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Assessment of Soil Properties Across the Land form Variability in Cauvery Command Area

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ABSTRACT

The sustainability of agriculture in India is increasingly challenged by soil degradation, salinity and declining soil fertility due to intensive cropping and poor water management. The study assessed the variability of key soil properties in the Cauvery command area of Mandya district, Karnataka, to understand their distribution and relationship under varied topography. The surface soil samples were collected and were analysed for physical and chemical properties, including soil texture, moisture constants, pH and electrical conductivity (ECe) of saturation paste extract and exchangeable cations. The results indicate a predominance of clay loam soils, with clay content ranging from 19.02 to 45.59 per cent. Soil moisture constants varied with maximum water-holding capacity (MWHC) ranging from 21.05 to 59.31 per cent, reflecting the influence of soil texture on water retention. Soil pH values ranged from 6.36 to 8.50, while ECe varied from 0.16 to 11.60 dSm^{-1}, highlighting the critical salinity issues in the low lands of water logged areas. Variations in soil properties across upland, midland and lowland regions were observed, with lowland areas showing higher clay content, moisture retention and salinity (2.77, 2.21 and 1.94dSm^{-1} in low, mid and uplands respectively) levels due to prolonged water stagnation and poor drainage. The findings emphasize the need for targeted soil and water management strategies to mitigate soil degradation and enhance agricultural productivity.

Keywords : Cauvery command area, Topography, Soil salinity

AGRICULTURE is a vital sector for the Indian economy, contributing 18 per cent to the national GDP and employing 60 per cent of the population (Parameswaran *et al*., 2018). It provides livelihoods for millions and plays a crucial role in maintaining food security and economic stability. However, the sustainability of agriculture faces growing challenges, including soil health deterioration, declining water resources, groundwater contamination and increasing salinity levels, primarily due to intensive farming practices (Sharma and Bali, 2017). A report by Mee *et al*. (2017) highlights the widespread issue of multi-nutrient deficiencies in Indian soils. These concerns have been addressed in several global scientific reviews (Bationo *et al*., 2007; Meena *et al*., 2017 and Park *et al*., 2022) emphasizing the urgent need for sustainable land and water management practices.

The Cauvery is, one of the major rivers in Southern India, plays a vital role for agriculture of Karnataka and Tamil Nadu. Its tributaries, which feed into the Krishna Raja Sagara (KRS) reservoir and a complex canal network in the Mandya and Mysore districts, provide irrigation to a lush landscape primarily dominated by paddy and sugarcane crops. These crops occupy around 70 per cent of the area (Shwetha *et al.*, 2021), highlighting the region's heavy dependence on agriculture. However, the dependency on a few major crops poses significant challenges.

The continuous monoculture of paddy and sugarcane in the Cauvery command area has resulted in shallow perched water table, worsening soil degradation, especially from salinity and sodicity and reducing overall productivity (Gopalakrishnana and Kumar, 2020). The excessive use of irrigation with out adequate drainage further contributes to salt accumulation in the soil, disrupting its structure and hindering crop growth and yields (Moharana *et al.*, 2019). As a result, the sustainability of agriculture in this region is under serious threat, requiring immediate action to implement better water management practices and diversify crop cultivation to enhance soil health and ensure long-term agricultural productivity.

The Cauvery command area exhibits considerable topographic variation, ranging from lowland flood plains near the river and canals to midland and upland regions with undulating terrain. The topographic differences significantly influence soil properties such as texture, moisture retention, organic matter content and salinity levels. Lowland areas, often subject to prolonged water logging, tend to accumulate finer particles, organic matter and soluble salts, leading to higher salinity and lower drainage efficiency. In contrast, midland regions shows a moderate soil development with variable fertility, while upland soils, characterized by better drainage, often exhibit lower organic matter and nutrient availability due to runoff anderosion. Understanding the variability is crucial for implementing site-specific soil management strategies. Assessing soil properties across different topographic positions lowland, midland and upland provides critical insights for optimizing land use planning, improving soil health and ensuring sustainable agricultural productivity.

To address these challenges, a comprehensive management strategy must be developed. A key component is to understand the variability of different soil properties. With this background, the present study was conducted with the objectives of assessing the variability of soil properties in the Cauvery command area of Mandya district and evaluating the influence of topography on soil properties.

MATERIAL AND METHODS

Description of the Study Area and Sampling Technique

The study area (Fig. 1), located in the Southern Dry Zone of Karnataka, covers 1,72,719 ha and receives irrigation from the Krishna Raja Sagara reservoir. The region has varied relief, with elevations between 455 m and 930 m and experiences a semi-arid climate with 770 mm annual rainfall and a mean temperature of 31°C. The soils are derived from granite and granite gneiss with varied soil texture from coarse texture to fine textured distributed with predominant soil orders of Entisols, Inceptisols and Alfisols. The command area is mainly cultivated with water-guzzling crops like sugarcane and paddy.

During summer 2023, a random sampling technique was followed to collect surface soil samples with sampling locations as depicted in Fig. 1. A total of 289 surface soil samples (0-15 cm depth) were collected with ancillary data *viz.,* geographic coordinates, parent material, topography, landform features, elevation, natural vegetation and current land use. The soil physico-chemical properties *viz.,* pH and EC of saturation paste extract, particle size analysis, exchangeable cations and soil moisture constants of the collected soil samples were analysed by following standard procedures as outlined by Jackson (1973).

Variability Assessment : A correlation study was conducted to assess if elevation is having influence on soil properties and then soil samples were categorized into lowland, midland and upland regions based on elevation from mean sea level as

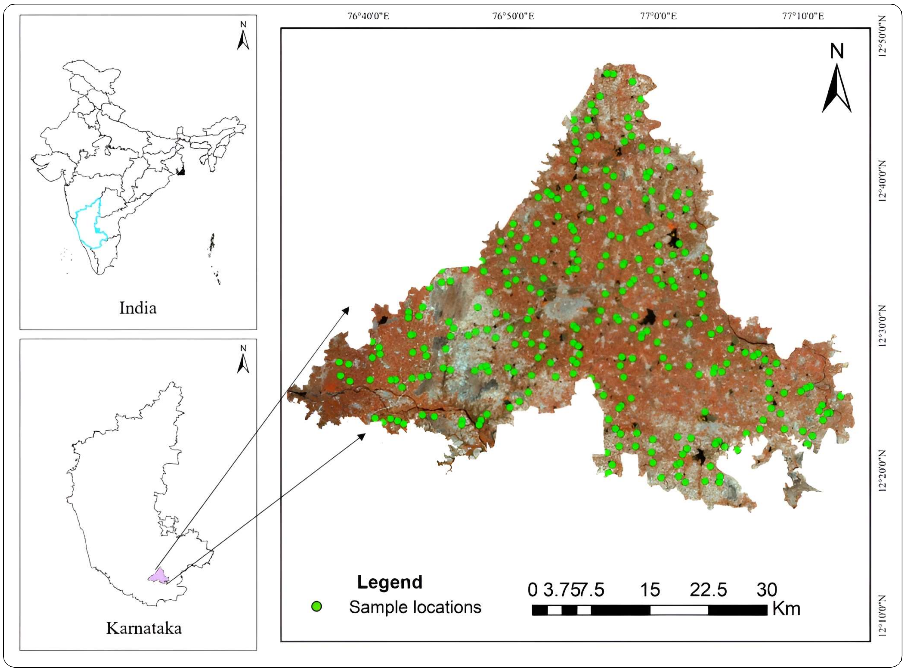

Fig. 1 : Location map of the study area and sampling locations

well as topography as whole. Various soil properties analyzed under varied land configurations, the data subjected for statistical analysis *viz.,* coefficient of variation, mean, kurtosis, skewness and standard deviation to understand their distribution and variability. Whereas, the particle size information of soil samples was plotted on USDA textural triangle using soilR package in R-studio to know the textural distribution. The statistical analyses help to identify key differences in soil characteristics across different topographic positions, aiding in the development of targeted soil management strategies to enhance agricultural productivity and sustainability.

Results and Discussion

Results of various soil properties analysed are presented in Table 1. Soil texture analysis revealed distinct variations in sand, silt and clay fractions. Clay content ranged from 19.02-45.59% (mean: 34.53%, CV: 11.97%), silt from 19.19-32.41% (mean: 26.84%, CV: 10.06%) and sand from 26.74-59.96% (mean: 38.63%, CV: 13.45%). Sand distribution showed positive skewness (1.30), indicating more samples with lower sand content, aligning with the predominance of clay. USDA textural triangle (Fig. 2) classified most samples as clay loam, reflecting a balanced proportion of sand, silt and clay.

The predominance of clay loam texture in the Cauvery command area is influenced by geological and climatic factors that enhance mineral weathering and

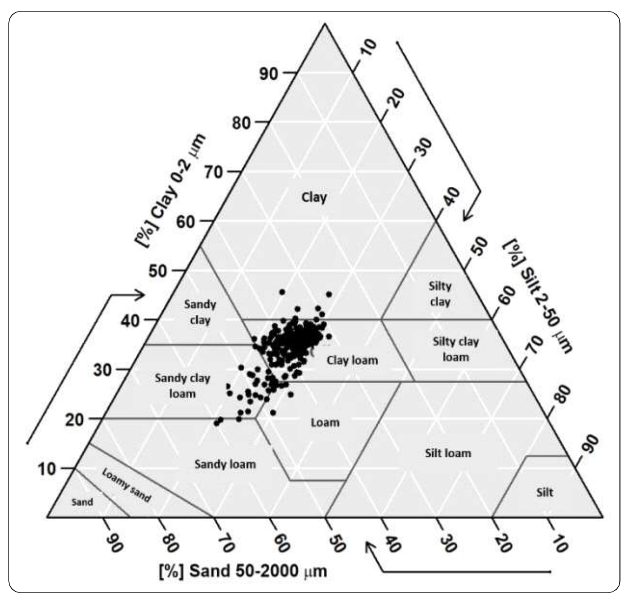

Fig. 2 : Soil texture distribution of the command area of Mandya district

TABLE 1
Descriptive statistics of soil properties in Cauvery command area of Mandya

Soil property		Max	Min	Mean	Kurtosis	Skewness	SD	CV
Clay	(%)	45.59	19.02	34.53	2.37	-1.35	4.13	11.97
Silt	(%)	32.41	19.19	26.84	-0.23	-0.68	2.70	10.06
Sand	(%)	59.96	26.74	38.63	2.13	1.30	5.19	13.45
MWHC	(%)	59.31	21.05	41.47	0.46	-0.03	6.18	14.90
FC	(%)	35.44	20.37	30.32	1.65	-0.51	2.19	7.21
PWP	(%)	19.75	9.01	15.89	1.30	-0.51	1.69	10.64
AWC	(%)	16.23	11.35	14.43	0.36	-0.62	0.76	5.24
ECe	(dS m^{-1})	11.60	0.16	2.35	6.17	1.51	1.45	61.84
pHs	-	8.50	6.36	7.48	-0.13	-0.43	0.38	5.10
Ca	(cmol (p+) kg^{-1})	20.70	0.80	8.67	-0.36	0.49	4.23	48.78
Mg	(cmol(p+) kg^{-1})	15.10	0.40	5.09	1.03	1.12	3.11	61.00
Na	(cmol(p+) kg^{-1})	6.90	0.03	0.50	34.19	5.33	0.77	153.62
K	(cmol(p+) kg^{-1})	0.85	0.03	0.20	4.48	1.79	0.13	64.44

clay accumulation under aquic conditions. In tropical regions like southern India, higher temperature and rainfall promote erosion and leaching, leading to clay enrichment in lower landscapes. The stable silt fraction suggests consistent depositional conditions, likely influenced by flood plain dynamics. Minimal silt variability indicates lower susceptibility to erosion, while higher sand variability may result from localized differences in parent material (Jenny, 1941). The variability in soil moisture constants, including maximum water holding capacity (MWHC), field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC) are closely related to the soil texture (Malavathi and Mani, 2015).

The soil texture in the study area is varying from *sandy loam* to *clay* with predominance of *Clay loam* soils (Fig. 2). Hence, the MWHC values showed wider range from 21.05 to 59.31 per cent, with a mean of 41.47 per cent, indicating that areas with higher clay content tend to retain more water, aligning with the general principle that finer textured soils have a higher water retention capacity (Zettl *et al*., 2011). This clearly indicates that clay rich soils can retain significant amount of water, indicating sufficiency to high water demanding crops like paddy and sugarcane. The FC in the study area ranged from 20.37 to 35.44 per cent (mean of 30.32%) also reflects the influence of soil texture, with finer fractions like clay and silt retaining more water compared to sandy soils.

The variation in soil moisture retention indicates that higher elevation areas with more sand (mean: 38.63%) drain water faster, leading to lower FC, similar to findings by Deb *et al*. (2014) in Sikkim. PWP ranges from 9.01 to 19.75 per cent (mean: 15.89%) and is influenced by soil texture, with lower PWP suggesting adequate moisture retention for plant growth. AWC (11.35 to 16.23%, mean: 14.43%) reflects the balance between FC and PWP, with clay rich areas providing better water availability for crops.

The pH of the saturation paste extract (pHs) ranges from 6.36 to 8.50 (mean: 7.48), indicating neutral to slightly alkaline conditions, which influence nutrient availability and microbial activity (Neina, 2019). Lower pHs favours nutrient accessibility, while higher pHs (>7.5) may lead to micronutrient deficiencies. Electrical conductivity (ECe) varies from 0.16 to 11.60 dS m^{-1} (mean: 2.35 dS m^{-1}), reflecting non-saline to saline conditions. Variability in pHs and ECe is influenced by excess irrigation with poor drainage and evaporation of water leaving behind the salts on soil surface.

Exchangeable cations *viz*. Ca, Mg, Na and K showed considerable variability, influenced by soil mineralogy, management and natural processes. Ca ranges from 0.8-20.7 cmol (p+) kg^{-1} (mean: 8.67, CV: 48.78%), with a balanced distribution, crucial for soil structure and root health. Mg varies more (0.4-15.1 cmol(p+) kg^{-1}, mean: 5.09, CV: 61%), influenced by parent materials and groundwater use (Meena *et al.,* 2017). High Na variability (0.03-6.9 cmol(p+) kg^{-1}, mean: 0.5, CV: 153.62%) indicates sodicity risks, requiring gypsum amendments in affected areas (Deb *et al*., 2014). K levels (0.03-0.85 cmol (p+) kg^{-1}, mean: 0.2, CV: 64.44%) suggest depletion in intensively farmed or sandy soils, necessitating targeted fertilization (Wang *et al*., 2008). The balance of these cations is vital for base saturation and soil fertility.

Influence of Elevation on Soil Properties

The correlation analysis revealed that elevation has a measurable influence on several soil physical and chemical properties in the Cauvery command area (Table 2), indicating the relevance of topographic position in understanding soil variability.

Among the soil texture fractions, sand content showed a positive correlation with elevation (0.228), while clay (-0.125) and silt (-0.247) exhibited weak negative correlations. The results highlight the textural variations among varied elevations, the coarse and finer textured soils were observed in higher and in lower elevations respectively. Soil moisture constants, including FC (-0.227), PWP (-0.150) and AWC (-0.322), were negatively correlated with elevation, suggesting moisture retention capacity is generally higher in lower topographic zones with clay dominated soils. Strong internal correlations among these moisture parameters (e.g., FC and PWP, r=0.956) and their positive relationships (0.224 to 0.628) with clay content highlights their inter dependence.

Electrical conductivity and pH of saturation paste extract also showed weak negative correlations (-0.217 and -0.154) with elevation, indicating a trend of increasing salinity and alkalinity towards lower elevations due to cultivation of water guzzling crops like paddy and sugarcane. While, exchangeable cations, Ca (-0.263) and Mg (-0.295) exhibited moderate negative correlations with elevation, while Na-0.199) and K (-0.113) showed lesser trends.

TABLE 2

Correlation between soil properties and elevation

	Elevation	CLAY	SILT	SAND	MWHC	FC	PWP	AWC	Ece	pHs	Ca	Mg	Na	K
Elevation	1.000													
CLAY	-0.125	1.000												
SILT	-0.247	0.118	1.000											
SAND	0.228	-0.857	-0.613	1.000										
MWHC	-0.159	0.493	0.059	-0.423	1.000									
FC	-0.227	0.563	0.343	-0.626	0.616	1.000								
PWP	-0.150	0.628	0.085	-0.544	0.637	0.956	1.000							
AWC	-0.322	0.224	0.803	-0.595	0.356	0.754	0.527	1.000						
Ece	-0.217	0.122	-0.043	-0.075	0.347	0.222	0.244	0.097	1.000					
pHs	-0.154	0.122	-0.116	-0.036	0.368	0.188	0.238	0.012	0.686	1.000				
Ca	-0.263	0.248	0.039	-0.217	0.573	0.413	0.419	0.258	0.532	0.590	1.000			
Mg	-0.295	0.123	0.060	-0.129	0.463	0.316	0.300	0.244	0.334	0.338	0.492	1.000		
Na	-0.199	0.133	0.015	-0.114	0.296	0.105	0.107	0.064	0.661	0.456	0.309	0.345	1.000	
K	-0.113	0.040	0.028	-0.047	0.202	0.154	0.145	0.119	0.130	0.015	0.138	0.272	0.048	1.000

Notably, Na was strongly correlated with ECe (0.661), suggesting a potential link between sodium and other salt accumulation leading to develop salt affected soils.

The correlation study suggests that, elevation is one of the key factor influencing soil properties, emphasising the need for assessing their variability across upland, midland and lowland regions to guide targeted soil and land management practices.

Variability of Soil Characteristics Under Upland, Midland and Low Land Conditions

Elevation in the study area varied from 455 to 930 m above mean sea level. The 289 soil samples were categorized into three elevation classes: upland (>720 m), midlands (656 to 720 m) and lowlands (<656 m). Among the samples, 91 were grouped under lowland soils, 161 as midland soils and 37 as upland soils. The variation in soil properties across these elevation categories were assessed and is presented in Tables 3 to 5 and Fig. 3 to 6.

Soil texture varied significantly across lowland, midland and upland areas in the study region (Fig. 3), influenced primarily by topographic and hydrological factors. Lowland soils exhibited the higher clay (35%) and silt (27.44%), with a lower sand content (37.55%). The textural distribution is the characteristic of lowlands, where flat terrain and reduced water flow allow finer particles like clay and silt to settle and accumulate. The favourable environment facilitate sediment deposition, particularly of finer particles transported from higher elevations (Ananthakumar and Meghana, 2022). Additionally, the higher kurtosis and skewness in lowland clay and silt suggested a predominant distribution with a few instances of higher clay and silt concentrations due to prolonged water logging (Seibert *et al*., 2007).

Soil moisture constants also varied across elevations due to soil texture differences (Fig. 4). Lowland soils, rich in clay and silt, retained the most moisture (MWHC: 42.11%, FC: 30.36%, PWP: 15.78%, AWC: 14.59%), aligning with findings from Mandal *et al.* (2021). Midland soils had moderate moisture retention (MWHC: 41.84%, FC: 30.8%, AWC: 14.53%, PWP: 16.28%) balancing water retention and drainage (Meerveld and McDonnell, 2006). Upland soils, with higher sand content, showed the lowest moisture constants (MWHC: 38.27%, FC: 28.12%, AWC: 13.64%), enabling faster drainage. These variations impact irrigation planning and crop management.

TABLE 3

Descriptive statistics of soil properties in lowlands (N= 91)

Soil property		Max	Min	Mean	Kurtosis	Skewness	SD	CV
Clay	(%)	45.59	19.02	35.00	4.75	-1.49	4.18	11.93
Silt	(%)	31.48	19.21	27.44	1.22	-1.27	2.71	9.89
Sand	(%)	59.96	26.74	37.55	5.27	1.98	5.22	13.90
MWHC	(%)	59.25	31.55	42.11	0.30	0.48	5.96	14.15
FC	(%)	35.13	26.75	30.36	0.03	0.51	1.73	5.71
PWP	(%)	19.75	13.40	15.78	0.08	0.74	1.43	9.05
AWC	(%)	15.61	12.60	14.59	1.08	-1.05	0.64	4.35
ECe	(dS m^{-1})	11.60	0.16	2.77	9.34	1.83	1.59	57.22
pHs	-	8.36	6.41	7.57	0.65	-0.89	0.38	5.00
Ca	(cmol (p+) kg^{-1})	20.70	0.80	9.74	-0.39	0.03	4.36	44.75
Mg	(cmol (p+) kg^{-1})	14.80	1.00	5.75	0.78	1.00	3.08	53.60
Na	(cmol (p+) kg^{-1})	6.90	0.04	0.70	20.46	4.24	1.01	144.41
K	(cmol (p+) kg^{-1})	0.85	0.04	0.22	6.03	2.08	0.14	62.60

TABLE 4

Descriptive statistics of soil properties in midlands (N= 161)

Soil property		Max	Min	Mean	Kurtosis	Skewness	SD	CV
Clay	(%)	42.12	19.74	34.66	2.12	-1.46	3.87	11.17
Silt	(%)	32.41	19.19	26.88	-0.36	-0.56	2.57	9.56
Sand	(%)	58.92	30.95	38.46	1.89	1.26	4.91	12.77
MWHC	(%)	59.31	21.05	41.84	0.63	-0.13	5.96	14.25
FC	(%)	35.44	24.79	30.80	0.23	-0.28	2.01	6.54
PWP	(%)	19.57	10.72	16.28	1.00	-0.59	1.56	9.59
AWC	(%)	16.23	12.78	14.53	-0.43	-0.35	0.71	4.88
ECe	(dS m^{-1})	8.90	0.37	2.21	3.30	1.26	1.37	62.05
pHs	-	8.50	6.36	7.43	-0.13	-0.27	0.39	5.19
Ca	(cmol (p+) kg^{-1})	20.10	1.10	8.52	-0.22	0.68	4.17	48.98
Mg	(cmol (p+) kg^{-1})	15.10	0.40	5.19	1.03	1.16	3.15	60.71
Na	(cmol (p+) kg^{-1})	6.18	0.03	0.44	40.25	5.67	0.66	149.58
K	(cmol (p+) kg^{-1})	0.64	0.03	0.19	1.62	1.32	0.12	62.75

TABLE 5

Descriptive statistics of soil properties in uplands (N= 37)

Soil property		Max	Min	Mean	Kurtosis	Skewness	SD	CV
Clay	(%)	41.12	21.40	32.83	-0.17	-0.88	4.66	14.19
Silt	(%)	29.77	20.25	25.16	-0.82	-0.16	2.52	10.01
Sand	(%)	54.61	29.94	42.01	1.25	0.64	4.94	11.75
MWHC	(%)	49.49	22.24	38.27	-0.41	-0.23	6.67	17.42
FC	(%)	34.71	20.37	28.12	2.43	-0.76	2.53	9.01
PWP	(%)	19.14	9.01	14.48	1.15	-0.74	2.00	13.85
AWC	(%)	15.57	11.35	13.64	1.98	-0.37	0.76	5.55
ECe	(dS m^{-1})	6.07	0.44	1.94	1.92	1.04	1.20	62.10
pHs	-	8.05	6.90	7.46	-1.13	-0.06	0.32	4.34
Ca	(cmol (p+) kg^{-1})	14.60	1.60	6.66	-0.32	0.52	3.19	47.87
Mg	(cmol (p+) kg^{-1})	8.10	0.70	3.08	0.50	1.07	1.94	63.07
Na	(cmol (p+) kg^{-1})	0.81	0.07	0.27	1.59	1.47	0.18	67.91
K	(cmol (p+) kg^{-1})	0.75	0.05	0.18	9.64	2.64	0.13	73.32

The pHs and ECe in the Cauvery command area varied across lowland, midland and upland regions, influenced by topography and landform features (Fig. 5). Lowland soils exhibited moderate pHs variability (6.41-8.36, mean 7.57, CV = 5%) with a slight negative skew (-0.89). ECe showed high variability (0.16-11.6 dSm-1, mean 2.77, CV = 57.22%), indicating salinity issues due to poor

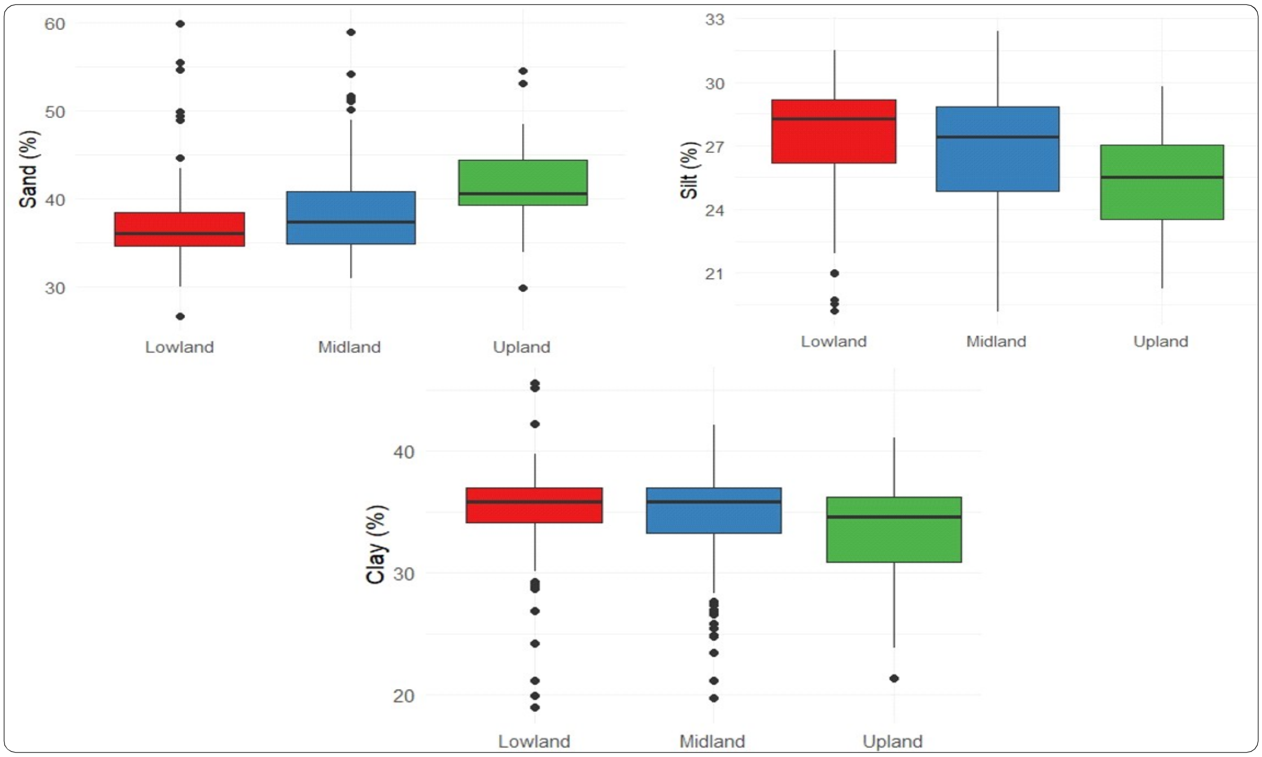

Fig. 3 : Variability of soil textural fractions in upland mid land and low lands of the study area

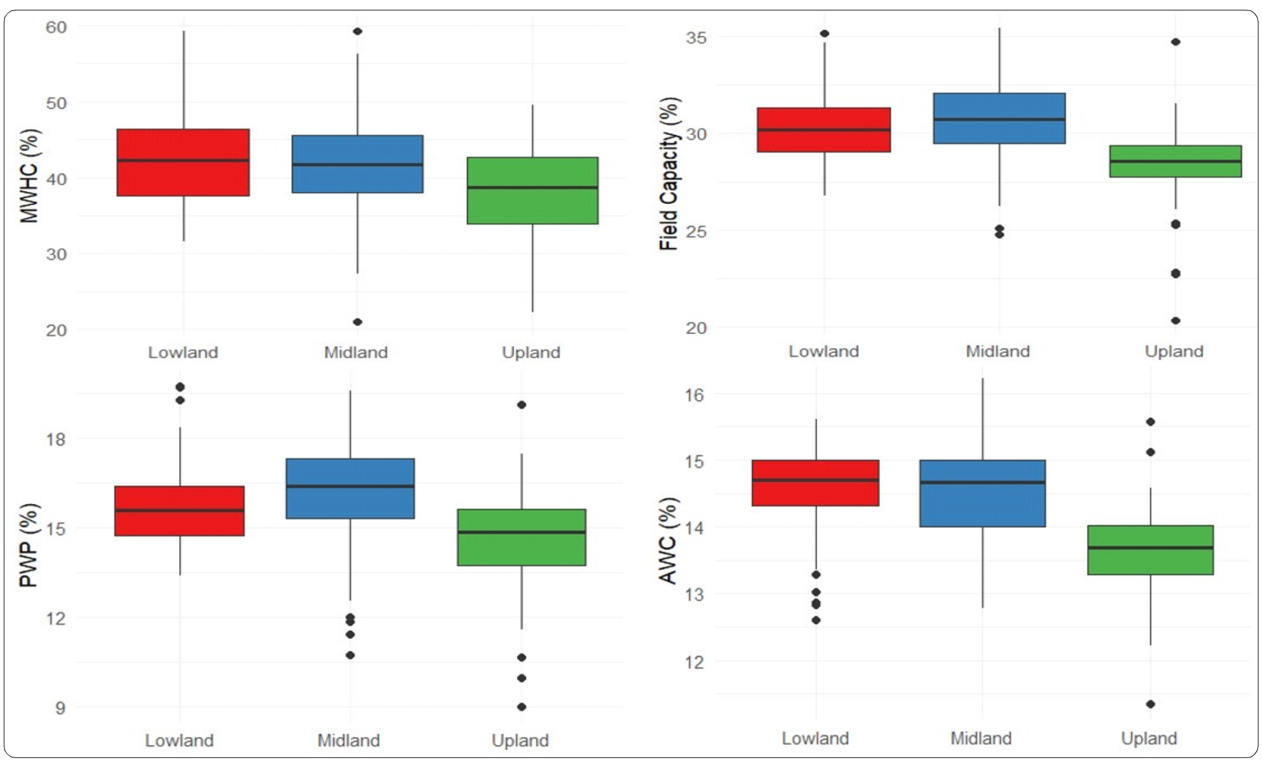

Fig. 4 : Variability of soil moisture constants in upland mid land and low lands of the study area

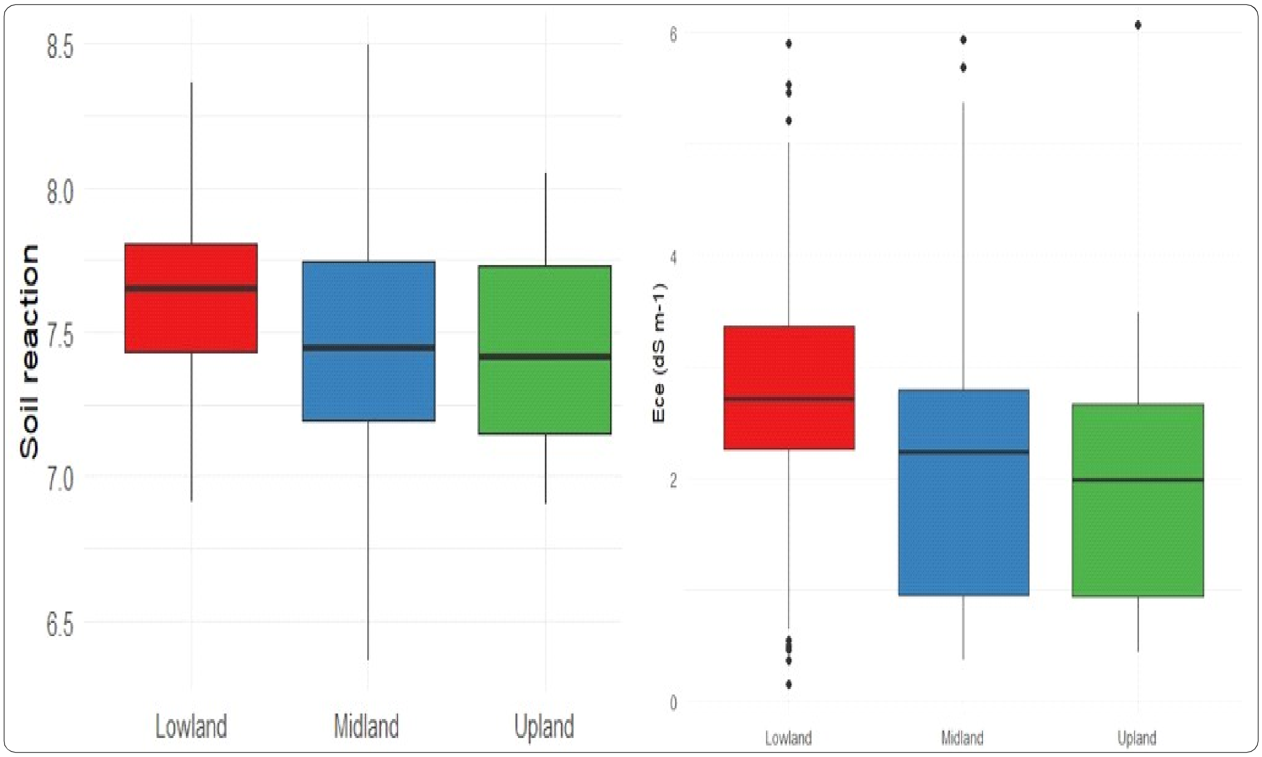

Fig. 5: Variability of soil pH and electrical conductivity in upland mid land and low lands of the study area

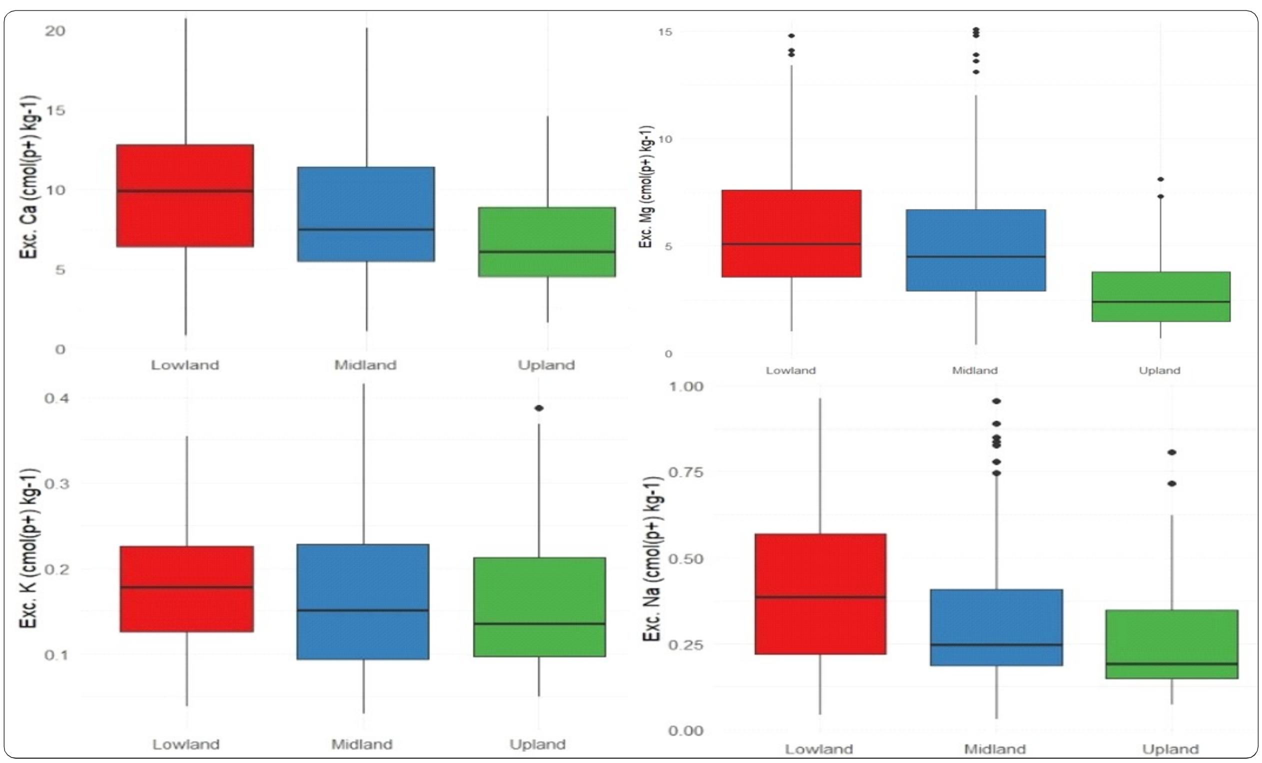

Fig. 6 : Variability of exchangeable cations in upland mid land and low lands of the study area

water management. Midland soils had similar pHs variability (6.36-8.5, mean 7.43, CV = 5.19%) and moderate salinity variation (ECe: 0.37-8.9 dSm^{-1}, mean 2.21 dSm^{-1}, CV = 62.05%). Upland soils had the least pHs variability (6.9-8.05, mean 7.46, CV = 4.34%) and lower salinity levels (ECe: 0.44-6.07, mean 1.94, CV = 62.1%).

The distribution of exchangeable cations *viz*., Ca, Mg, Na and K, varied considerably across elevation classes. Lowland soils showed the highest mean concentration of Ca (9.74 cmol (p+) kg^{-1}) and Mg (5.75 cmol (p+) kg^{-1}), which can be attributed to lower elevations, finer texture and better retention of cations due to the higher clay content (Meena *et al*., 2017). Na and K concentrations in lowlands were slightly higher than midland and upland regions, with a mean of 0.7 cmol (p+) kg^{-1} for Na and 0.22 cmol (p+) kg^{-1} for K, suggesting moderate accumulation of basic cations. Midland soils exhibited similar cation concentrations to lowlands but with slightly lower mean values for Ca (8.52 cmol (p+) kg^{-1}) and Mg (5.19 cmol (p+) kg^{-1}), likely due to a balanced texture that allows moderate leaching and retention (Fogg *et al*., 2004). In upland soils, the lower mean values were observed for Ca (6.66 cmol (p+) kg^{-1}) and Mg (3.08 cmol (p+) kg^{-1}), as well as for Na (0.27 cmol (p+) kg^{-1}) and K (0.18 cmol (p+) kg^{-1}), which reflects higher sand content and greater drainage in these areas, leading to reduced cation retention. Variability in Na levels was particularly high, as indicated with higher CV value of 144.41, 149.58 and 67.91 per cent for lowland, midland and upland soils, respectively, due to the sporadic nature of sodium accumulation. Skewness and kurtosis values also suggest non normal distributions for Na and K across regions, with higher skewness in uplands, indicating occasional elevated values (Deb *et al*., 2014). Similar findings of higher concentration of exchangeable cations in lowlands compared to uplands was reported in various studies (Wang *et al*., 2008 and Deb *et al*., 2014). These observed variations suggest that elevation related factors such as soil texture and drainage may influence the spatial distribution of exchangeable cations, with potential implications for soil fertility management.

These findings highlight the need for targeted soil management: salinity control in lowland areas, balanced soil health maintenance in midland zones and degradation prevention in uplands. Improved water management strategies are essential to sustain agricultural productivity (Harsha *et al*, 2020).

The study highlights the variability of soil properties in the Cauvery command area and their strong association with topography. The predominance of clay loam soils and variations in moisture retention, pHs and salinity stress the need for improved water management practices. Lowland coupled with water logging areas are more susceptible to salinity due to poor drainage, while upland soils with higher sand content, exhibit faster water loss. The variations have important implications for irrigation planning and crop selection. To sustain long-term agricultural productivity, strategies such as crop diversification, improved drainage systems and site-specific soil amendments should be implemented. The findings provide valuable insights for policymakers, farmers and researchers aiming to optimize land and water management strategies.

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