	100
14-28	8.18	0.649	0.58	12.61	9.85	4.23	1.36	0.35	15.78	15.45	100
28-54	8.62	0.226	0.54	9.66	8.00	3.20	0.43	0.15	18.43	7.21	100
54-78	8.70	0.245	0.80	8.09	10.2	3.40	0.78	0.30	14.68	13.18	100
78-98	8.76	0.260	0.60	12.36	11.3	4.21	0.78	0.25	16.54	14.52	100
P4: Santhapuram (STP) series											
0-21	6.74	0.499	2.17	11.89	5.73	3.44	0.92	0.42	10.50	12.15	86
21-38	8.17	0.336	0.21	9.52	9.23	5.21	1.01	0.46	15.91	15.39	100
38-48	8.30	0.335	0.16	10.41	11.3	5.29	1.18	0.47	18.29	17.74	100
P5: Sundekuppam (SDK) series											
0-19	8.01	1.640	1.49	7.84	23.5	12.32	6.74	0.93	43.53	43.12	100
19-49	8.36	1.100	0.41	11.44	24.0	14.20	7.02	0.60	45.82	43.22	100
49-75	8.87	1.040	0.35	9.92	25.0	15.45	10.72	0.34	51.51	49.20	100
75-110	9.10	1.340	0.29	18.33	24.0	14.00	14.27	0.24	52.51	51.55	100
110-150	9.19	0.528	0.29	22.39	25.0	13.20	18.07	0.28	56.55	54.00	100

TABLE 5 Nutrient's status of the KRP Dam soils

Depth (cm)	Macronutrients P	K	Secondary and Macronutrients S	B	Fe	Mn	Cu	Zn
	(Kg ha^{-1})		(mg kg^{-1})					
P1: Nagojanahalli (NGH) series								
0-16	9	174	12.13	0.15	4.64	5.68	0.34	0.12
16-37	7	189	13.64	0.17	2.90	5.42	0.62	0.04
37-90	6	187	8.34	0.26	1.86	2.82	0.56	0.04
P2: Malayandahalli (MLD) series								
0-23	5	104	4.16	0.47	8.22	3.06	0.68	0.16
23-53	3	58	6.66	0.56	6.18	11.3	0.66	0.08
53-88	4	44	5.83	0.26	4.40	8.36	0.50	0.14
88-109	3	49	5.00	0.35	4.02	6.94	0.36	0.10

continued on next page

Table 5 continued

Depth (cm)	Macronutrients P	K	Secondary and Macronutrients S	B	Fe	Mn	Cu	Zn
	← (Kg ha^{-1}) →		←			(mg kg^{-1})		→
P3: Kalveli (KLV) series								
0-14	71	323	106.3	0.23	7.78	1.38	2.04	1.76
14-28	52	360	56.34	0.15	5.32	1.46	1.94	0.80
28-54	16	210	16.66	0.07	2.86	1.08	0.56	0.14
54-78	14	363	13.49	0.24	1.38	1.26	1.08	0.04
78-137	18	316	15.87	0.16	1.24	1.10	0.48	0.02
P4: Santhapuram (STP) series								
0-21	64	359	59.16	0.36	74.5	2.18	2.70	3.30
21-38	3	349	20.83	0.04	3.70	0.46	1.76	0.12
38-48	8	367	19.16	0.15	2.04	0.36	1.28	0.18
P5: Sundekuppam (SDK) series								
0-19	57	638	58.33	0.12	6.70	3.40	2.16	1.06
19-49	5	384	36.66	0.12	2.04	1.70	1.44	0.20
49-75	1	248	17.50	0.09	1.32	1.02	0.68	0.14
75-110	3	203	21.66	0.27	1.20	1.20	0.90	0.18
110-150	1	207	45.00	0.12	0.76	1.92	1.18	0.10

3.5.3 | Lowland Entisols

Kalveli series (KLV) is classified as Typic Ustifluvents (Sandy, mixed, isohyperthermic, calcareous). It lacks diagnostic horizons, has fluvial parent material with stratification, shows a decrease in organic carbon with depth, and has a calcareous, sandy texture. Entisols are recent deposits, and the KLV series reflects alluvial deposition with limited horizon development. Soil-forming factors like drainage, moisture, landform, age, human activities, and parent material influence soil types. Well-drained uplands have more developed soils, while lowlands with saturation or recent deposition have less developed soils. Human activities like tillage disrupt horizons, complicating classification. Landscape position affects weathering, impacting classification, which can be uncertain based on climate and morphology. Hydrological conditions influence soil properties, but were not measured here.

Soils from five major Dam catchments were classified by the USDA based on their morphological traits and soil properties, influenced by climate, topography, and vegetation. Upland soils are mainly Alfisols (NGH: Typic Haplustalfs, MLD: Rhodic Palustalfs) due to argillic horizons and an ochric epipedon. STP and SDK soils are Inceptisols (STP: Typic Haplustepts, SDK: Fluvic Haplustepts) with cambic epipedons. Lowland Kalveli soil (KLV) is an Entisol, despite lacking epipedon and endopedon. Water fluctuations cause poor oxidation and biological activity, limiting development. Upland soils drain well, leading to rapid leaching and accumulation in lower layers.

3.6 | Correlation Analysis

The correlation between the different soil parameters is depicted on the network map; green lines indicate positive correlation, red lines indicate negative correlation, and the thickness of the line indicates the degree of the association (Fig. 3). Exchangeable Ca, Mg, Clay, and sum cations exhibit significant positive associations with CEC. Silt appears to have a positive correlation with both CEC and AWC (available water content), while AWC has a positive correlation with both CEC and clay. Results show that sandy soils have reduced nutrient retention and water-holding ability, and exhibit substantial negative associations with clay, CEC, and AWC. A few variables, such as BS and the sum of the bases, have negative associations with organic carbon (OC). The sum of the cations, exchangeable calcium, and pH all have a positive correlation with base saturation (BS). A similar outcome was also verified by Lalitha *et al.,* (2023). There are no measurable relationships between soil hydraulic functions and morphological features of soil structure. There is a strong correlation between the qualitative evaluations of micro-morphological features and unsaturated conductivity, which is linked to soil fluxes to macro-morphological elements (Vervoort & Cattle, 2003).

3.7 | Soil Management

Major soil variability in the KRP Dam catchment, based on the landforms, water movement, and their resources and management are given in Figure 4. Mango, ragi, pulses, and oilseed crops are grown on moderately to severely degraded upland soils (NGH and MLD). The soil's color ranges from dark reddish brown to dark red, depending on the well-drained, excess leaching of base cations (Ca, Mg, Na, and K), and the presence of iron and aluminum ions (Srinivasan *et al.,* 2021). Soils are shallow to fairly deep. The texture of the soil ranges from sandy loam to sandy clay, which is classified as having a medium amount of clay content and a low capacity to retain water. Adopting soil-based land use methods, applying organic manures to promote soil fertility, and using carbon-enhancing techniques to increase sequestration are all ways to manage upland soils (Li *et al.,* 2025). Various soil and water conservation techniques are used to manage soil erosion issues (Raj *et al.,* 2024). In the KRP Dam basin, paddy, coconut, and jasmine are mostly supported by lowland soils (KLV, STP, and SDK). The soils have a high clay concentration, are deep, poorly drained, and have a high AWC. Excess calcium and sodium salts make the soil unsuitable for various cropping systems, and inadequate drainage results in poor water quality and workability. Management of lowland paddy soils where need to be adopt suitable drainage systems, and excess salt content in water and soils needs to be evaluated and recommended suitable reclamation techniques to improve crop performances and productivity (Kumar *et al.,* 2022). To increase the contribution of hydropedology to the hydrology with respect to land use in KRP catchments by measuring crop yield and soil water regime. Hydropedologists might be able to make a substantial contribution with similar work on other land-use and climate change issues (Vepraskas *et al*., 2009)

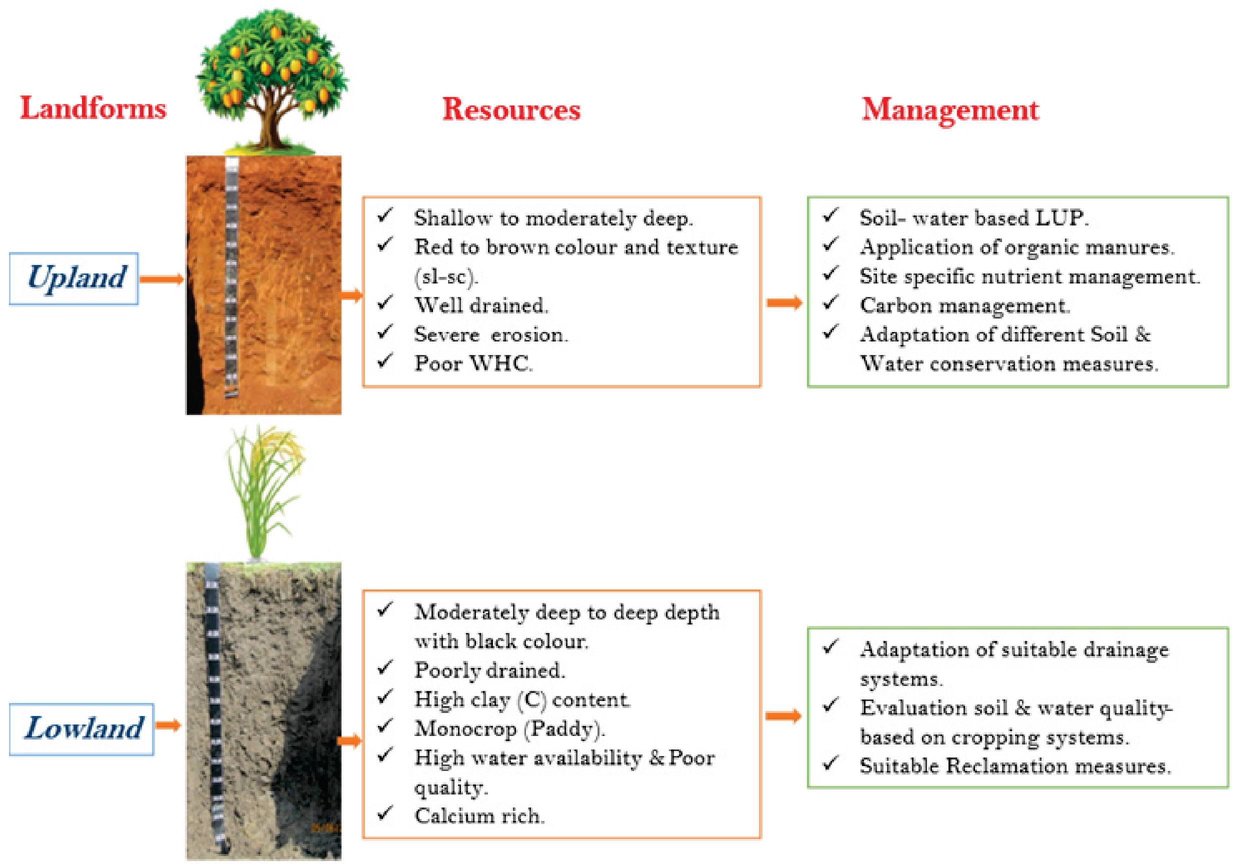

FIGURE 4 Conceptual framework for soil and water management based on identified soil limitations (**Proposed interventions require field validation*)

4 | CONCLUSIONS

A detailed soil survey of the KRP Dam catchment at a 1:10,000 scale identified five major soil series with distinct properties linked to landform position. Variations in soil characteristics support topography's influence on pedogenesis. Upland soils (Nagojanahalli and Malayandahalli, classified as Alfisols) are moderately deep (90-109 cm), well-drained, dark reddish-brown to reddish-brown, with sandy loam to sandy clay textures and argillic horizons. These soils show moderate to severe erosion, low organic carbon (0.15-0.41%), limited water holding capacity (5.44-7.99%), and nutrient depletion (P: 3-9 kg ha^{-1}), requiring soil conservation, organic matter, and fertility management. Coarse fragments (15-40%) further reduce agricultural potential. Lowland soils (Kalveli, Santhapuram, and Sundekuppam, classified as Entisols and Inceptisols) exhibit features of periodic saturation: dark gray to black colors, massive, puddled surface horizons, and higher clay content (37-58%). They have higher water capacity (11.89-22.39%), better nutrients (available P: 23-71 kg ha^{-1}), and greater cation exchange capacity (43-54 cmol [p^{+}] kg^{-1}). Yet, they also show elevated electrical conductivity (up to 1.64 dS m^{-1}), alkaline pH (8.01-9.19), and zinc deficiency (<0.60 mg kg^{-1}), indicating potential issues with drainage, salinity, and micronutrient availability. Correlation analysis revealed strong positive relationships between clay, cation exchange capacity, silt, and exchangeable bases, and negative correlations with sand. These findings highlight the importance of soil texture in nutrient retention and water holding capacity, supporting texture-based management zoning.

Several limitations must be acknowledged. First, drainage class assignments relied solely on morphological indicators like soil color, structure, and landscape position, without direct water table measurements or hydrological monitoring. The classification of soils as "periodically saturated" or "poorly drained' is inference, not measured hydrology. Second, while the study identifies areas with contrasting pedological features, soil-water dynamics such as seasonal water table fluctuations, hydraulic conductivity, and moisture patterns remain unquantified. Third, proposed management interventions for upland soils (contour bunding, organic amendments, water conservation structures) and lowland soils (subsurface drainage, gypsum, zinc) are conceptual and require validation through controlled experiments with replication and farmer participation. Future research should include: (i) installing piezometric networks for water table monitoring; (ii) using soil moisture sensors; (iii) measuring hydraulic conductivity; (iv) assessing irrigation water quality; (v) setting up long-term experimental plots to test management options with economic analysis; and (vi) integrating soil and hydrological data to develop quantitative models. Despite limitations, this study contributes by: (a) providing the first detailed soil map of the KRP Dam catchment at 1:10,000 scale, creating a baseline for future monitoring; (b) characterizing soil variability across 8,477 ha (67.94%) with 92 profiles; (c) identifying soil-landscape relations to guide precision agriculture; (d) documenting soils supporting current cropping systems; and (e) establishing a framework for future hydropedological research. In conclusion, the data offers an essential baseline for land use and agriculture planning. Soils indicating water regimes offer initial management guidance, but hydropedological understanding needs integration with hydrological monitoring. The proposed framework is a research agenda needing field validation, not ready-to-implement recommendations. This study lays the pedological groundwork for future soil-hydrology research to develop site-specific strategies for sustainable agriculture and ecosystem management in dam-affected areas.

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CONFLICT OF INTEREST

There is no conflict of interest in the study.

DATA AVAILABILITY STATEMENT

Data is available with the corresponding author and will be provided if it's required.

AUTHOR CONTRIBUTION

SR: Concept planning, Field survey and data preparation, Methodology and drafting manuscripts.

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