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RESEARCH ARTICLE

Assessment and GIS mapping of DTPA-extractable cationic micronutrients and hot water-soluble boron in soils of Rajouri District, Jammu & Kashmir, India

Renuka[1], Sarabdeep Kour[1*], Vikas Sharma[1], Meenakshi Gupta[2], Divya Sharma[3], Rajeev Bharat[4] & Dhamni Patyal[2]

[1]Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Chatha 180 009, Jammu & Kashmir, India

[2]Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Chatha 180 009, Jammu & Kashmir, India

[3]Govt. GLDM Degree College, Hiranagar 184 142, Jammu & Kashmir, India

[4]Division of Plant Breeding & Genetics, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Chatha 180 009, Jammu & Kashmir, India

*Correspondence email - sarabdeepkaur98@gmail.com

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Abstract

Increased production of crops utilising high yielding varieties requires larger input of macronutrients which has accelerated micronutrient deficiencies in soils. The soil micronutrient status indicates extent of depletion and future projections for prediction of their requirements, refinement of critical levels and delineation of micronutrient deficient and toxic areas. This study was carried out with the objective of generating soil fertility maps of Rajouri District of Jammu & Kashmir using geographical information system (GIS) approach. Mapping of diethylene triamine pentaacetic acid (DTPA)-extractable cationic micronutrients and hot water-soluble boron (B) was carried out. Soil samples were collected from various land uses viz: agriculture, horticulture, forest, pasture and waste lands. The spatial visualisation of maps was done using inverse distance weight (IDW). The soil was found to be moderately acidic to moderately alkaline in reaction (pH 4.9 to 9.0) and free from the problem of salinity. The soil organic carbon (OC) content in the district ranged between 1.20 and 25.80 g kg^{-1}. The DTPA-iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) content in soils varied from 1.26 to 58.03 mg kg^{1}, traces to 58.15 mg kg^{-1}, 0.20 to 4.82 mg kg^{-1} and traces to 10.69 mg kg^{-1} respectively under various land use systems whereas hot water soluble B content varied from 0.10 to 5.95 mg kg^{-1}. The content of Fe, Mn and Zn were higher in agricultural soils, whereas Cu and B content were found higher under horticultural soils. Soil micronutrient maps clearly showed areas where lack of micronutrients limited crop growth. Zinc was deficient in >50 % of sites; Fe and Mn were sufficient in >95 % of sites, 5 % sites were having low B content and approximately 35 % sites were having low copper content. The values of micronutrient content, organic carbon and clay content had a positive relationship. The study emphasises the need for targeted nutrient management strategies; especially zinc fertilisation in deficient areas, to support crop productivity. Additionally, managing organic matter and carefully using micronutrient fertilisers can help maintain long-term soil health and avoid future deficiencies.

Keywords: available boron; copper; DTPA-extractable iron; geographical information system; land use system; manganese; zinc

Introduction

Micronutrients are assimilated by plants in trace amounts as compared to macronutrients but mostly act to stimulate, activate or accelerate the enzyme activities in metabolic processes of plants. However, if micronutrients are not readily available, key plant metabolic processes are hindered, resulting in poor growth of plants and decreased output. This might also contribute to reduced soil fertility. Because of the continual removal of essential minerals by crops, Indian researchers have discovered widespread micronutrient deficits in agricultural fields (1). A combination of high yielding varieties and hybrids, declining organic manure usage and reduced crop waste recycling has resulted in nutrient depletion and widespread micronutrient deficiency (2). However, there is wide variation among soil micronutrients across various land management units (3, 4). Farmers also fail to provide micronutrients for soil, resulting in higher deficiency levels. On the contrary, micronutrients play an important role in the stability of agricultural yields through balanced plant nutrition (5). Rhizosphere factors such as soil organic matter content, pH and adsorptive surfaces, as well as soil physico-chemical and biological properties also influence soil micronutrient availability (6). Micronutrient dynamics in soils are also influenced by processes like adsorption, desorption, precipitation, dissolution and complexation with organic ligands. These processes control the bioavailability of micronutrients to plants. Soil texture, mineral content and redox potential are important factors that determine how micronutrients move and transform in agricultural ecosystems.

Malnutrition due to insufficient micronutrients affects most of the global population, which is referred to as hidden hunger (7). Micronutrient deficiencies have a complicated effect on human health and have substantial negative effects on immunological function, newborn and child growth and development, maternal health and pregnancy outcomes (8). From a soil science viewpoint, managing micronutrients in soil sustainably needs regular monitoring, soil testing and the use of specific nutrient management practices for each site (9). Applying organic amendments, green manures and fertilisers rich in micronutrients can help restore depleted soils. Thus, understanding the soil's capacity to supply micronutrients and the factors influencing their availability is fundamental for designing balanced fertilisation strategies, maintaining soil fertility and supporting long-term agricultural sustainability.

Geographical information system (GIS) is a unique technique for partial study of natural resources and database management. To provide meaningful information, it integrates various forms of spatial information, including agro-climatic zones, land use and soil management (10, 11). It is an effective and versatile tool to automate the transformation of soil nutrient data into soil/ natural resource information system. These tools can be effectively utilised to create soil fertility maps. This also helps to monitor the changes in nutrient status over a period as georeferenced sampling side can be revisited with the help of global positioning system (GPS), which is otherwise difficult in random sampling. The maps can also be useful for guiding the farmers to decide the amount of micronutrient fertilisers for optimum/economic returns areas having deficiency of one or more nutrients than those having sufficient nutrients. The imbalance of micronutrient fertilisers over a period can be minimised by using soil fertility maps (12).

The Rajouri District of Jammu & Kashmir has varied agro-climatic zones like subtropical, intermediate and temperate and due to diversity in climate of three zones, this area can cultivate a variety of field crops, vegetables and fruit plants at various altitudes. Also, there is a huge area under forests, pastures and wastelands in the district. However, farmers are emphasising the application of macronutrients only and ignoring the use of micronutrients. So, there is a huge research gap as the information on micronutrient status under various land use systems in the district is limited and scattered and no previous attempt has been made to map micronutrients in this area. Therefore, the goal of current investigation was to generate information regarding micronutrient status with respect to land uses in the Rajouri District and generate prediction maps with the assistance of geoinformatics.

Materials and Methods

Study location

The study area was Rajouri District of Jammu & Kashmir union territory of India which is northern most region of the country. This district possesses three agro-climatic zones viz., subtropical, intermediate and temperate. This district is surrounded by Reasi district in east, Mirpur district (Pakistan occupied Jammu & Kashmir) in west and Kashmir valley in north and Poonch district in northwest (Fig. 1) and is endowed with metallic, non-metallic minerals and solid fuels. It has an elevation of 917 m (3009 ft) from mean sea level. It is located between 32°58′ to 33°35′ North latitude and 74°1′ to 74°40′ East longitude. The area of Rajouri District is about 2630 sq. km. Due to its sub-tropical, transitional and temperate climates, the area can cultivate a variety of crops at various heights. Because of the district's high altitude, the climate fluctuates. Temperature can reach 38 °C at times and seldom fall below 1.5 °C. The major soils of this area are brown red and sub-mountainous soil and are classified as inceptisols. Rajouri, being part of the Western Himalayas, has significant areas covered by mountain soils, which are further categorised into mountain forest soils at lower altitudes and mountain meadow soils in higher areas. Rice, maize and wheat are the major crops grown in the district. Trees, grasses and shrubs make up the natural vegetation. Planting two or three crops at a time is common in sub-tropical to intermediate climates and triple cropping is used for short-term crops such as vegetables and fodder crops, potatoes, summer pulses, oilseeds and other short-term crops.

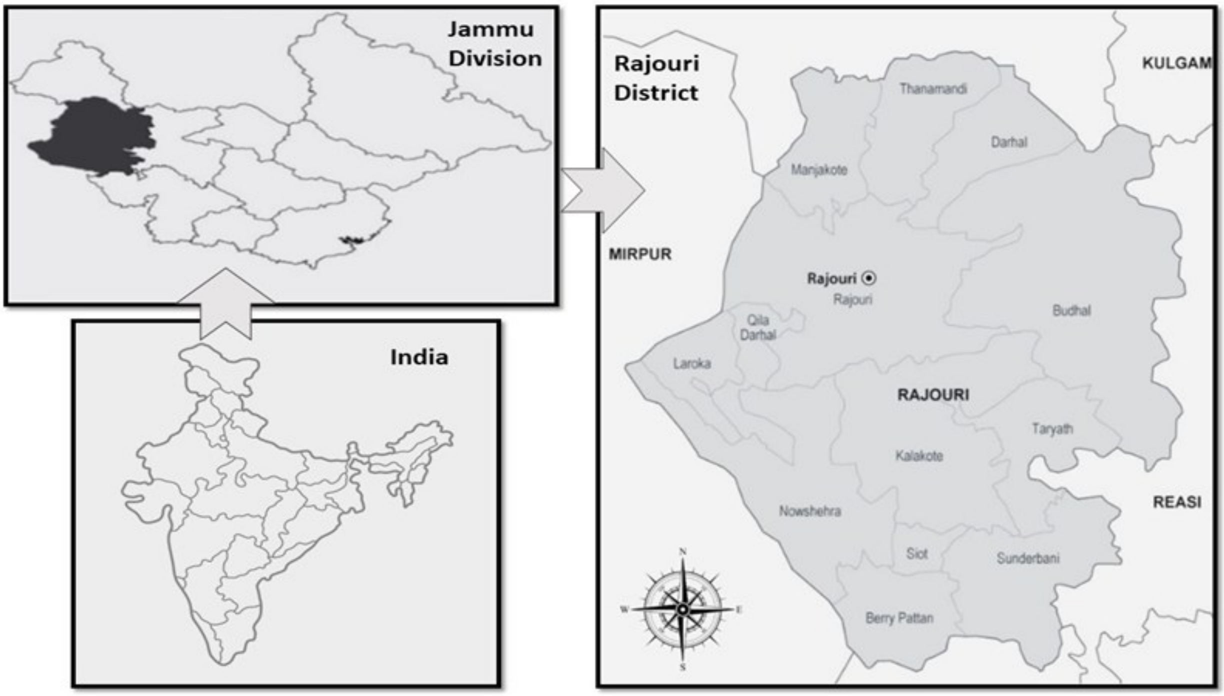

Fig. 1. Map of the study location. Source: Prepared using ArcGIS software.

Gathering and analysing soil samples

Surface (0–15 cm) soil samples were collected by utilising stratified random sampling with land use being major variable from 250 locations of entire district. The various categories of land use taken were agriculture, horticulture, forests, wastelands and pastures. In forest areas and barren land, samples were collected within around 8–10 km due to low variability in soil but in case of cultivated areas, samples were collected within around 2–4 km because of high heterogeneity in soil properties due to different types of cropping systems, variations in fertilisation and land use types. In other areas like horticulture and pasture lands, samples were taken around 2–4 km. Georeferenced soil samples were collected using handheld GPS by Garmin. The collected soil samples were then air-dried, ground and passed through a 2-mm sieve and then the samples were analyzed for basic physico-chemical properties as per the standard procedures. The DTPA extractable micronutrients (Fe, Zn, Cu and Mn) were analysed as per the methods proposed by Lindsay and Norwell (1978) (13) and concentrations of Fe, Zn, Cu and Mn were determined using atomic absorption spectrophotometer (AAS). A calibration curve for micronutrient analysis by AAS was prepared by measuring the absorbance of standard solutions with known concentrations of each micronutrient, allowing quantitative determination of sample concentrations based on their absorbance values. Available boron (B) was extracted with hot water and then analysed by using Azomethine-H method (14). The spatial nutrient visualisation was interpolated using the linearly weighted combination of the sample points in the GIS software (ArcMap Version 10.3) with Inverse distance weighted (IDW) interpolation tools.

Statistical analysis

Analyses of descriptive statistics were carried on the DTPA-extractable cationic micronutrients and hot water-soluble B in soils. The software used for analyses was SPSS v16.0 (SPSS Inc., Chicago, IL, USA).

Generation of thematic soil fertility maps

The soil fertility maps of basic physico-chemical characteristics and micronutrients were prepared by using Arc-GIS software version 10.3. The overlay steps used in map making are shown in Fig. 2. The inverse distance weighting (IDW) technique was adopted to generate maps. As the sample size was limited and the interpolation method used was deterministic in nature, error estimation parameters such as R^2 and RMSE were not applied. The maps were prepared by categorising the available micronutrients under different ranges as per agriculture land use, by showing appropriate legends (colours) for Fe, Zn, Cu, Mn and B. The percentage of soil samples falling in deficient category were calculated based on critical limits given in Table 1 (15).

Results and Discussion

Basic characteristics of soils

The soils from Rajouri District were moderately acidic to moderately alkaline (4.9–9.0) in reaction and free from the problem of salinity and alkalinity under various land use systems (Fig. 3d & f). The slightly acidic pH was observed in hilly areas of the district whereas majority of the land use systems have neutral pH. The variation in soil pH was mainly on account of variation in topography, slope and use of farmyard manure (FYM) at varying rates (16). The wide pH range of 4.9–9.0 significantly affects micronutrient availability. In acidic soils, with a pH lower than 6.0, elements like iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) are generally more soluble and available to plants. However, their solubility drops sharply in neutral to alkaline soils due to precipitation or adsorption on soil particles. In contrast, B availability tends to decrease in acidic soils but rises in neutral to slightly alkaline conditions. Therefore, the variation in pH across different land uses directly impacts the distribution and availability of micronutrients. This highlights the importance of managing nutrients based on pH levels. The lower values of electrical conductivity (EC) in all land use systems may be the result of dominant sandy loam texture that leaches down the salt easily, resulting in low EC (17). The soil organic carbon (OC) in the district was generally high; however, it ranged between 1.20 and 25.80 g kg^{-1} under various land use systems (Fig. 3f). Soils under agriculture, horticulture and forests contain more OC than soils under pasture and wasteland soils. In general, higher reaches and forest soils of the district showed higher organic carbon content. High OC content was because most of the areas of hilly terrains were covered with forest type of vegetation that facilitates the accumulation of organic material to the soil through leaf and plant litter (18, 19). Higher OC content in forest soils of intermediate zone of Rajouri District were observed in previous studies (20). The prominent textural class of the study location was sandy loam (Fig. 3a–c). Moreover, the areas having subtropical climate showed

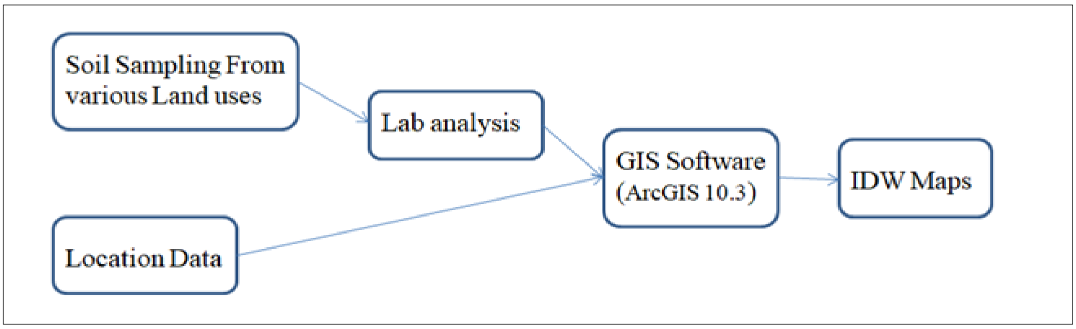

Fig. 2. Diagram illustrating the overlay steps used in map making.

Table 1. Critical level of deficiency of micronutrients in soil

Micronutrient	Extractant/method used	Critical limit in soil	Unit
Iron (Fe)	Diethylenetriamine pentaacetic acid (DTPA)	2.5–5.8	mg/kg
Zinc (Zn)	DTPA	0.5–1.0	mg/kg
Copper (Cu)	DTPA	0.2–0.5	mg/kg
Manganese (Mn)	DTPA	2.0–4.0	mg/kg
Boron (B)	Hot water soluble	0.5–1.0	mg/kg

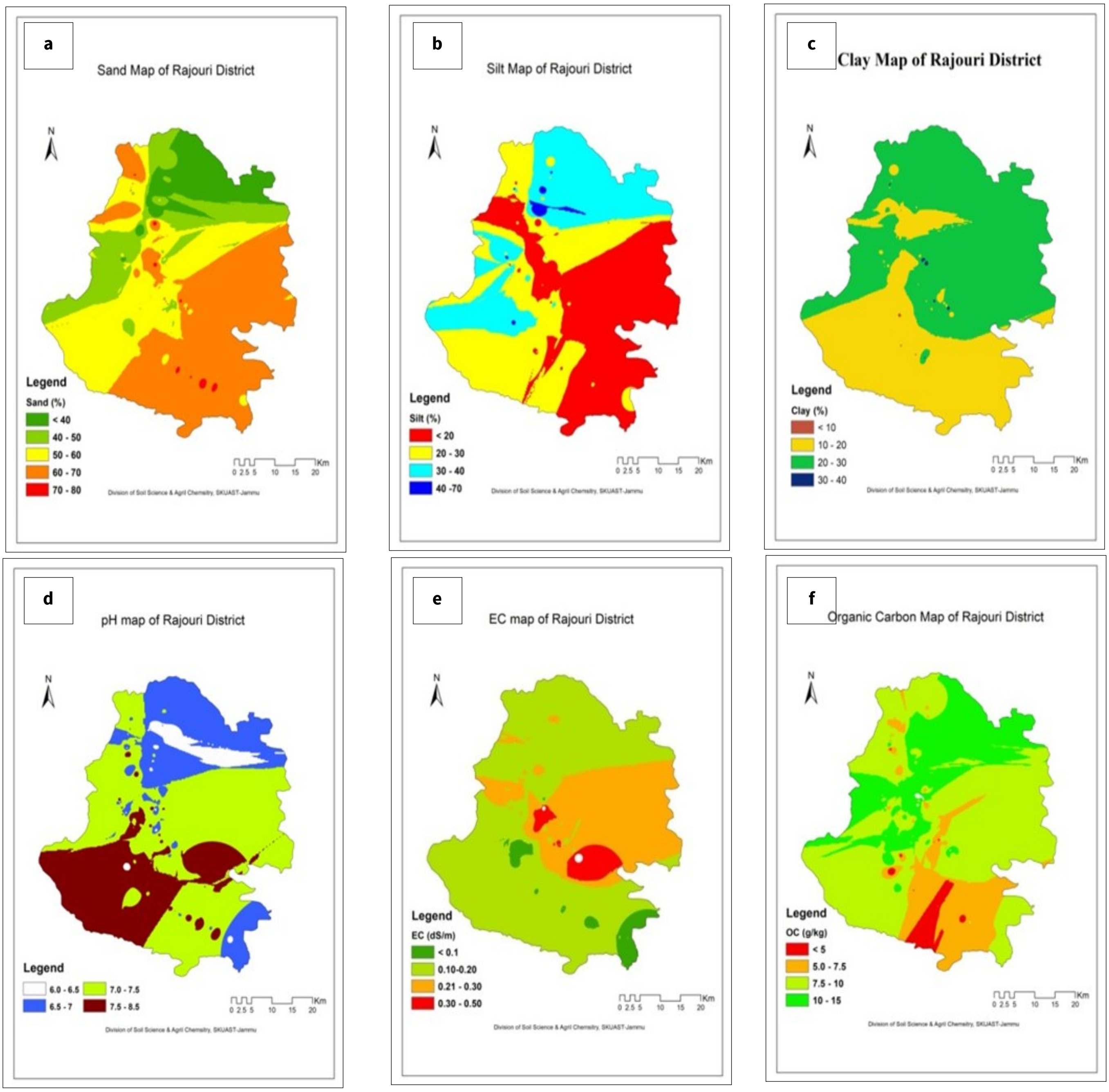

Fig. 3. Thematic maps of (a) sand content; (b) silt content; (c) clay content; (d) soil pH; (e) EC; (f) soil organic carbon. Source: Prepared using ArcGIS software.

higher sand content than the areas having intermediate and temperate climate. Higher sand content in subtropical soils and higher clay content in intermediate and temperate zone soils of Jammu region was also observed in previous studies (21). Among the land uses, wasteland soils contain higher sand content as compared to the other land use systems whereas silt and clay content was high in agriculture soils. Comparable outcomes were reported that waste land soils had higher sand content than those of agriculture, horticulture, pasture and forest land use systems (22).

DTPA extractable micronutrients

All the micronutrients exhibited wide variations across land uses and their distribution pattern was assessed using skewness and kurtosis values (Table 2).

DTPA-Zinc

The findings showed that the DTPA-Zn content in soils was sufficient in few areas of the district except certain locations of Sunderbani, Kalakote, Nowshera and Rajouri tehsils. The maximum value of Zn content was observed in agriculture land use system (4.82 mg kg^{-1}) followed by horticulture (2.71 mg kg^{-1}) and it was lowest in wasteland and pasture lands (Table 2). Considering 0.5–1.0 mg kg^{-1} DTPA-extractable Zn as the critical limit, the Zn was deficient in >50 % areas of the district (Fig. 4a). Maximum coefficient of variance was found under agriculture land use (67.61) system followed by horticulture land use (58.91) and minimum were found under wastelands (32.09). The variations in Zn content may be due to neutral to alkaline pH and application of phosphatic fertilisers in cultivated soils (23). Zinc availability in cultivated soils was adversely affected by high level of available phosphorus in soils (24). Agricultural soils exhibited high positive skewness (2.41) and strong leptokurtosis (8.30) for Zn content, indicating dominance of low Zn values with a few extreme highs. Wasteland soil also showed similar irregularity (skewness 1.92; kurtosis 4.55). In contrast, horticultural and pastureland soils were close to normal distribution with mild skewness and near-zero kurtosis, while forest soils showed moderate right skewness (1.62) with leptokurtic nature (3.08).

Table 2. Range of micronutrients in different land use systems of Rajouri district

Range of micronutrients	Type of land use systems				
	Agriculture	Horticulture	Forest	Pasture	Wasteland
			Zn (mg kg^{-1})		
Min.	0.20	0.48	0.33	0.32	0.53
Max.	4.82	2.71	1.83	2.00	1.49
Mean	1.05	1.29	0.68	0.97	0.81
± S.E.	0.06	0.25	0.07	0.10	0.07
CV	67.61	58.91	51.47	52.57	32.09
Skewness	2.41	0.79	1.62	0.82	1.92
Kurtosis	8.30	−0.22	3.08	−0.23	4.55
			Cu (mg kg^{-1})		
Min.	Traces	0.01	Traces	Traces	0.10
Max.	5.29	10.69	1.47	3.21	0.38
Mean	0.82	1.46	0.08	0.71	0.25
± S.E.	0.09	1.15	0.06	0.21	0.02
CV	78.84	236.98	424.15	136.62	28.00
Skewness	1.94	2.96	2.49	1.42	−0.45
Kurtosis	4.55	8.85	9.55	1.32	0.23
			Fe (mg kg^{-1})		
Min.	1.26	9.93	1.88	6.17	3.32
Max.	58.03	22.04	36.14	54.14	41.25
Mean	21.84	14.82	10.28	23.86	12.81
± S.E.	1.28	1.53	1.90	2.88	3.79
CV	67.43	31.08	94.36	56.78	98.20
Skewness	0.76	0.78	1.38	0.74	1.56
Kurtosis	−0.22	−0.99	1.09	−0.36	1.52
			Mn (mg kg^{-1})		
Min.	Traces	Traces	0.08	Traces	3.97
Max.	58.15	13.92	36.74	50.28	33.53
Mean	19.12	4.14	10.48	15.03	16.61
± S.E.	1.26	1.93	2.06	2.96	3.26
CV	75.92	141.46	100.66	92.61	65.20
Skewness	0.67	1.06	1.01	1.16	0.20
Kurtosis	−0.15	−0.82	0.36	0.62	−1.61
			B (mg kg^{-1})		
Min.	0.10	1.00	0.30	0.20	0.45
Max.	5.30	5.95	4.35	3.28	4.40
Mean	1.81	3.06	2.32	1.84	1.87
± S.E.	0.08	0.54	0.25	0.19	0.40
CV	56.35	53.26	55.17	49.45	71.65
Skewness	0.97	0.62	−0.02	−0.34	0.65
Kurtosis	1.27	−0.51	−1.18	−0.89	−0.68

DTPA-Copper

The DTPA-Cu content of the investigated soils varied from traces to 10.69 mg kg^{-1} under various land use systems of the district. The highest mean Cu content of 1.46 mg kg^{-1} was observed in horticulture soils followed by agriculture (0.82 mg kg^{-1}), pasture and then wastelands whereas lowest mean value of Cu content was observed for forest soils (Table 2). The soil fertility map showed that higher Cu content was observed in northern hilly terrains whereas it was lower in plains of district (Fig. 4b). The accessible Cu concentration in soil increased with fineness of soil texture, as it is clear from the positive relationship of Cu with clay and OC content. The high Cu content in some areas may come from the chelating effect of organic matter (25, 26). This organic matter forms stable complexes with Cu and helps it stay in the soil. However, the very high coefficient of variation (CV > 400 %) seen in forest soils points to significant spatial differences. This could be due to uneven litter deposition, localised accumulation of organic material or different rates of mineral weathering. Such wide variation might also result from sampling bias or outliers. Copper distribution was highly uneven in horticultural (skewness 2.96; kurtosis 8.85) and forest soils (skewness 2.49; kurtosis 9.55), suggesting strong heterogeneity and the presence of extreme values. Agricultural soils also showed right skewness with moderate leptokurtosis, whereas pasture soils were comparatively stable (skewness 1.42; kurtosis 1.32). Wasteland soils had near-normal distribution with slight left skewness (−0.45) and low kurtosis (0.23), reflecting uniformity (Table 2).

DTPA-Iron

There was a great variation in the soil Fe content (1.26 to 58.03 mg kg^{-1}) under various land use systems in the studied location. The higher mean Fe content was noted in agriculture and pasture soils as compared to other land use systems. Iron content varied from 1.26 to 58.03 mg kg^{-1} under agriculture, 9.93 to 22.04 mg kg^{-1} under horticulture, 1.88 to 36.14 mg kg^{-1} under forest, 6.17 to 54.14 mg kg^{-1} under pasture and 3.32 to 41.25 mg kg^{-1} under wasteland soils (Table 2). Maximum coefficient of variance (98.20) was found under wastelands whereas it was minimum under horticulture soils (31.08). The level of Fe content was high in those areas where the soil pH was slightly acidic as the availability of Fe was adversely affected by high pH in agriculture soils (27). Considering 2.8–5.85 mg kg^{-1} DTPA-extractable Fe as the critical limit, the Fe was sufficient throughout the district and high availability of Fe was due to slightly acidic condition and high OC content in soil (Fig. 4c). The coefficient of variation was over 98.20 % in wastelands and 94.36 % in forest soils. This indicates a significant spatial difference in Fe distribution. Such high variability may come from variations in topography, the accumulation of organic matter, redox conditions and the intensity of land use. These factors influence Fe solubility and mobility. However, agricultural, horticultural and pasture soils recorded near-normal distribution with mild skewness (0.74–0.78) and negative kurtosis, indicating balanced spread. Forest and wasteland soils, however, showed greater irregularity with higher skewness (>1.3) and positive kurtosis (>1.0), reflecting localised enrichment of Fe.

DTPA-Manganese

The DTPA-Mn status of various soils varied from traces to 58.15 mg kg^{-1} under various land use systems and it was higher under agriculture and forest soils in contrast to other land use systems. The highest mean value of 19.12 mg kg^{-1} was noticed in agriculture soils (Table 2). However, maximum coefficient of variance was found under horticulture land use system. Considering 2.0–4.0 mg kg^{-1} DTPA-extractable Mn as the critical limit, the Mn was sufficient in the district (Fig. 4d). The sufficiency of DTPA extractable Mn might be due to high quantity of organic matter content and neutral pH in the studied area (28–30). The distribution of Mn was relatively balanced in agricultural (skewness 0.67; kurtosis −0.15) and

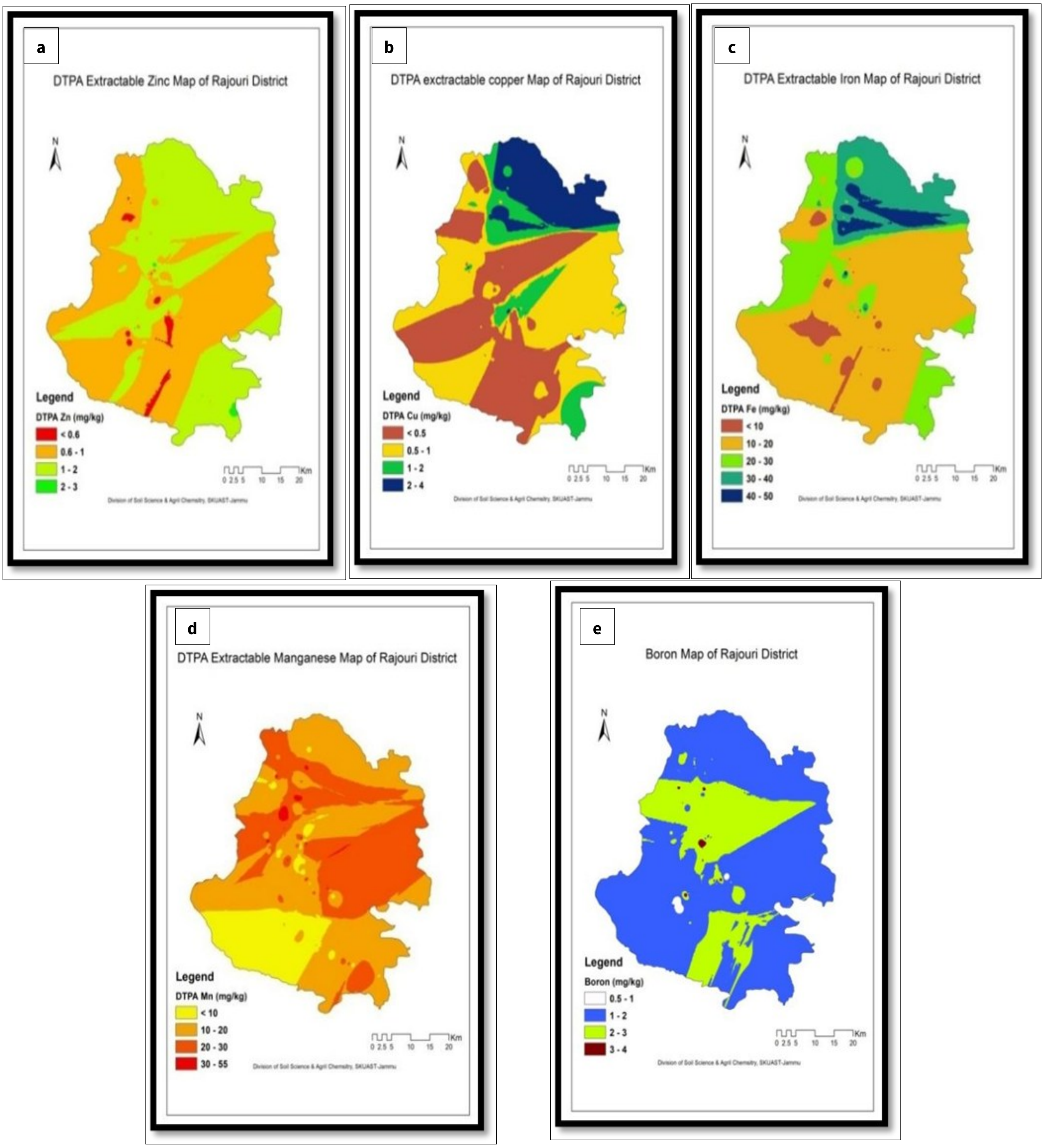

Fig. 4. Thematic maps of (a) available zinc; (b) available copper; (c) available iron; (d) available manganese; (e) available boron. Source: Prepared using ArcGIS software.

wasteland soils (skewness 0.20; kurtosis −1.61), suggesting near-normal to flat distributions. Forest and pasture soils were moderately skewed (1.01–1.16) with slight leptokurtosis, while horticultural soils had higher variability with skewness 1.06 and negative kurtosis (−0.82).

Hot water-soluble boron

The hot water-soluble B content was sufficient throughout the district except few locations of Nowshera and Kalakote tehsils (Fig. 4e). The highest average value of B content was observed in horticulture soils (3.06 mg kg^{-1}) as compared to forest (2.32 mg kg^{-1}) and agriculture soils (1.81 mg kg^{-1}) (Table 2). Maximum coefficient of variance (71.65) was found under wasteland land use system followed by agriculture land use (56.35) and minimum were found under pasture lands (49.45). These outcomes may be caused by high concentration of OC in horticulture, forest and agriculture soils. Slight deficiency of B was observed in few areas of the district that possibly may be due to unavailability of B in alkaline pH of soils (31). Considering 0.5–1.0 mg kg^{-1} as the critical limit, the B was sufficient in the district (Fig. 4e). As the soil pH is slightly acidic in most land use systems, B deficiency has not been reported. Boron becomes less available to plants as soil pH increases, especially in soils with a pH above 6.5 (32). As far as descriptive statistics were considered, the agricultural soils showed right skewness (0.97) and leptokurtosis (1.27), suggesting uneven accumulation with some extreme values. Forest (skewness −0.02; kurtosis −1.18) and pasture soils (skewness −0.34; kurtosis −0.89) exhibited almost symmetrical and flat distributions, indicating greater stability. Horticultural and wasteland soils showed mild right skewness with negative kurtosis, reflecting moderate variability.

Correlation between different physico-chemical properties and soil micronutrient content

The availability of micronutrients was influenced by number of variables such as soil pH, EC, soil OC and soil texture. The correlation coefficients between soil properties (sand, silt and clay content and soil pH, EC and OC) and micronutrients are presented in Fig. 5. The positive correlation of Zn was observed with sand, clay, OC, available N, available P and available K content. However, negative correlation of Zn content was observed with soil silt content, pH and EC although it was not significant (33). The available Cu content revealed a significant and favorable association with OC, silt and clay content, whereas a negative and significant correlation with pH (34, 35). DTPA-Fe showed significant and positive correlation with silt, clay and OC, whereas negative and significant correlation was observed with pH (36). Available Mn showed negative association with sand content, soil pH, EC and OC, whereas positive correlation with silt and clay. The contradiction between Mn having a positive correlation with silt/clay content and its declining availability in heavier soils may be too different between total Mn content and bioavailable Mn. Heavier soils often contain more total Mn, but this Mn is largely fixed or locked into unavailable forms due to high pH and other factors (37). A negative relationship of available Mn with sand and pH and a favorable association of available Mn with silt and clay content was also reported (37). The available B showed positive association with

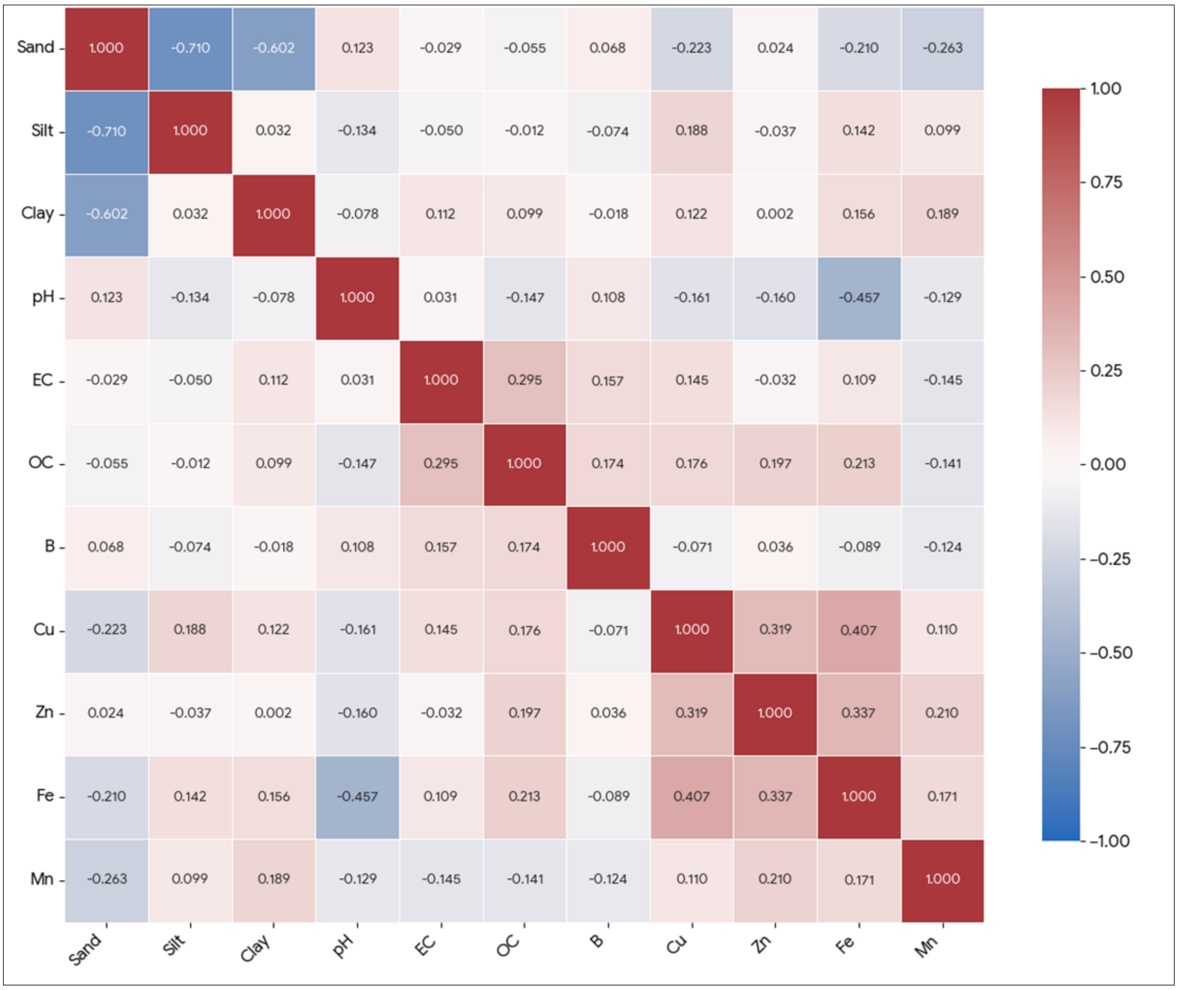

Fig. 5. Soil properties correlation matrix of Rajouri district. **Correlation is significant at 1 % level of significance *Correlation is significant at 5 % level of significance.

pH, EC and OC and negative relationship with silt and clay content although the correlation was not significant Similar observations were given in previous studies (38).

Conclusion

The soils in the study were strongly acidic to moderately alkaline in reaction. They had low salinity and medium to high levels of OC content. Among the DTPA-extractable micronutrients, Fe, Mn, Cu and B were present in sufficient amounts across different land use systems, but Zn was lacking in some tehsils of district. Creating spatial distribution maps gave a clearer view of nutrient variability than traditional point-based assessments; this provided a scientific foundation for site-specific nutrient management. These results have wider implications for the agro-ecology of the Himalayas, where varied terrain, different land uses and reduced organic inputs often lead to imbalances in micronutrients. This study would help refine micronutrient management strategies in the region. From a management standpoint, Zn supplementation should be prioritised in areas lacking it through soil and crop interventions to maintain long-term productivity in Rajouri and similar Himalayan districts. The maps created can be useful tools for policymakers, extension agencies and farmers to implement balanced fertilisation practices. So, there is need for Zn fertilisation at regular intervals to maximise yield, otherwise Zn deficiency will gradually become a major crop productivity constraint.

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Authors' contributions

R and SK designed the experiment and carried out experiment and wrote the manuscript. VS, MG and RB reviewed the manuscript. DS and DP participated in the sequence alignment. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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