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Spatial Variability Mapping of Soil Properties in the Upper Banas River Basin using Geographic Information Systems (GIS) Techniques

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ABSTRACT: A survey was conducted during the pre-monsoon season of the year 2021 in the Upper Banas River Basin to map the spatial variability of soil properties using Geographic Information Systems (GIS) techniques. The study area covered various tehsils in the Rajasthan state, India. Soil samples were collected and analyzed for pH, electrical conductivity (EC), soil organic carbon (SOC), calcium carbonate ($CaCO_3$), available nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) content. The results indicated that the soil in the area was neutral to slightly alkaline in reaction, with low salinity levels. The majority of soils had sufficient organic carbon, medium to high calcium carbonate content, and medium levels of available nitrogen and phosphorus. Available potassium was generally at a medium level, while available sulfur was low in most areas. The generated soil fertility maps can be valuable tools for optimizing nutrient management and promoting sustainable farming practices in the region. These findings provide essential insights for precision agriculture, allowing farmers to tailor their nutrient application strategies based on specific soil conditions. By leveraging GIS technology and the comprehensive soil fertility maps, stakeholders can make informed decisions to enhance crop productivity while minimizing environmental impacts.

Keywords: Soil properties, Geographic Information Systems (GIS), Upper Banas River Basin, pre-monsoon season, nutrient management.

INTRODUCTION

Soil plays a vital role in sustaining and nourishing all life on Earth. It is a precious natural resource that takes years to develop even an inch of soil. The proper use of soil significantly impacts the life support system and socio-economic development of nations. As a crucial component of our geosphere-biosphere system, soil provides essential resources like food, fiber, fodder, and fuel wood, supporting various basic human needs. It also influences vegetation growth and plays a crucial role in regulating water and nutrient cycles.

In addressing the challenges posed by environmental degradation, Geographic Information Systems (GIS) have emerged as a powerful tool for handling spatial data at different scales. With the ability to manage vast amounts of information, including soil data, rainfall, temperature, and socio-economic data, GIS allows integrated analysis of various resources in a region. By employing GIS techniques, researchers can arrive at optimal solutions for addressing environmental problems (Adornado and Yoshida 2008).

Furthermore, the utilization of GIS extends beyond environmental concerns and permeates into fields such as urban planning, disaster management, agriculture, and public health. GIS provides decision-makers with valuable insights into the spatial relationships between different variables, enabling informed and strategic planning. For instance, urban planners can use GIS to optimize land use and infrastructure development, while disaster management agencies can assess vulnerability and plan emergency responses based on spatial data. In agriculture, GIS assists in precision farming by analyzing soil variability and recommending tailored cultivation practices. Moreover, GIS plays a pivotal role in public health by mapping disease outbreaks, identifying at-risk populations, and facilitating efficient resource allocation (Bhatta, 2010; Carr and Zwick 2015).

The growing emphasis on environmental sustainability arises from the deterioration of natural resources through physical, chemical, and biological degradation, resulting in ecological disruptions. The significant problem of land degradation has emerged due to the excessive exploitation and inadequate management of land resources. In addressing this challenge, Geographic Information Systems (GIS) have demonstrated their pivotal role in comprehending and alleviating environmental concerns (Iftikar *et al*., 2010). Furthermore, GIS enables the integration and analysis of multifaceted data, such as soil characteristics, climate patterns, and socioeconomic factors, fostering a holistic approach to environmental assessment and management. By visualizing spatial relationships and patterns, GIS aids in identifying vulnerable areas, predicting potential hazards, and formulating targeted strategies for sustainable resource utilization (Weng, 2002; Li *et al*., 2018). Moreover, GIS-based modeling facilitates the simulation of complex environmental scenarios, offering decision-makers valuable insights into the potential outcomes of various interventions. This predictive capability enhances the planning and implementation of effective policies, enabling proactive measures to prevent further degradation and promote ecosystem restoration (Eastman, 2009; Mendoza *et al*., 2020).

The present study focuses on the Upper Banas River Basin, where an assessment of soil fertility in different land use systems was conducted. GIS-based soil fertility maps were generated, providing valuable insights into the distribution and trends of various soil properties. These maps serve as decision support tools for nutrient management and benefit farmers, policymakers, and planners in making informed decisions regarding soil management.

The GIS-based soil fertility mapping enables the identification of fertility status at specific locations within the study area. This information allows for continuous monitoring of soil fertility changes over time, aiding future research and promoting sustainable soil management practices. Moreover, these soil fertility maps serve as essential references for scientific soil management and contribute to the formulation of effective fertilizer use and cropping strategies. The integration of GIS in soil management practices empowers precision farming, maximizing crop production, maintaining soil health, and minimizing fertilizer misapplication. By leveraging GIS technologies and the insights from soil fertility maps, stakeholders can work towards enhancing agricultural productivity while ensuring sustainable land use and environmental conservation.

MATERIALS AND METHODS

A. Description of the Study Site

The Upper Banas River basin, one of the main tributaries of the Chambal River basin, is situated between 73º 22’55.603” to 75º 01’27.048” E Longitude and 24º 43’21.982” to 25º 24’22.925” N Latitude. The basin encompasses SOI toposheets of 43C12, 15,16, 43D9, 13, 43G3, 4, 7, 8, 11, 12, 15, and 43K3 at a scale of 1:50,000. It spans across 17 tehsils, including Kumbhalgarh, Nathdwara, Rajsamand, Relmagra, Amet, and Devgarh tehsil of Rajsamand, Gangapur, Bhilwara, Raipur, Kotri, and Mandalgarh tehsil of Bhilwara district, Gogunda, Kotra, and Vallabhnagar tehsil of Udaipur district, and Gangrar, Kapasan, and Rashmi tehsil of Chittorgarh district in Rajasthan. Approximately 56 percent of the total basin area lies within Rajsamand and Bhilwara districts. The region is characterized by undulating topography, featuring rolling uplands and filled valleys, leading to high runoff velocity during monsoon rainfall events. For reference, the location map of the Upper Banas River Basin is depicted in Fig. 1.

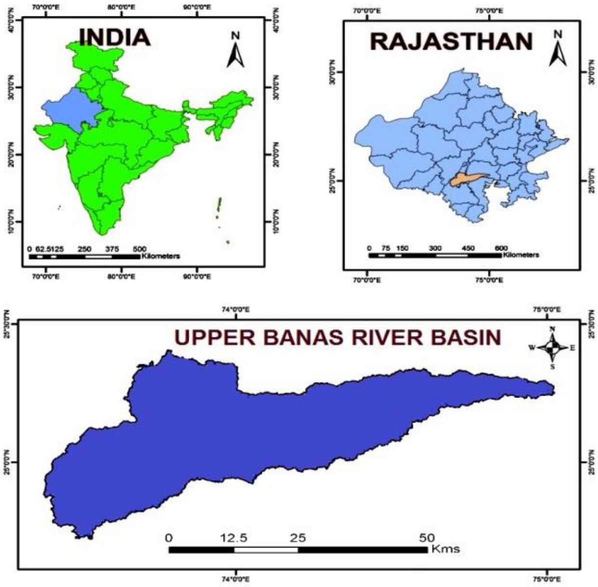

Fig. 1. Location map of Upper Banas River Basin.

B. Geography of the area

The study area, Banas River Basin, is situated in east-central Rajasthan, India, spanning between latitudes 24º15’ and 27º20’N, and longitudes 73º25’ and 77º00’E. It is surrounded by several other basins, including Luni Basin to the west, Shekhawati, Banganga, and Gambhir Basins to the north, Chambal Basin to the east, and Mahi and Sabarmati Basins to the south. The basin covers parts of various districts in Rajasthan, namely Jaipur, Dausa, Ajmer, Tonk, Bundi, Sawai Madhopur, Karauli, Udaipur, Rajsamand, Bhilwara, and Chittorgarh. Encompassing a total catchment area of 47060 sq. km, the Banas basin exhibits diverse topography. The western region is characterized by hilly terrain, part of the Aravali chain, with ground elevations ranging from 850 to 1123 m above mean sea level. In contrast, the eastern portion comprises an alluvial plain gently sloping eastwards, with ground elevations ranging from 280 to 850 m above mean sea level.

C. Soil sampling and laboratory analysis

During the pre-monsoon season of the year 2021, soil samples from the Banas River Basin were collected using the grid method after the harvest of winter crops. Approximately 100 soil samples were obtained from various locations, covering the entire study area. These samples were carefully labelled and then air-dried at temperatures ranging from 40 to 60 °C. After drying, the soil samples were sieved through a 2-mm sieve to prepare them for the analysis of soil fertility parameters.

For the analysis, pH and electrical conductivity (EC) were determined using a soil-water suspension in a 1:2 ratio, following the method suggested by Richards (1954). Soil organic carbon content was measured using the Walkley and Black method (1934). The available nitrogen (N) content was estimated using the alkaline permanganate method as described by Subbiah and Asija (1956).

To assess the available phosphorus (P) content, the Olsen method (1954) was employed, which utilizes 0.5 M $NaHCO_3$ (Olsen's reagent) as an extractant. The available potassium (K) content was determined using the flame photometry method, established by Jackson (1973). Lastly, the available sulfur (S) content was determined using the Turbidimetric method introduced by William and Steinberg (1959).

By employing these analytical techniques, the study aimed to understand the soil fertility parameters and assess the nutrient availability in the soils of the Banas River Basin. These findings would provide valuable insights for agricultural practices and nutrient management in the region.

RESULT AND DISCUSSION

A. Spatial distribution and mapping of soil properties

To effectively discern and demarcate regions suitable for efficient land use and management, the spatial variations in soil properties were systematically categorized. This involved the classification of these properties into distinct classes, each indicative of either insufficiency or adequacy. These categories were established by delineating ranges that mirror the magnitude of these soil attributes. The resultant distribution of these classes across geographical space was then computed and tabulated, as illustrated in Table 2.

Table 1. Status of pH, EC, SOC, $CaCO_3$, N, P, K and S in soils of Upper Banas River Basin.

Parameters	Minimum	Maximum	Mean
pH (1:2)	7.00	7.98	7.48
EC (dS m^{-1}) (1:2)	0.25	3.42	1.09
SOC (%)	0.05	0.98	0.55
$CaCO_3$	0.58	4.93	2.21
Available N (kg ha^{-1})	120.39	488.39	260.45
Available P (kg ha^{-1})	13.14	56.70	29.63
Available K (kg ha^{-1})	165.95	416.56	268.57
Available S (kg ha^{-1})	5.03	15.25	8.64

B. Spatial distribution and mapping of pH, EC and $CaCO_3$

The soils within the Upper Banas River Basin exhibit a considerable spectrum of pH values, spanning from 7.00 to 7.98, as depicted in Table 1. This range distinctly signifies that the soil predominantly tends towards neutrality, with a slight alkaline inclination. Notably, a significant portion (51%) of the study area showcases a near-neutral pH range of 6.5 to 7.5, while the remaining 49% demonstrates a slightly alkaline pH of 8.0 (as indicated in Table 2 and visualized in Fig. 2). These findings align with similar observations made by Kumar *et al.* (2017a) and Kumar *et al.* (2019) regarding the soils of western Rajasthan.

The electrical conductivity (EC) levels observed in the soil across the study area encompassed a range of 0.25 to 3.42 dS m^{-1}. Notably, the soil samples exhibited predominantly low EC values, signifying minimal salt presence within these soils, as evidenced by the data presented in Table 1. A significant proportion (92.0%) of the soils within the study area demonstrated a non-saline nature, with EC values remaining below 2 dS m^{-1}. However, a small percentage (3-4%) of the Upper Banas River Basin exhibited a slightly to moderately saline character (as indicated in Table 2 and illustrated in Fig. 3). The heightened concentration of soluble salts in these soils could potentially be attributed to several factors, including prolonged irrigation with saline water and the inherent characteristics of parent materials, a notion previously discussed by Moharana *et al.* (2017) and Kumar *et al.* (2017a).

C. Spatial distribution and mapping of soil organic carbon, $CaCO_3$ and available N, P, K and Sulphur

The soil organic carbon content in the Upper Banas River Basin ranged from 0.05 to 0.98 percent, as shown in Table 1. Approximately 39.0 percent of the area exhibited a deficiency in soil organic carbon (SOC) levels (<0.5%), while a total of 61.0 percent of the area demonstrated sufficient SOC levels (>0.5%), as indicated in Table 2 and Fig. 4. The relatively low SOC content in these soils can be attributed to factors such as high temperatures, limited rainfall, topsoil erosion, and the coarse texture of the soil, all of which contribute to an accelerated rate of organic matter decomposition (Kumar and Lal 2011).

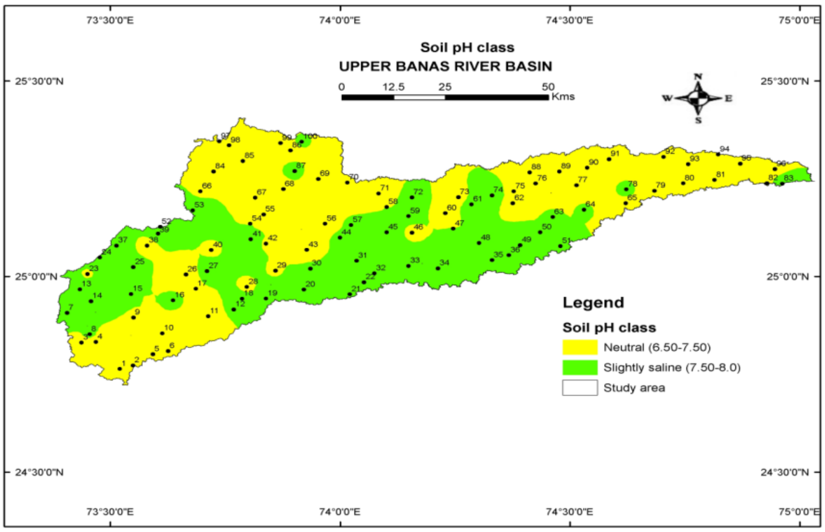

Fig. 2. Soil reaction (pH) in soils of Upper Banas River Basin.

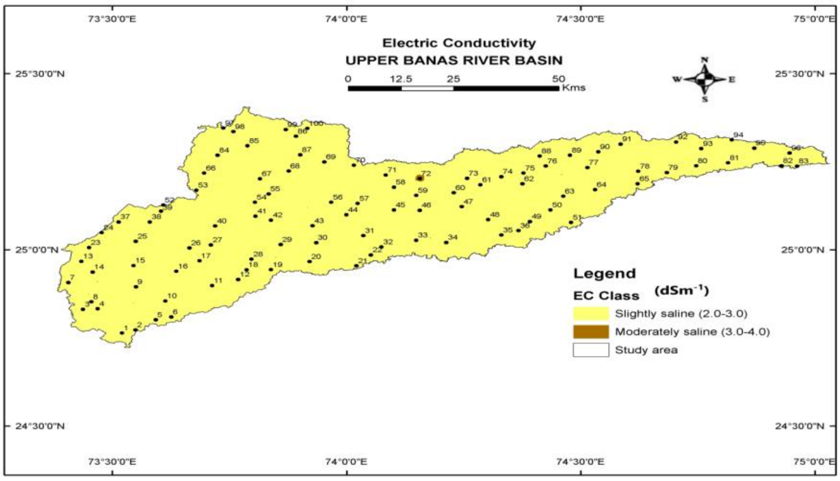

Fig. 3. EC in soil of Upper Banas River Basin.

Table 2. Frequency distribution of fertility parameters.

Parameters	Rating	Class	Area (ha)	% of total area
pH (1:2)	<6.5	Slightly acidic	Nil	Nil
	6.5-7.5	Neutral	251940	51.0
	7.5-8.0	Slightly alkaline	242060	49.0
	>8.0	Alkaline	Nil	Nil
EC (1:2)	<2	Non-saline	454480	92.0
	2-3	Slightly saline	19600	3.96
	3-4	Moderately saline	19600	4.0
	>4	Highly saline	Nil	Nil
SOC (%)	<0.5	Deficient	192660	39.0
	>0.50	Sufficient	301340	61.0
Soil $CaCO_3$ (%)	<0.50	Low	Nil	Nil
	0.50-1.50	Medium	93860	19.0
	1.50-2.0	Moderately high	13380	27.0
	>2.0	High	266760	54.0
Nitrogen (kg ha^{-1})	<250	Low	27170	55.0
	250-560	Medium	22230	45.0
	>560	High	Nil	Nil
Phosphorus (kg ha^{-1})	<10	Low	17290	35.0
	10-25	Medium	301340	61.0
	>25	High	19760	4.0
Potassium (kg ha^{-1})	<120	Low	Nil	Nil
	120-240	Medium	316160	64.0
	>240	High	177840	36.0
Sulphur (mg kg^{-1})	<10	Low	375440	24.0
	10-20	Medium	118560	76.0
	>20	High	Nil	Nil

Conversely, the presence of adequate SOC in these soils can be attributed to the natural residues of crops, the application of farmyard manure (FYM), and the utilization of inorganic fertilizers through various crop management practices (Kumar *et al.,* 2017b). Furthermore, the importance of SOC in soil fertility and its influence on various soil functions are well documented in the literature. High SOC levels have been associated with improved soil structure, enhanced water retention, and increased nutrient availability (Rengasamy, 2010; Blanco-Canqui and Ruis 2018). This emphasizes the significance of addressing factors that contribute to the maintenance and enhancement of SOC content in agricultural soils. The calcium carbonate content in the soils of the Upper Banas River Basin ranged from 0.58 to 4.93 percent, as presented in Table 1. A total of 19.0 percent of the area exhibited a medium CaCO3 content (<0.50%), while 27.0 percent of the area showed a moderately high $CaCO_3$ content (1.50-2.0%), and a substantial 54.0 percent of the area had a high $CaCO_3$ content, as detailed in Table 2 and Figure 5. Similar observations regarding $CaCO_3$ content in soils were reported in other regions, such as the Shevgaon Tehsil of Ahmednagar District (Medhe *et al.*, 2012) and the ARS farm, MPKV Rahuri (Nalwade and Pawale 2014).

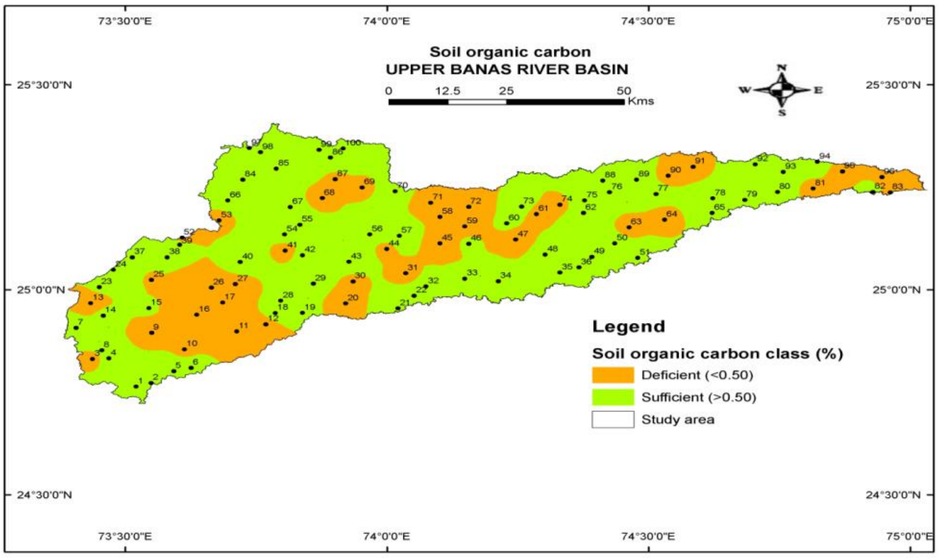

Fig. 4. Soil Organic Carbon in soils of Upper Banas River Basin.

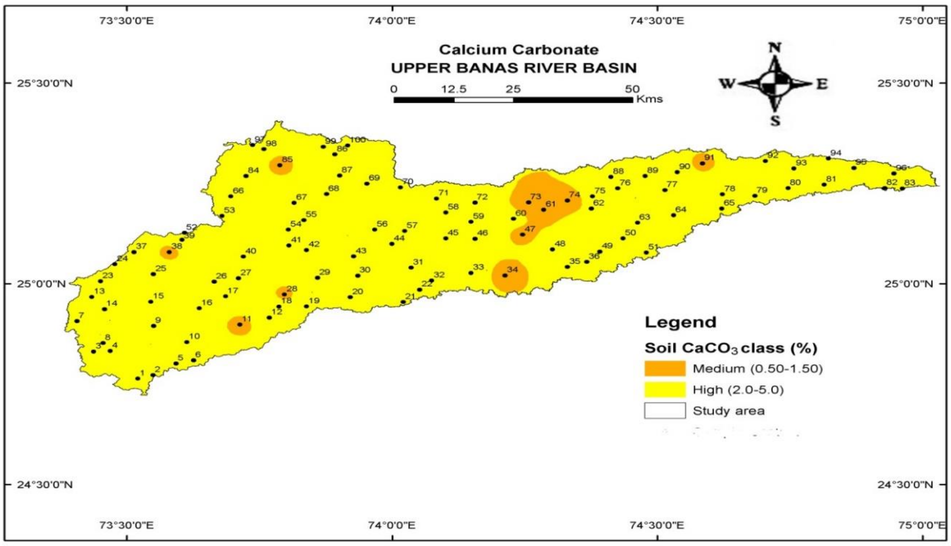

Fig. 5. Calcium Carbonate in the soils of Upper Banas River Basin.

The available nitrogen content in the study area exhibited a range of 120.39 to 488.39 kg ha^{-1}, as presented in Table 1. The data pertaining to available N, shown in Table 2, revealed that 55.0 percent of the central regions in the study area were deficient in available N (< 250 kg ha^{-1}), as depicted in Figure 6. The insufficiency of available N could potentially be attributed to factors such as low SOC content, a high rate of mineralization, and limited application of organic manures and N-fertilizers, as highlighted by Moharana *et al.* (2017). In contrast, the Upper Banas River Basin showed that available N was sufficient (> 250 kg ha^{-1}) in 45.0 percent of the area, as detailed in Table 2 and Fig. 6. This sufficiency in available N might be attributed to an adequate input of plant residues and improved crop management practices adopted by farmers. Similar findings were reported by other researchers (Kumar *et al.,* 2019) in the context of soils from semi-arid regions in India.

The available phosphorus content in the study area exhibited a range of 13.14 to 56.70 kg ha^{-1}, as detailed in Table 1. The spatial variability map for available P revealed that 35 percent of the area had low availability (< 10 kg ha^{-1}), while 61.0 percent of the area exhibited medium availability (10-25 kg ha^{-1}), as indicated in Table 2 and depicted in Fig. 7.

The low concentration of available P in the study area might be attributed to a low rate of application of P-fertilizers and the fixation of P as Ca-P on clay minerals due to the slightly alkaline nature of the soil reaction. This finding is consistent with the results reported by Kumar *et al.* (2019), highlighting the significant impact of soil pH and crop management practices on P availability. In contrast, the available P was found to be high (>25 kg ha^{-1}) in 4.0 percent of the study area, as indicated in Table 2 and Figure 7. This higher availability could potentially be attributed to effective native vegetation, limited erosion, and a relatively higher application of organic and inorganic fertilizers through crop management practices in these specific areas, aligning with the findings of Moharana *et al.* (2017) and Kumar *et al.* (2019).

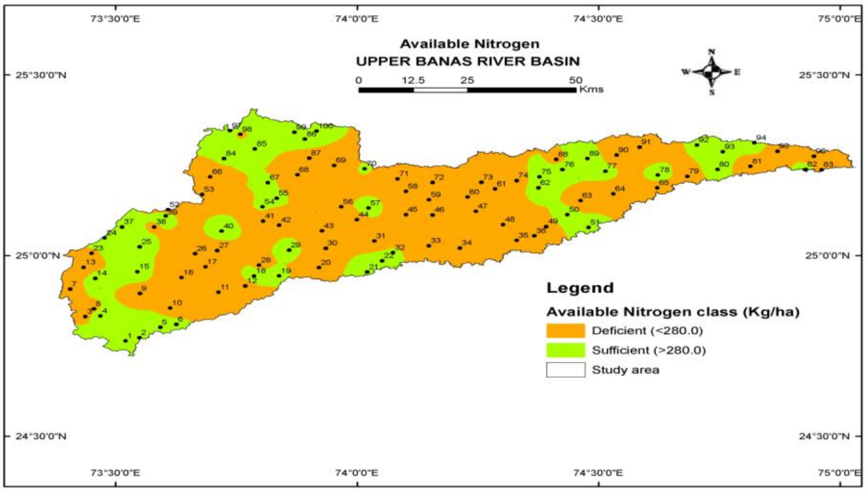

Fig. 6. Available Nitrogen in soils of Upper Banas River Basin.

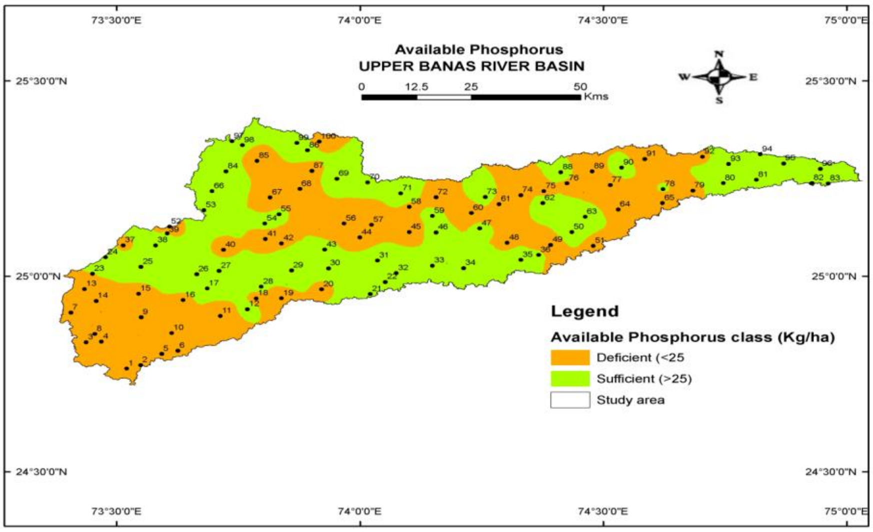

Fig. 7. Available Phosphorus in soils of Upper Banas River Basin.

The potassium content within the Upper Banas River Basin exhibited a range from medium to high, specifically from 165.95 to 416.56 kg ha^{-1}, as documented in Table 2. Within the study area, 64.0 percent of the region displayed a medium availability (120-240 kg ha^{-1}) of potassium, as presented in both Table 2 and Fig. 8. This phenomenon could be attributed to several factors, including a low amount of soil organic carbon (SOC), the coarse texture of the soils, and a comparatively lower application rate of both organic manures and K-fertilizers, as discussed by Kumar *et al.* (2017b).

In contrast, an elevated availability of potassium (>280 kg ha^{-1}) was observed in 36.0 percent of the Upper Banas River Basin, as indicated in Table 2 and Figure 8. This occurrence could potentially be explained by the relatively finer soil texture, featuring clay fractions composed of mica (illite), smectite, and vermiculite. The predominance of mica as the primary clay mineral in the coarser clay fraction might have contributed to the higher availability of potassium. Additionally, the improved cropping history of the area, along with the increase in organic matter content in soils, may have led to enhanced clay-humus complexes, providing more exchange sites and facilitating greater access to potassium, as discussed by Sharma *et al.* (2009) and Kumar *et al.* (2019).

The available sulfur content within the soils of the Upper Banas River Basin exhibited a range spanning from 5.03 to 15.25 mg kg^{-1}, as presented in Table 1. Analysis of the data displayed in Table 2 and Figure 9 revealed that 24.0 percent of the region was characterized by low sulfur levels (<10%), while a substantial 92.0 percent of the area featured high sulfur levels falling within the range of 1.50-2.0%.

The prevalence of sulfur in the soil is primarily in an organic combination; consequently, soils rich in organic matter tend to exhibit higher sulfur content, a relationship noted by Kanwar (1976). Furthermore, it is noteworthy that coarse-textured sandy soils generally tend to possess lower total sulfur content in comparison to their fine-textured counterparts. The adequacy of available sulfur is closely linked to the organic matter content within the soil, indicating a direct proportional relationship. This observation aligns with similar findings documented by Hundal *et al.* (2006) in the soils of Punjab, India, and Jat and Yadav (2006) in the Entisols of Jaipur District, Rajasthan.

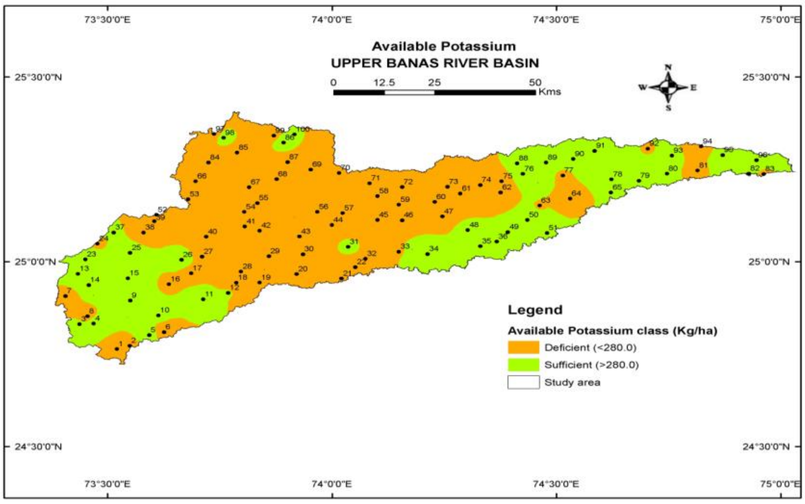

Fig. 8. Available Potassium in soils of Upper Banas River Basin.

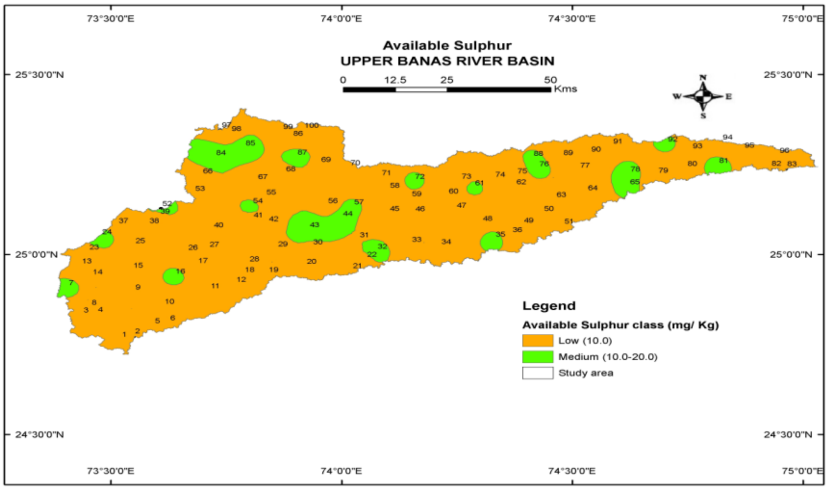

Fig. 9. Available Sulphur in soils of Upper Banas River Basin.

CONCLUSION

In the context of the Upper Banas River Basin, the predominant soil reactions were found to be neutral to slightly alkaline. The collected soil samples consistently displayed an electrical conductivity (EC) reading of less than 2 dS m^{-1}, suggesting the absence of significant salinity concerns across the area. Within this framework, the organic carbon content of the majority of soils was determined to be satisfactory. Calcium carbonate levels ranged from medium to high, indicating a notable presence. Available nitrogen and phosphorus content generally exhibited low to medium concentrations, while available potassium content was more evenly distributed within a medium range. The available sulfur content, however, tended to be comparatively low. The generated soil maps offer practical utility by delineating cohesive soil units, thereby assisting farmers in making informed decisions regarding the appropriate type and quantity of macro-nutrients to apply. This targeted approach aims to optimize economic outcomes by tailoring nutrient management strategies to the unique demands of each specific location. The incorporation of geo-referenced sampling sites using GPS technology enables recurrent visits to monitor shifts in nutrient status over time. This innovative methodology surpasses the limitations of conventional sampling techniques, providing a robust and accurate assessment of nutrient dynamics in the region.

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Conflict of Interest. None

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