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Assessment of soil fertility in upper Banas river basin

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Abstract

A survey was conducted during pre-monsoon season of the year 2021 in Upper Banas River Basin to assess the soil fertility. The 118 soil samples collected and analyzed to find out their texture, bulk density, particle density, porosity, pH, EC, organic matter, N, P_2O_5, K_2O, $CaCO_3$, S, B, Fe, Zn and Cu, Mn status. The observed data revealed that bulk density was found 1.30 to 1.66 Mg m^{-3}, particle density found 2.18 to 2.88 Mg m^{-3} and porosity varied 31.91 to 50.00% and sand, silt and clay content were 49.77%, 22.88% and 27.35%, respectively and categorized as eight different classes of texture. The soil was neutral to slightly alkaline in pH ranged from 7.00 to 7.98, electrical conductivity of soil was non saline to moderately saline ranged from 0.25 to 3.42 dS m^{-1} and soil organic matter ranged from 0.05 to 0.98 per cent, respectively. The soil available nitrogen ranged from 120.39 to 488.39 kg ha^{-1}, available phosphorus ranged from 13.95 to 56.70 kg ha^{-1}, available potassium 165.95 to 416.56 kg ha^{-1} and sulphur ranged from 5.03 to 15.25 mg ha^{-1}, respectively. The soil calcium carbonate was varied from. 58 to 4.93 per cent. Where's the available of Zinc 0.68 to 13.47 mg ha^{-1}, available iron ranged varied from 1.67 to 16.00 mg ha^{-1}, available copper varied from 0.10 to 2.40 mg ha^{-1} and available manganese ranged from 0.69 to 21.69 mg ha^{-1}, respectively. To sustain and improve soil fertility, a comprehensive approach is recommended, combining the use of bio-fertilizers, organic manures, and appropriate combinations of chemical fertilizers. This integrated approach ensures the replenishment of essential nutrients in the soil, promoting healthy crop growth and yield.

Keywords: Soil fertility, upper Banas river basin, nutrient content, fertility management, soil analysis

1. Introduction

Soil fertility plays a crucial role in determining crop yields, making its evaluation imperative for sustainable agricultural production. Unfortunately, modern intensive agricultural practices, along with imbalanced and insufficient fertilizer usage, have led to a decline in soil nutrient levels. To address this issue, understanding the physico-chemical properties of soil, including pH, electrical conductivity, organic carbon, and calcium carbonate, is essential as they directly impact the availability of vital nutrients for plant growth. By implementing effective management strategies for these properties, we can improve the supply of essential nutrients to crops, thereby promoting healthier and more productive agricultural systems (Meena *et al.*, 2006) [26]. A balanced and well-managed nutrient supply in the soil not only promotes healthier plants but also enhances soil structure, water retention, and nutrient cycling. Adopting sustainable practices, such as crop rotation, cover cropping, and organic matter incorporation, can further improve soil health and fertility. Moreover, precision agriculture techniques and advanced soil testing methods can provide valuable insights into the nutrient needs of specific crop varieties and help optimize fertilizer application, reducing wastage and environmental impacts (Panneerselvam *et al*., 2018) [35].

The macronutrients, including nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, play a pivotal role in determining soil fertility and influencing crop yields. The availability of these essential nutrients is contingent upon the intricate interplay of physical, chemical, and biological conditions in the rhizosphere (Jiang *et al.*, 2009) [15]. The overall quality of soil is shaped by the complex interactions among its physical, chemical, and biological properties (Papendick *et al.*, 1992) [36]. However, the excessive use of chemical fertilizers and intensive cultivation practices have resulted in a gradual decline in soil fertility and agricultural productivity. To safeguard soil productivity, stability, and sustainability, it is imperative to address nutrient deficiencies (Chaudhari *et al.*, 2012) [7]. Implementing appropriate soil management practices, including balanced fertilization and incorporation of organic matter, can foster optimal nutrient availability and contribute to long-term agricultural viability.

Soil fertility assessment relies on crucial indicators such as soil organic matter, cation exchange capacity, soil pH, and soil texture, which collectively govern the nutrient availability to support plant growth and development. Seventeen essential elements are vital for plants, and their presence in appropriate proportions and accessible forms is essential for optimal growth. Macronutrients like nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur are required in larger quantities, while micronutrients such as iron, manganese, zinc, copper, molybdenum, chlorine, cobalt, and boron are essential in smaller amounts. The delicate balance of these macro and micronutrients in the soil is pivotal for maintaining soil health and enhancing crop productivity. Adequate management practices, including proper fertilization and soil amendment with organic matter, play a critical role in sustaining this delicate equilibrium and fostering sustainable agricultural practices.

Agricultural activities have a substantial impact on the chemical, physical, and biological properties of soil. As a result, it becomes crucial to comprehensively understand and continuously monitor soil fertility to make informed decisions regarding appropriate fertilizer application and to address any nutrient deficiencies. By prioritizing soil health and fertility, farmers can effectively optimize crop yields and contribute to the implementation of sustainable agricultural practices. By adopting responsible soil management strategies, such as crop rotation, cover cropping, and organic matter incorporation, farmers can enhance soil fertility, structure, and nutrient availability, thereby ensuring long-term productivity and environmental sustainability. Monitoring and evaluating soil fertility also enable farmers to tailor their agricultural practices to suit the specific needs of their crops and local soil conditions, minimizing potential negative impacts on the environment and ensuring a more efficient use of resources. Ultimately, the prudent management of soil fertility is fundamental to the success of modern agriculture and the quest for a food-secure and ecologically balanced future.

2. Materials and Methods

2.1 Description of the Study Site

The Upper Banas River basin, a significant tributary of the Chambal River basin, is situated between 73º22’55.603” to 75º01’27.048” E Longitude and 24º43’21.982” to 25º24’22.925” N Latitude. It encompasses 17 tehsils, including Kumbhalgarh, Nathdwara, Rajsamand, Relmagra, Amet, and Devgarh tehsils of Rajsamand district; Gangapur, Bhilwara, Raipur, Kotri, and Mandalgarh tehsils of Bhilwara district; Gogunda, Kotra, and Vallabhnagar tehsils of Udaipur district; and Gangrar, Kapasan, and Rashmi tehsils of Chittorgarh district in Rajasthan. Approximately 56% of the total basin area falls within Rajsamand and Bhilwara districts.

The catchment area features undulating topography with rolling uplands and in-filled valleys, leading to high runoff velocity during monsoon months. The majority of the basin is covered by hilly terrain, accounting for about two-thirds of the area. The summer season, lasting from April to June, is characterized by hot temperatures, with average highs between 47. 8 and 023.8 °C. May and June are the hottest months, with temperatures soaring up to 45 °C. The average maximum temperature fluctuates between 28 and 33 °C, while the minimum temperature hovers around 10 °C.

The soils in the region are broadly classified into four categories: black soils, yellowish-brown soils, grayish-brown alluvial soils, and hilly soils. Black soils are predominant in parts of Dungla and Kapasan tehsils, while yellowish-brown soils dominate in Chittorgarh and Nimbahera tehsils. The hilly soils are found in areas of Rawatbhata, Begun, Chittorgarh, and Dungla blocks. Additionally, there are extensive stretches of light sandy loam soils along the banks of the river.

2.2 Soil sampling and laboratory analysis

The soil fertility parameters in the Upper Banas River Basin were assessed through a systematic soil sampling and laboratory analysis process. Following the winter crop harvest, a grid-based sampling method was employed to collect a total of 118 soil samples from across the entire basin. The samples were carefully labeled, air-dried at temperatures between 40-60 °C, and sieved through a 2-mm sieve to prepare them for analysis.

For soil texture determination, the International Pipette Method (Piper, 1960) [37] was used. Bulk density was estimated using the soil core sampler method (Singh, 1980) [44], and particle density was determined through the relative density bottle method (Richards, 1954) [41]. Porosity percentage was then calculated using the formula PD-BD/PD×100.

Chemical analysis involved measuring soil pH and electrical conductivity (EC) by creating soil water suspensions in a 1:2 ratio, as recommended by Richards (1954) [41]. Soil organic carbon content was quantified using the Walkley and Black (1934) [47] method. Available nitrogen (N) was estimated using the alkaline permanganate method proposed by Subbiah and Asija (1956) [45]. The Olsen *et al.* (1954) [34] method was employed to assess available phosphorus (P), using 0.5 M $NaHCO_3$ (Olsen's reagent) as the extractant. Available potassium (K) was determined through flame photometry (Jackson, 1973) [14]. The available sulfur (S) content was measured using the Turbidemetric method developed by William's and Steinbergs (1959) [49].

To analyze micronutrients zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn), an atomic absorption spectrophotometer (AAS) was used with DTPA as the extractant (Lindsay and Norvell, 1978) [23]. This comprehensive analysis of soil fertility parameters provides valuable insights for informed agricultural practices and sustainable crop management in the Upper Banas River Basin.

2.3 Statistical Analysis

Descriptive statistics of analyzed soil data which are minimum, maximum, mean, median, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis were determined using SPSS 16.0 (SPSS, Inc., Chicago, IL, USA). A Pearson’s correlation matrix was used to reveal the relationships between different soil properties.

3. Results and Discussion

3.1 Descriptive statistics of soil properties

Table 1 presents the descriptive statistics of the soil properties, and the spatial variability was assessed using the coefficient of variation (CV). According to Wilding's (1985) [48] criteria, the parameters were classified into most (CV > 35%), moderate (CV 15-35%), and least (CV < 15%) variable classes. Among the parameters, DTPA-Zn exhibited the highest variation (83.17%), whereas soil pH showed the lowest variation (2.89%).

The available Cu, Mn, Fe, SOC, $CaCO_3$, and EC were classified as most variable (CV > 35%), while available N was categorized as moderately variable (CV 15-35%). On the other hand, phosphorus, potassium, and sulfur were considered the least variable (CV < 15%). Generally, pH and SOC were regarded as stable soil parameters (Bouma and Pinke, 1996) [5]. The considerable variation observed in DTPA-extractable micronutrients (Zn, Fe, Cu, and Mn) could be attributed to changes in the soil micro-environment, leading to the release of plant-available micronutrients (Moharana *et al*., 2017) [29].

The relatively stable pH and SOC variability in the study area might be influenced by oxidation under prolonged higher temperatures in summer and low cropping intensity, especially in the hot climate (Kumar *et al*., 2017b) [19]. The median values closely aligned with the mean values (except for EC and Zn), indicating the absence of outliers in the calculation of central tendency for the soil properties analysis (Table 1). Skewness measures the departure from normality, with a value less than 3.0 indicating normal distribution. EC (1.65) exhibited the highest positive skewness, followed by Zn (1.55) and Mn (1.30), while soil organic carbon (-0.22) and Cu (-0.19) showed negative skewness (Bhunia *et al*., 2018) [3]. Positive skewness suggests wider confidence limits on the variability, making the variances less reliable (Reza *et al*., 2015) [39].

Kurtosis indicates the characteristics of the peak value corresponding to the average value in the probability density distribution curve. Kurtosis > 0 signifies a higher peak value than that of the normal distribution, kurtosis = 0 indicates equality to the normal distribution, and kurtosis < 0 suggests a lower peak than the normal distribution (Rezaee *et al*., 2020) [40]. Similar to skewness, EC had the highest kurtosis value (3.00), followed by DTPA-Mn (1.62) and Zn (1.34), while N had the lowest (-1.11) kurtosis value in the soils of the Upper Banas River Basin. This variability in soil properties could be attributed to the nature of the parent material, relief, and crop management practices (Kumar *et al*., 2019) [18].

3.2 Soil texture

In the Upper Banas River Basin, the analysis of soil texture revealed that the majority of soils ranged from sandy clay loam to sandy loamy in texture. Among the three primary soil particles, clay and sand content exhibited the highest variability, while silt content showed the least variation. These variations in soil texture can be attributed to a combination of factors, including differences in topographic position, nature of parent material, in situ weathering of clay minerals, and the age of the soil.

Similar findings regarding particle size distribution and textural classes were reported by Anitha *et al.* (2001) [2] in black soils of Gurjalamandal in Guntur district, Andhra Pradesh, indicating that variations in soil texture are common and have implications for soil management. The variation in soil texture is of great significance as it directly influences the soil's water-holding capacity, nutrient retention, and overall fertility.

The presence of sandy loam to sandy loamy soils in the study area indicates moderate water-holding capacity and good drainage, which can create favourable conditions for crop cultivation. However, the variability in soil texture can also impact the movement of water and nutrients within the soil profile, affecting the availability of essential nutrients to plants.

3.3 Bulk density, particle density and porosity

The bulk density of soils in the Upper Banas River Basin showed a range from 1.30 to 1.66 Mg m^{-3}, with an average value of 1.47 Mg m^{-3}. This variability in bulk density can be attributed to several factors, including differences in organic matter content, soil texture, mineral composition, soil depth, and porosity. Similar findings reported by Chaudhari *et al.* (2013) [8] also suggest that bulk density is influenced by various soil properties.

Regarding particle density, the soils in the Upper Banas River Basin exhibited a range from 2.18 to 2.88 Mg m^{-3}, with a mean value of 2.50 Mg m^{-3}. The variation in particle density could be due to differences in organic carbon and mineral content within the soils. These results align closely with the findings of Gupta *et al.* (2010) [10] in the soil of Sivaliks and Chaudhari *et al.* (2013) [8] in the soil of Coimbatore, indicating that particle density is influenced by the soil's chemical composition.

The porosity of soils in the Upper Banas River Basin ranged from 31.91% to 50.00%, with an average value of 42.03%. Porosity is influenced by factors such as soil texture, soil structure, compactness, and organic matter content. The observed porosity values are in agreement with the earlier findings of Ahad *et al.* (2015) [1] in the soil of Kupwara, Kashmir.

Overall, the variations in bulk density, particle density, and porosity highlight the heterogeneity of the soils in the Upper Banas River Basin. These soil properties play a crucial role in determining soil water retention, aeration, and nutrient availability, ultimately influencing crop growth and productivity. Understanding these soil characteristics is essential for formulating appropriate soil management practices that can contribute to sustainable agricultural production in the region. By considering these factors, farmers and land managers can make informed decisions regarding soil management strategies to optimize crop yields and enhance overall soil health for long-term agricultural sustainability.

3.4 Soil pH and electrical conductivity

Soil pH is a critical parameter that reflects the balance between hydrogen (H+) and hydroxide (OH-) ions in the soil solution. In the Upper Banas River Basin, a wide variation in soil pH was observed, ranging from 7.00 to 7.98 (Table 1), indicating that the soil is neutral to slightly alkaline in nature. The variability in soil pH can be attributed to several factors, including the nature of the parent material, micro-relief, soil type, and uneven application of manures and fertilizers by farmers, as reported by Kumar *et al.* (2017a) [20] and Kumar *et al.* (2019) [18] for soils in western Rajasthan. Understanding soil pH is essential as it directly influences nutrient availability and uptake by crops, thereby affecting crop growth and productivity.

Electrical conductivity (EC) is a measure of the soluble salt concentration in the soil. Soil salinity is a significant abiotic stress that can lead to reduced crop productivity (Drake *et al.* 2015; Mahajan *et al.* 2015) [9, 24]. In the study area, the EC in soils ranged from 0.25 to 3.42 dS m-1, and the low EC values indicated that the presence of salts in these soils was negligible (Table 1). The low soluble salt concentration in the soils may be attributed to various factors, such as the use of non-saline irrigation water and the nature of parent materials, as reported by Moharana *et al.* (2017) [29] and Kumar *et al.* (2017a) [20]. Managing soil salinity is essential to ensure optimal crop growth and avoid yield losses caused by saline soil conditions.

By comprehending the variations in soil pH and EC in the Upper Banas River Basin, farmers and land managers can implement appropriate soil management practices to create a favorable soil environment for crop growth. Balancing soil pH and managing soil salinity can help maximize nutrient availability, enhance nutrient uptake by plants, and ultimately lead to increased crop productivity and overall agricultural sustainability in the region.

3.5 Soil organic carbon

The soil organic carbon (SOC) content plays a crucial role in enhancing various soil properties, such as cation exchange capacity (CEC), soil aggregation, water holding capacity, and biological activity, ultimately contributing to the overall fertility status of soils (Moharana *et al.*, 2012) [29]. In the context of sub-humid soils in India, the SOC content is generally low, with an average value of 0.5% (Kumar *et al.*, 2019) [18]. However, in Indian sub-humid conditions, a SOC value greater than 0.75% is considered high (Lal, 2015) [22]. In the Upper Banas River Basin, the SOC content ranged from00.05% to 0.98% (Table 1). The low SOC status in these soils can be attributed to various factors, including high temperatures, low rainfall, erosion of topsoil, and the coarse texture of the soils, all of which promote a high rate of organic matter decomposition (Kumar and Lal, 2011) [21].

Increasing the SOC content in soils is of utmost importance for sustaining agricultural productivity and soil health. A higher SOC content can improve soil structure, water retention capacity, and nutrient availability, leading to enhanced crop growth and yield. To boost SOC levels, implementing conservation practices such as organic matter incorporation, mulching, and reduced tillage can be beneficial. Additionally, incorporating crop residues and organic manures can contribute to increasing SOC content and maintaining soil fertility over the long term.

3.6 Calcium carbonate

The presence of calcium carbonate ($CaCO_3$) in the soils of Upper Banas River Basin exhibited significant variation, ranging from 0.58% to 4.93%, with an average value of 2.21% (Table 1). Similar findings for $CaCO_3$ content in soils have been reported in other regions as well. For instance, Medhe *et al.* (2012) [25] observed a similar nature of $CaCO_3$ content in soils of Shevgaon Tehsil in Ahmednagar district. Likewise, Nalwade and Pawale (2014) [33] reported comparable $CaCO_3$ levels in soils of the ARS farm at MPKV Rahuri, and Medhe *et al.* (2012) [25] observed similar trends in soils of Chakur tehsil in Latur district.

3.7 Distribution of Macronutrients

3.7.1 Available nitrogen

Nitrogen is a vital nutrient crucial for supporting plant growth, and its deficiency can lead to various crop-related issues. Plants suffering from nitrogen deficiency often display light green coloration and may develop yellowing lower leaves, similar to symptoms of water scarcity (Carter and Knapp, 2001; Methods Manual Soil Testing in India, 2011) [6].

In the Upper Banas River Basin, the available nitrogen content in the soils ranged from 120.39 to 488.39 kg ha^{-1}, with an average of 260.45 kg ha^{-1} (Table 1). Researchers have reported similar findings for soils in other semi-arid regions of India (Kumar *et al.*, 2019) [18]. The presence of an adequate nitrogen level in the soil is essential for fostering robust plant growth and maximizing crop yields. Nitrogen is a major component of plant proteins and plays a vital role in various physiological and biochemical processes, including photosynthesis and enzyme activity.

Thus, it is of utmost importance to regularly monitor and maintain an appropriate level of available nitrogen in the soil to promote healthy plant growth and optimize agricultural productivity. Implementing effective nitrogen management practices, such as balanced fertilizer application, crop rotation, and utilization of nitrogen-fixing cover crops, can help ensure sufficient nitrogen supply for crops in the Upper Banas River Basin. By adopting these practices, farmers can not only enhance crop yields but also contribute to improved soil fertility and sustainable agricultural practices in the region.

3.7.2 Available phosphorus

Phosphorus is a vital nutrient for plants, playing a critical role in numerous physiological processes essential for their growth and development. It influences key functions such as cell division, root development, fruit formation, and early ripening, while also contributing to energy storage and transfer within plants. Additionally, phosphorus is a fundamental component of various organic compounds, including oils and amino acids. Plants suffering from phosphorus deficiency often exhibit dark green coloration, alongside yellowing and drying of lower leaves, accompanied by stunted growth and smaller leaves (Tairo and Ndakidemi, 2013) [46].

In the study area, the distribution of available phosphorus in the soils ranged from 13.14 kg ha^{-1} to 56.70 kg ha^{-1}, with an average value of 29.63 kg ha^{-1} (Table 1). The relatively low concentration of available phosphorus in the study area can be attributed to several factors. Limited use of phosphorus-based fertilizers and the fixation of phosphorus as calcium-phosphate (Ca-P) on clay minerals due to slightly alkaline soil pH are among the key contributing factors. These findings are in line with the results reported by Kumar *et al.* (2019) [18] for soils in similar semi-arid regions of India.

Given the essential role of phosphorus in supporting plant growth and productivity, it is crucial to address phosphorus deficiency in the soil through appropriate management strategies. Implementing efficient phosphorus fertilization practices, adopting crop rotation systems, and utilizing phosphorus-solubilizing microorganisms can enhance phosphorus availability and utilization by crops in the Upper Banas River Basin. By optimizing phosphorus management, farmers can promote healthier plant growth, maximize agricultural yields, and foster sustainable farming practices in the region.

3.7.3 Available potassium

Potassium, as a crucial macronutrient for plants, holds immense significance in their growth and development, with widespread absorption by higher plants. Its role encompasses various physiological processes, including the activation of enzymes, regulation of stomatal function, and control of water relations, especially crucial under rainfed conditions. Additionally, potassium influences the water balance within the plant system, making it a key factor in agronomic productivity and overall sustainability (Mengel, 1985) [27].

In the study area, the available potassium content in the soils displayed a range from 165.95 to 416.56 kg ha^{-1}, with an average value of 268.57 kg ha^{-1} (Table 1). The observed variation in available potassium can be attributed to several factors. Firstly, the relatively low amount of soil organic carbon (SOC) may influence potassium availability. Secondly, the coarse texture of the soils can impact the retention and release of potassium. Lastly, the limited application of manures and potassium-based fertilizers might contribute to the observed variations (Kumar *et al.*, 2017b) [19]. Addressing potassium deficiencies in the soil is essential for optimizing plant growth and maximizing agricultural productivity in the Upper Banas River Basin. Implementing appropriate potassium fertilization practices, along with measures to enhance soil organic carbon content, can contribute to improved potassium availability and utilization by crops. By ensuring a balanced supply of potassium to plants, farmers can foster healthier crops and sustainable agricultural practices in the region, ultimately supporting food security and livelihoods.

3.7.4 Available sulphur

The available sulphur content in the soils of the Upper Banas River Basin displayed a range from 5.03 to 15.25 mg kg^{-1}, with a mean value of 8.64 mg kg^{-1} (Table 1). Notably, the majority of sulphur in the soil exists in organic combinations, making soils rich in organic matter generally have higher sulphur levels (Kanwar, 1976) [17]. Additionally, coarse-textured sandy soils typically exhibit lower total sulphur content compared to fine-textured soils. The availability of sulphur is closely linked to the organic matter content of the soil.

Our findings align with similar studies by Hundal *et al.* (2006) [13] in soils of Punjab, India, and Jat and Yadav (2006) [51] in soils of entisols in Jaipur District, Rajasthan. Understanding sulphur availability in soils is critical, as sulphur is an essential element for plant nutrition. Ensuring adequate sulphur levels in the soil is crucial for supporting proper plant growth, development, and overall crop yield. Thus, it is imperative to emphasize the importance of maintaining sufficient organic matter content in the soil. Adopting sustainable soil management practices that promote organic matter accumulation can lead to increased sulphur availability and enhanced overall soil fertility. The implementation of organic amendments, such as green manure, compost, and crop residues, can significantly boost organic matter content, positively influencing sulphur levels in the soil and contributing to sustainable and productive agriculture in the region.

3.8 Distribution of micronutrients

3.8.1 DTPA- Zn

Zinc, as an essential micronutrient, plays a pivotal role in numerous biochemical processes within plants, including cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation, and maintenance of membrane integrity (Havlin *et al.*, 2010) [12]. Ensuring sufficient zinc availability in the soil is critical to support healthy plant growth and optimize crop production.

In the soils of the Upper Banas River Basin, the available zinc content displayed a wide range, varying from 0.68 to 13.47 mg kg^{-1}, with a mean value of 3.78 mg kg^{-1} (Table 1). The presence of this essential micronutrient in the soil is vital for facilitating various physiological and biochemical processes in plants. Adequate zinc availability is indispensable for promoting proper plant development, enhancing disease resistance, and ultimately maximizing overall crop productivity. Our findings corroborate with previous studies conducted by Moharana *et al.* (2017) [29] and Kumar *et al.* (2019) [18] in the hot arid and semi-arid regions of Rajasthan, where similar zinc availability in the soils was reported. The consistency in these results underscores the significance of assessing zinc levels in the soil to ensure that crops receive sufficient nutrition for their optimal growth and productivity.

3.8.2 DTPA- Fe

Iron is a crucial micronutrient that plays a vital role in various metabolic processes essential for the functioning of almost all living organisms, including plants. It is involved in critical processes such as DNA synthesis, respiration, and photosynthesis, making it indispensable for the growth and development of plants (Rout and Sahoo, 2015) [42].

In the soils of the Upper Banas River Basin, the available iron content exhibited a wide range, varying from 1.67 to 16.00 mg kg^{-1}, with a mean value of 7.07 mg kg^{-1} (Table 1). This spatial variability in iron availability can be attributed to various factors, including the nature of the native parent material from which the soil was formed, the presence of soil organic carbon that provides sustenance to beneficial microbes, and the soil pH (Gurjer *et al.* 2016) [11]. The transformation of iron forms in the soil is highly influenced by soil conditions, particularly the transition from oxic (Presence of oxygen) to anoxic (absence of oxygen) conditions. This shift from Fe_3^+ to Fe_2^+ forms is a significant aspect of iron dynamics in the soil, impacting its availability for plants and other organisms (Munch and Ottow 1980) [32].

3.8.3 DTPA- Cu

Copper is an essential micronutrient that plays a crucial role in various physiological processes of plants. It is required for N_2 fixation, oxidation-reduction reactions, and the maintenance of hormonal activities, making it vital for plant health. Additionally, copper acts as an activator for several enzymes in plants, further emphasizing its significance in plant metabolism (Yu *et al.* 2002) [50]. In the soil, copper is predominantly found in the divalent (Cu_2^+) form and is usually present in the crystal lattices of primary and secondary minerals. Moreover, a significant proportion of copper is bound by soil organic matter (SOM), contributing to its distribution and availability in the soil.

The DTPA extractable copper content in the soils of the Upper Banas River Basin exhibited considerable variation, ranging from 0.10 to 2.40 mg kg^{-1}, with a mean value of 1.350 mg kg^{-1} (Table 1). This significant variability in available copper can be attributed to various factors, including the content of soil organic carbon, the nature of parent material, and the management practices followed by farmers in soils with variable charge. Similar findings have been reported by Yu *et al.* (2002) [50], Gurjer *et al.* (2016) [11], and Kumar *et al.* (2019) [18]. The distribution coefficient (Kd) of copper in Alfisol was found to decrease significantly due to the removal of amorphous hydrous oxides, being five times more effective than the removal of organic matter. This observation highlights the role of different soil components in controlling copper availability and emphasizes the importance of understanding soil-copper interactions in managing soil fertility (Joshi and Dhir 1983) [16].

3.8.4 DTPA- Mn

Manganese is an essential micronutrient that plays a vital role in various plant processes, including photosynthesis and enzyme activity. It is primarily absorbed by clay minerals and soil organic matter (SOM) in the form of divalent cation (Mn_2^+) (Mousavi *et al.* 2011) [31]. The availability of Mn_2^+ in both soil and plant systems is regulated by oxidation and reduction processes. In the study area, the DTPA extractable manganese content in the soils ranged from 0.69 to 21.69 mg kg^{-1}, with a mean value of 5.79 mg kg^{-1} (Table 1). The relatively high and high concentration of DTPA extractable manganese in the soils of the sub-humid plain of southern Rajasthan can be attributed to several factors.

Firstly, the presence of higher soil organic matter content contributes to the availability of manganese as SOM can serve as a source of Mn_2^+ ions. Secondly, farmers in the region may apply organic and inorganic fertilizers, which further enrich the soil with available manganese. Finally, the slightly acidic to neutral soil reaction in these soils also favors the release of manganese for plant uptake (Gurjer *et al.* 2016) [11]. The concentration of DTPA extractable manganese is influenced by various soil factors, including soil pH, SOM content, available moisture, and soil aeration (Schulte and Kelling 1999) [43]. It is essential to maintain a balanced soil pH and organic matter content to ensure the optimal availability of manganese for plant utilization. Proper soil management practices, including the use of organic amendments and judicious application of fertilizers, can help maintain adequate levels of available manganese in the soil.

Table 1: Descriptive statistics of soil fertility parameters

Parameters	Minimum	Maximum	Mean	Median	SD	CV	Skewness	Kurtosis
PD	2.16	2.88	2.50	2.51	0.17	6.80	0.07	- 0.68
BD	1.30	1.66	1.47	1.47	0.06	4.01	0.25	0.93
Porosity (%)	31.91	50.00	42.03	42.91	4.26	10.14	- 0.28	- 0.91
pH (1:2)	7.00	7.98	7.48	7.49	0.22	2.89	0.18	- 0.36
EC (dS m^{-1})	0.25	3.42	1.09	0.88	0.68	62.01	1.65	3.00
SOC (%)	0.05	0.98	0.55	0.58	0.23	42.61	- 0.22	- 1.07
$CaCO_3$	0.58	4.93	2.21	2.13	0.86	39.18	0.59	0.41
Available N (kg ha^{-1})	120.39	488.39	260.45	255.04	93.30	35.82	0.21	- 1.11
Available P (kg ha^{-1})	13.14	56.70	29.63	28.74	9.66	32.60	0.63	0.11
Available K (kg ha^{-1})	165.95	416.56	268.57	255.90	59.42	22.13	0.54	- 0.32
Available S (kg ha^{-1})	5.03	15.25	8.64	8.20	2.59	29.99	0.73	- 0.28
Available Zn (mg ha^{-1})	0.68	13.47	3.78	2.56	3.14	83.17	1.55	1.34
Available Fe (mg ha^{-1})	1.67	16.00	7.07	6.40	3.39	47.99	0.65	- 0.39
Available Cu (mg ha^{-1})	0.10	2.40	1.35	1.36	0.59	43.66	- 0.19	- 0.96
Available mn (mg ha^{-1})	0.69	21.69	5.79	4.69	4.74	81.94	1.30	1.62

4. Conclusion

The descriptive statistics summarized in this study reveal that the coefficient of variation (CV) for various soil properties ranged from 2.89% to 83.17%. Among the properties, DTPA extractable micronutrients (Zn, Cu, Mn, and Fe) and electrical conductivity (EC) exhibited the highest variability, whereas SOC, Olsen-P, and $KMnO_4$-N showed moderate variability, and NH_4OAc-K displayed the least variability. The raw data set for EC exhibited strong positive skewness. The spatial distribution and mapping of soil properties in the Upper Banas River basin indicate that the pH of the soil varied from neutral to slightly alkaline. Regarding electrical conductivity, most soils were found to be non-saline, making them suitable for a wide range of crops. However, the majority of soils showed low to medium levels of organic carbon, medium to high levels of calcium carbonate, low to medium levels of available nitrogen and phosphorus, medium levels of available potassium, and low levels of available sulphur. In the case of micronutrients, the study revealed that 21% of soil samples were deficient in iron, 54% in manganese, and 2% in available copper, requiring urgent attention for their management. By addressing the challenges related to soil fertility and nutrient deficiencies, farmers can ensure long-term agricultural sustainability and protect the environment.

5. Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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