



Physico-chemical analysis of soil samples collected from different dams of Karauli District, Rajasthan

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Abstract

The current study aims to showcase comparative soil quality of six different regions of Karauli, including Panchana dam (Site 1), Rangwana ka talab (Site 2), Needar Dam (Site 3), Jaggar dam (Site 4), Sagar (Site 5) and Kalisil dam (Site 6) during summer season (March-June), monsoon season (July-October) and Winter season (November-February). pH showed significant seasonal fluctuations, ranging from 7.30–8.12, with the highest values in summer and the lowest in winter. EC varied between 0.27–0.56 dS/m, recording maximum concentrations during summer due to salt accumulation and minimum values during winter and rainy seasons. Organic content differed substantially across seasons, with the lowest levels in summer (0.13–0.58%) and highest levels in winter (0.18–0.75%), reflecting the influence of temperature and moisture on microbial decomposition. Macronutrients demonstrated clear seasonal trends: phosphorus varied from 27–58 kg/ha, sulphur from 7–16 kg/ha, and potassium from 265–380 kg/ha, with all three nutrients showing maximum availability in winter and minimum in summer. Similarly, micronutrient concentrations displayed strong seasonal dependence, with Zn (0.24–0.58 ppm), Fe (4.20–6.50 ppm), Cu (0.20–0.70 ppm), and Mn (2.60–4.35 ppm) peaking during winter when cooler, moist conditions enhanced solubility and nutrient mobility. Overall, the findings demonstrate that soil fertility parameters follow the distinct trend winter > rainy > summer, highlighting the substantial influence of seasonal environmental conditions on nutrient availability. These results offer valuable insights for optimizing nutrient management strategies and improving crop productivity in semi-arid agricultural systems.

Keywords: Soil quality, electrical conductivity, organic carbon, macronutrients, Karauli District etc

Introduction

Soil forms the foundational component of terrestrial ecosystems and plays a key role in sustaining life on this earth. Soil is an indispensable component of the ecosystem owing to its crucial role in sustaining agricultural productivity, regulating hydrological cycles, as well as supporting the growth of plants, microbes, and faunal life on earth. In arid and semi-arid regions like Karauli district of Rajasthan, the quality of soil is highly sensitive to changes owing to seasonal variation, local geomorphology, as well as anthropogenic pressures such as overgrazing, deforestation, and unsustainable agricultural practices. Therefore, it is very important to understand the physicochemical characteristics of soil and the multifarious ways in which these parameters fluctuate seasonally. Optimization of these parameters forms the essential basis of optimizing land use, maintaining soil fertility, while ensuring the promotion of sustainable agriculture in these climatically vulnerable landscapes (Sharma *et al.*, 2015; Yadav *et al.*, 2022; Kumar *et al.*, 2020; Meena *et al.*, 2023; Akhand *et al.*, 2024)^[1, 11, 12, 19, 22].

The Karauli region in Rajasthan experiences extremes of weather conditions, ranging from intense summer heat, sparse winter precipitation, to very short yet intense monsoon spells. All these factors in conjunction presents a unique opportunity to assess various ways in which environmental factors affect soil quality. Seasonal variations of a region significantly affect key physico-chemical soil parameters including pH, electrical conductivity (EC), organic carbon, macro- and micronutrients, and moisture content, all of which in turn govern soil health as well as

crop performance. However, there is dearth of localized studies focusing on site-specific as well as seasonally resolved soil health assessments in this region.

Considering this, the current study has been drafted to bridge this knowledge gap by analyzing and comparing 14 key physicochemical soil parameters across six ecologically diverse sites—Panchana Dam, Rangwana ka Talab, Needar Dam, Jaggar Dam, Sagar, and Kalisil Dam—over three seasons: summer, winter, and monsoon. Each of these analyzed sites represents distinct landforms, vegetation patterns, as well as anthropogenic influences, all of which enable a holistic understanding of spatial and temporal soil variability in these areas. The key objectives of this study are to evaluate the seasonal dynamics of the physicochemical properties of soil. Following which, the researchers aimed to establish a correlation between observed environmental patterns and the anthropogenic factors, followed by recommendations for improving soil quality in these areas. The findings of the current study will not only contribute to the scientific understanding of soil variability in semi-arid regions, but also provide deeper insights for local farmers as well as policymakers working in the area of climate-resilient agriculture and land restoration.

Materials and Methods

Soil samples were collected in different seasons – summer (March-June), rainy (July-October) and winter (November-February). Soil samples were collected in sterile conditions. Collected samples were immediately sent for characterization.

Soil samples were tested for temperature, pH, EC, organic content, phosphorous, sulphur, potassium, zinc, iron, copper and manganese during the month of summer, winter and rainy season.

Temperature of soil samples was measured by a routing mercury thermometer. EC was measured by EC meter and pH by pH meter. These parameters were tested on the collection sites. Organic matter, and micronutrients were determined by the method of Jackson, (1973) [9]. Macronutrients were determined by Atomic Absorption Spectroscopy (AAS).

Results

Soil analysis in summer season

The physicochemical analysis of summer season soil samples from six selected sites of Karauli district revealed alkaline to slightly alkaline conditions, with pH ranging from 7.55 (Site 6) to 8.25 (Site 4). Electrical conductivity remained low across all sites (0.34–0.56 dS/m), indicating non-saline soils. Water holding capacity showed considerable variation, being lowest at Site 6 (32.28%) and highest at Site 5 (54.33%), largely reflecting differences in soil texture, which ranged from deep brown loamy to deep dark brown sandy soils. Bulk density varied between 0.64 mg m⁻³ (Site 4) and 1.41 mg m⁻³ (Site 1), while moisture content was generally low during summer, with minimum values at Site 4 (7.9%) and comparatively higher values at Site 1 (21.29%) and Site 6 (18.52%). Organic content was uniformly low across sites (0.13–0.58%), indicating poor organic matter status typical of summer soils in semi-arid regions. Among macronutrients, available phosphorus ranged from 27 to 46 kg/ha, potassium from 265 to 340 kg/ha, and sulphur from 7 to 11 kg/ha, showing moderate variability among sites. Micronutrient analysis revealed zinc levels between 0.24 and 0.45 ppm, iron between 4.20 and 5.50 ppm, copper between 0.20 and 0.54 ppm, and manganese between 2.60 and 3.65 ppm, indicating generally adequate but site-specific micronutrient availability during the summer season (Table 1).

Soil analysis in winter season

The winter season soil analysis of six selected sites in Karauli district showed slightly alkaline to near-neutral pH values ranging from 7.30 at Site 6 to 7.99 at Site 4, indicating a marginal decline in alkalinity compared to the summer season. Electrical conductivity values were low across all sites

(0.27–0.46 dS/m), reflecting non-saline soil conditions during winter. Water holding capacity increased at all sites, varying from 34.08% (Site 6) to 56.31% (Site 5), which corresponded with soil texture and improved moisture retention. Bulk density ranged from 0.43 (Site 4) to 1.21 (Site 1), showing generally lower compaction during winter. Moisture content was markedly higher than in summer, with values ranging from 17.91% to 48.25%, the highest being recorded at Site 6, indicating better soil water availability. Organic content also increased across sites (0.18–0.75%), suggesting seasonal accumulation of organic matter. Available macronutrients showed improved status, with phosphorus ranging from 38 to 58 kg/ha, potassium from 310 to 380 kg/ha, and sulphur from 11 to 16 kg/ha. Micronutrient concentrations were comparatively higher in winter, with zinc (0.32–0.58 ppm), iron (5.00–6.50 ppm), copper (0.32–0.70 ppm), and manganese (3.20–4.35 ppm), indicating enhanced nutrient availability under cooler and moister winter conditions (Table 2).

Soil analysis in rainy season

The physicochemical characteristics of soils from six selected sites of Karauli district during the rainy/monsoon season showed slightly alkaline conditions, with pH values ranging from 7.42 (Site 6) to 8.12 (Site 4). Electrical conductivity remained low (0.29–0.50 dS/m), indicating the absence of salinity stress despite seasonal rainfall. Water holding capacity increased considerably during the monsoon, varying from 44.82% at Site 6 to 57.01% at Site 5, consistent with soil texture and enhanced moisture retention. Bulk density values were generally lower (0.41–1.11), reflecting improved soil structure under wet conditions. Moisture content was highest during this season, ranging from 38.98% to 69.18%, with maximum values recorded at Site 1 and Site 6, demonstrating the direct influence of rainfall on soil water status. Organic content showed a moderate increase (0.16–0.67%), likely due to enhanced microbial activity and organic matter inputs during the monsoon. Available macronutrients exhibited moderate levels, with phosphorus ranging from 32 to 52 kg/ha, potassium from 291 to 367 kg/ha, and sulphur from 9 to 14 kg/ha. Micronutrient analysis revealed zinc concentrations of 0.29–0.52 ppm, iron of 4.72–6.20 ppm, copper of 0.25–0.62 ppm, and manganese of 2.97–4.15 ppm, indicating adequate but seasonally influenced micronutrient availability under monsoon conditions (Table 3).

Table 1: Analysis of physicochemical parameters of soil samples of selected sites of Karauli district in summer season

Sr. No.	Physicochemical parameters	Study sites					
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1	pH	8.18	8.22	7.88	8.25	7.91	7.55
2	Electrical Conductivity (EC) (dS/m)	0.38	0.34	0.56	0.40	0.37	0.37
3	Water Holding Capacity (%)	40.51	43.34	47.54	53.55	54.33	32.28
4	Soil texture	Deep brown loamy	Deep brown loamy	Deep dark brown sandy	Medium brown loamy	Shallow brown loamy	Deep brown loamy
5	Bulk density (mg m ⁻³)	1.41	0.98	1.02	0.64	1.09	1.21
6	Moisture content (%)	21.29	13.47	12.08	7.9	10.47	18.52
7	Organic content (%)	0.13	0.15	0.52	0.13	0.40	0.58
8	Phosphorous (Kg/ha)	33	40	45	27	34	46
9	Sulphur (Kg/ha)	7	10	9	11	10	8
10	Potassium (Kg/ha)	310	340	270	280	300	265
11	Zinc (PPM)	0.24	0.27	0.37	0.33	0.36	0.45
12	Iron (PPM)	4.60	4.35	4.50	5.50	4.20	4.40
13	Copper (PPM)	0.44	0.54	0.27	0.46	0.31	0.20
14	Manganese (PPM)	2.90	3.65	2.60	3.20	3.50	3.60

Table 2: Analysis of physicochemical parameters of soil samples of selected sites of Karauli district in winter season.

Sr. No.	Physicochemical parameters	Study sites					
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1	pH	7.95	7.98	7.65	7.99	7.70	7.30
2	Electrical Conductivity (EC) (dS/m)	0.30	0.27	0.46	0.31	0.29	0.29
3	Water Holding Capacity (%)	41.01	45.04	50.45	55.05	56.31	34.08
4	Soil texture	Deep brown loamy	Deep brown loamy	Deep dark brown sandy	Medium brown loamy	Shallow brown loamy	Deep brown loamy
5	Bulk density	1.21	0.88	0.98	0.43	1.13	1.04
6	Moisture content (%)	40.91	23.43	22.18	17.91	30.02	48.25
7	Organic content (%)	0.18	0.20	0.67	0.18	0.55	0.75
8	Phosphorous (Kg/ha)	40	48	56	38	45	58
9	Sulphur (Kg/ha)	11	15	13	16	14	12
10	Potassium (Kg/ha)	350	380	315	325	345	310
11	Zinc (PPM)	0.32	0.35	0.48	0.44	0.48	0.58
12	Iron (PPM)	5.60	5.20	5.40	6.50	5.00	5.30
13	Copper (PPM)	0.58	0.70	0.38	0.60	0.44	0.32
14	Manganese (PPM)	3.50	4.35	3.20	3.90	4.20	4.30

Table 3: Analysis of physicochemical parameters of soil samples of selected sites of Karauli district in rainy/monsoon season.

Sr. No.	Physicochemical parameters	Study sites					
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1	pH	8.06	8.10	7.76	8.12	7.80	7.42
2	Electrical Conductivity (EC) (dS/m)	0.33	0.29	0.50	0.35	0.32	0.32
3	Water Holding Capacity (%)	49.89	50.04	53.45	56.35	57.01	44.82
4	Soil texture	Deep brown loamy	Deep brown loamy	Deep dark brown sandy	Medium brown loamy	Shallow brown loamy	Deep brown loamy
5	Bulk density	1.11	0.75	0.89	0.41	1.08	0.97
6	Moisture content (%)	69.18	45.33	44.18	38.98	54.92	63.57
7	Organic content (%)	0.16	0.18	0.61	0.16	0.48	0.67
8	Phosphorous (Kg/ha)	38	45	51	32	39	52
9	Sulphur (Kg/ha)	9	13	11	14	12	10
10	Potassium (Kg/ha)	333	367	298	305	325	291
11	Zinc (PPM)	0.29	0.31	0.42	0.38	0.42	0.52
12	Iron (PPM)	5.25	4.93	5.13	6.20	4.72	5.03
13	Copper (PPM)	0.52	0.62	0.32	0.54	0.37	0.25
14	Manganese (PPM)	3.25	4.15	2.97	3.67	3.92	4.05

Discussion

The current study aims to evaluate the physicochemical variability of soil across six different sites in Karauli, Rajasthan, namely Panchana Dam (Site 1), Rangwana ka Talab (Site 2), Needar Dam (Site 3), Jaggar Dam (Site 4), Sagar (Site 5), and Kalisil Dam (Site 6), across three seasons—summer, winter, and monsoon. The results of the study showcase significant seasonal and spatial fluctuations in the soil quality of all the regions, as evident from significant variation in physio-chemical soil parameters. This variability maybe attributed to several reasons including variable climatic patterns, land use, hydrology, as well as variability in anthropogenic inputs in these regions. To begin with, the study showed that pH values, soil pH showed clear seasonal variation across all sites, reflecting the influence of rainfall, temperature, and soil moisture on soil chemistry. During the rainy season, pH values remained moderately alkaline (7.42–8.12), as leaching of basic cations was balanced by the inherently calcareous nature of the soils, keeping them within an alkaline range. In the summer season, pH increased further (7.55–8.25) at all sites due to high temperatures and strong evaporation, which concentrate soluble salts such as carbonates and bicarbonates in the upper soil layers, raising alkalinity while reduced microbial activity limits organic acid production. In contrast, winter recorded the lowest pH values (7.30–7.99), as cooler temperatures, better moisture availability, and

enhanced microbial activity promote the formation of organic acids that temporarily neutralize alkaline ions, leading to a slight decline in pH. Overall, the seasonal trend followed the pattern summer > rainy > winter, showing that alkaline conditions peak under hot, dry conditions and decrease under cool, moist conditions, with important implications for nutrient availability and soil fertility. Electrical Conductivity (EC) showed clear seasonal fluctuations across the study sites, reflecting changes in soil moisture, salt accumulation, and leaching patterns. During the rainy season, EC values were the lowest (0.29–0.50 dS/m) because heavy rainfall and high percolation diluted soluble salts and promoted their downward movement, reducing surface salinity. In the summer season, EC increased noticeably across all sites (0.34–0.56 dS/m), driven by intense evaporation and minimal leaching, which concentrate dissolved salts in the root zone and elevate EC levels; this effect was particularly evident at Site 3, where the highest summer EC was recorded. In winter, EC values decreased again (0.27–0.46 dS/m) due to improved soil moisture, lower evapotranspiration, and partial redistribution of salts within the profile. Overall, the seasonal trend followed the pattern summer > rainy ≈ winter, indicating that salt concentration is highest during dry, hot months and lowest during periods of rainfall or cooler temperatures, which plays a critical role in determining nutrient availability and soil salinity status.

High EC during summer may occur due to high evaporation rates, whereas low EC during monsoon occurs due to excessive salt leaching and dilution (Russenes *et al.*, 2016; Yamashita *et al.*, 2016; Hoque *et al.*, 2008; Zhao *et al.*, 2011; Dong *et al.*, 2022; Behera *et al.*, 2015)^[2, 6, 8, 17, 24].

Organic content showed marked seasonal variation across the study sites, largely influenced by temperature, soil moisture, and microbial activity. During the rainy season, organic matter levels were moderate to high (0.16–0.67%), supported by abundant moisture that enhances microbial decomposition and incorporation of fresh plant residues into the soil. In the summer season, organic content decreased noticeably (0.13–0.58%) at all sites due to intense heat and low moisture, which slow microbial activity and accelerate oxidation of organic residues, leading to reduced organic matter accumulation. Conversely, winter showed the highest organic content among the three seasons (0.18–0.75%), as cool and moist conditions favour microbial processes, promote gradual decomposition, and support the buildup of humus. Overall, the seasonal trend followed the pattern winter > rainy > summer, demonstrating that organic matter is highest under cool, moist conditions and lowest during hot, dry periods, significantly influencing soil nutrient availability, structure, and fertility. On the contrary, soil from site 1 would need manure/green cover for the restoration of the biological health of crops (Onwuka *et al.*, 2018; Prommer *et al.*, 2020)^[15, 16].

Higher WHC in Sites 4 and 5 directly corresponds to loamy texture as well as good organic matter content in the soil, which directly augments the capillary water retention. Site 6's poor WHC is indicative of presence of compacted or coarse subsoil layers that restrict water infiltration in this area. During summer months, excess evaporation causes drying of organic colloids in soil, leading to reduced WHC. On the contrary, rainfall causes increased WHC due to swelling of colloids and increased organic input. As a general thumb rule, sites with WHC > 50% (like Site 5) are well-suited for water-demanding crops whereas sites with lesser WHC Bulk density of the soils was found to be highest at Site 1 (1.41 mg/m³, summer), indicating presence of compacted soil at this site, which may impede root penetration as well as aeration. On the contrary, lowest values of bulk density at Site 4 in monsoon (0.41 mg/m³) are reflective of the well-aerated, porous soil which is ideal for root growth. Summer months generally cause drying of soil, leading to decreased bulk density while monsoon causes moisture retention with microbial activity during monsoon months causing loosening of soil aggregates, hence, higher bulk density. Monsoon content in the soils was highest during the monsoon season, owing to increased rainfall and precipitation. On the contrary, during summer months, moisture content drastically falls due to increased evapotranspiration rates and poor soil cover. Looking at this, it can be interpreted that high bulk density with less moisture content makes Site 4 less viable for summer crop plantation, whereas Site 1 may sustain rainfed cropping in monsoon, but needs tillage in summer (Onwuka *et al.*, 2018; Nunes *et al.*, 2016; Dai *et al.*, 2020; Tanveera *et al.*, 2016)^[5, 14, 15, 21].

Macronutrient availability—particularly phosphorus (P), sulphur (S), and potassium (K)—showed clear and predictable seasonal variation across the study sites, reflecting the combined effects of rainfall, plant uptake, mineralization, and soil moisture dynamics. During the

rainy season, macronutrient levels were moderate to high, with P (32–52 kg/ha), S (9–14 kg/ha), and K (291–367 kg/ha) reflecting enhanced mineralization and improved nutrient mobility under moist conditions, although some leaching may have mildly reduced nutrient retention in certain sites. In the summer season, all three macronutrients showed noticeable declines, as P (27–46 kg/ha), S (7–11 kg/ha), and K (265–340 kg/ha) were reduced due to intense plant uptake, low mineralization rates, and limited moisture, which restrict nutrient diffusion and make them less available. Conversely, winter recorded the highest macronutrient levels among the three seasons, with P (38–58 kg/ha), S (11–16 kg/ha), and K (310–380 kg/ha) increasing due to slower plant nutrient demand, enhanced mineralization in cool, moist soil, and reduced losses through leaching or volatilization. Overall, the macronutrient pattern followed winter > rainy > summer, indicating that nutrient availability is greatest under cool, moist conditions and lowest during hot, dry periods, strongly influencing soil fertility and crop nutrient management. On the other hand, summer months promoted minimal leaching but led to volatilization of nitrogen from the soil. Therefore, looking at soil health, site 3 showed optimum growth conditions for plants, owing to nutrient balance and optimum number of macronutrients. On the contrary, soil from Site 1 needs nitrogen supplementation to support plant growth.

Next in row, the different micronutrients (Cu, Zn, Mn, Fe) in soil from different sites were evaluated. Micronutrient concentrations showed distinct seasonal fluctuations across the study sites, closely linked to soil moisture, temperature, and pH-driven changes in nutrient solubility. During the rainy season, levels of all four micronutrients were moderate, supported by favourable moisture conditions that enhance mineral dissolution and nutrient mobility; however, slight leaching during heavy rains prevented excessive accumulation. In the summer season, micronutrient availability declined across all sites, as higher soil pH and intense dryness reduced solubility and mobility of Zn, Fe, Cu, and Mn, causing nutrients to become increasingly bound to soil particles and less available to plants. In contrast, winter recorded the highest micronutrient concentrations among the three seasons because cooler temperatures, improved moisture, and slightly lower pH enhanced the solubility and release of these elements from soil minerals. Overall, the trend winter > rainy > summer reflects the strong influence of seasonal moisture and pH changes on micronutrient availability, with winter creating the most favourable conditions for their mobilization and summer the least. On the other hand, leaching losses during monsoon cause decreased number of mobile elements, primarily Zn and Mn. Presence of micronutrients significantly affects plant growth and development in the soil. Therefore, soil from site 5 being deficient in Cu and Zn may affect enzyme activities in plants, leading to redundant plant growth. Similarly, soil from site 6, being high in Fe, may be unfit for iron sensitive crops (Nadeem *et al.*, 2018; Shrivastav *et al.*, 2020; Johnson *et al.*, 2020)^[10, 13, 20].

Conclusion

Concluding the findings of the study in a nutshell, soil quality in Karauli district showcases significant seasonal variation as well as site-dependent heterogeneity, which may be attributed to natural topography, parent material, as

well as anthropogenic pressures in these areas. Monsoon significantly improves fertility across soil in all the analysed sites, leading to enhanced organic matter, microbial activity, as well as leaching of salts. Among the six sites, Needar Dam (Site 3) demonstrated the most favourable soil properties for agriculture. On the contrary, Kalisil Dam (Site 6) posed serious constraints due to fluoride toxicity, poor water holding capacity as well as low nutrient content. Considering this, future agricultural productivity in the region must be undertaken keeping in account the site-specific soil management, especially in marginal areas, through supplementation of existing soil with organic amendments and balancing of micronutrients with macronutrients.

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