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Mapping of Soil Physicochemical Properties of Kishtwar District of Jammu and Kashmir (J&K) Using Geographic Information System (GIS)

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Authors' contributions

All authors have contributed equally in the manuscript and they are well aware of the same. All authors read and approved the final manuscript.

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ABSTRACT

Objective and Background: A study was carried out to assess and generate the prediction maps of the physicochemical properties of the soil in the Kishtwar district. The Kishtwar district of Jammu and Kashmir covers an area of 7737 sq. km. and falls in the temperate zone of the state. It is an upland valley in the northeast corner of the Jammu region.

Methods: Soil samples were collected from the entire Kishtwar district in a stratified random manner. The digitization process and generation of maps were carried out with ArcGIS 10.0.

Results: Sandy loam was the dominant textural class in the district. Soil pH varied widely across the Kishtwar district ranging from as low as 4.87 to as high as 8.00, with a mean value of 6.73. The coefficient of variation CV (coefficient of variation) was 8.08%. Electrical Conductivity (EC) ranged from 0.03 to 9.80 dS m^{-1} with a mean value of 1.50 dS m^{-1}. The variability of Electrical Conductivity (EC) was high. Organic carbon (OC) ranged from 0.20 to 2.68%, with a mean value of 1.18% with a

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coefficient of variation (CV) of 48.14%. Calcium carbonate went from traces to 3.60% with a mean value of 0.79% and had a high variability with a CV of 90.38%. Cation exchange capacity (CEC) ranged from 2.50 to 29.40 cmol p^+/kg with a mean value of 17.14 and CV of 39.79%.

Conclusion: Almost all recorded physicochemical properties of Kishtwar district soils were conducive to crop growth. However, the major area of the district was either devoid of cultivation or difficult to cultivate because the region has undulating topography.

Keywords: Geographic Information System (GIS); mapping; soil physico-chemical properties.

1. INTRODUCTION

Soil variability is caused by various ongoing processes and interactions occurring between these processes in soil. These are further impacted by multiple soil management practices employed [1]. The inherent variability of soil controls soil variables with stronger spatial dependence. Information about within-field variability is necessary before implementing new technologies [2,3]. Information regarding nutrient availability is provided by soil testing, on which fertilizer recommendations are based for maximizing crop yields. From various previous studies, we can conclude that most soil properties and crop yield vary spatially [4-6]. The variability of crop production results from soil's physical and chemical properties [7,8].

GIS is developing as the primary technology for investigating large-scale patterns and processes at a rapid pace. The maps generated through the Geographic information system (GIS) and Global Positioning System (GPS) help in delineating the equivalent units to decide on the sampling size and thereby saving a lot of time, which is otherwise, in the random sampling approach difficult [9]. The costly and tedious conventional methods required to have soil nutrient information will also be less needed when nutrient levels are mapped because the affordability of those conventional methods is less [10]. So mapping is the best alternative for resource conservation and resource allocation. Information about soil properties in crop fields is beneficial to governing fertilizer requirements and the site-specific management of crops and soil [11]. Some processes depend on crop and soil management, others on natural phenomena. In assessing spatial variability in some soil properties related to soil alkalinity and salinity, it concluded that soil properties resulting from extraneous factors such as groundwater level, drainage, irrigation systems and micro topography exhibited substantial spatial variability.

Jammu and Kashmir is bestowed with diversity in geology, topography, vegetation, and landforms, leading to the development of a wide variety of soils. The dominant soil in the state falls under the Entisols soil order, covering about 34% of the area, followed by Inceptisols, Alfisols, and Mollisols which cover 6.4%, 0.5%, and 0.2%, respectively. The first steps toward making site-specific decisions on soil and crop management practices, fertilizer applications, and irrigation scheduling are quantifying soil chemical and physical properties and their variability. Based on spatial variations within a field, soil, pests, and crops are managed by site-specific crop management [12]. These properties consequently affect water movement in the soil layers and air quality, thus the soil's ability to function. Therefore, soil physicochemical properties have a significant influence on soil quality. To develop innovative resource management strategies and understand and regulate the terrestrial ecosystem's behaviour at regional and global scales, consideration of soil chemical reactions and processes is essential [13]. Soil texture especially can have a reflective effect on many other properties. Estimating soil physicochemical properties gives us an idea about nutrient availability, as almost all soil properties are affected by the chemical and physical characteristics of the soil.

Very limited information regarding the variability of soil properties is accessible. The study was therefore conducted with the primary objective being to determine the soil physico-chemical properties of district Kishtwar and develop their maps for future planning and management.

2. MATERIALS AND METHODS

2.1 Study Area

Kishtwar District is in the Jammu Division of Jammu and Kashmir state of India. It lies between 32°53' and 34°21' N latitude and 75°1' and 76°47' E longitude (Fig. 1). Altitude in the district diverges from 900 to 6575 meters above mean sea level. It has an average elevation of

1107 meters (3361 feet) from mean sea level, experiencing a wide range of climates. Commonly known as the 'Land of Saffron and Sapphire,' it is also rich in forest products. Kishtwar is surrounded by the Anantnag and Doda districts of J&K and also borders Himachal Pradesh. High altitudes of this district hardly receive monsoon. Hence there is less rainfall in those areas. The average annual rainfall in the community is 887.8 mm. Due to topographic variation, rainfall varies from place to place in the district. The coldest month is January, with a mean maximum temperature of about 6°C and a mean minimum temperature of about -3°C. The minimum temperature sometimes drops to below -10°C, and in an extreme hilly part of the district minimum temperature may drop down to about -30° to -40°C. The increase in human and cattle population puts tremendous pressure on the state's resources, especially forests, soil, and water. Soil erosion is the major problem because of its hilly terrain, undulating topography, fragile ecosystem, climatic conditions, and loss of vegetation cover due to excessive grazing, lopping, illicit felling, and encroachments. Land degradation is further aggravated by triggering landslides, earthquakes, development activities including road constructions, railway lines, hydroelectric projects, etc. In 2007, district Kishtwar was carved out, commonly known as the 'Land of Sapphire and Saffron. It is also very rich in forest products.

2.2 Collection and Analysis of Soil Samples

A total of 167 surface soil samples were collected following a stratified random sampling technique. Location coordinates of sampling sites were recorded using a Gramin GPS. The collected soil samples were air-dried, grounded using a wooden pestle and mortar, sieved 2-mm and stored for further analysis. They were analyzed for pH (1:2.5 soil: water suspension), EC (1:2 soil: water supernatant), organic carbon (OC) [14], $CaCO_3$, and Cation exchange capacity (CEC) by Piper, [15]. Soil texture was determined by the International pipette method. The USDA textural triangle was used for deciding textural classes [1].

2.3 Mapping and Interpolation

Mapping the spatial distribution of soil properties requires spatial interpolation methods. The location data, along with attributes, were transferred to ArcMap10.0. In the present study, the interpolation technique inverse distance weighting (IDW) was employed, and soil maps of each property were generated in ArcMap 10.0. These interpolation techniques have been commonly used in mapping soil properties [16,17,18,19]. Some workers found that the kriging method performed better than IDW [20,21], while others showed that kriging was no better than unconventional methods [22,23].

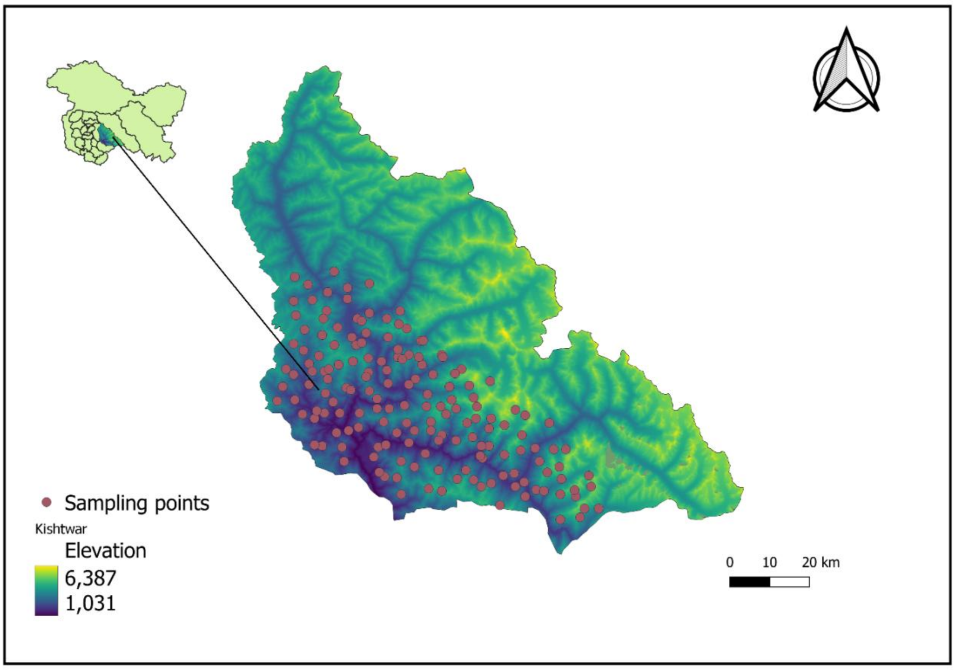

Fig. 1. Map of the study area

3. RESULTS AND DISCUSSION

3.1 Soil Texture

To determine the suitability of the crop textural property of soil is used to envisage the responses to environmental and management states. The texture of Kishtwar soils was categorized into nine different categories depending upon the varying content of sand, silt, and clay. Sandy loam texture was dominant (30.5%) in the district, followed by silty clay, clay loam, clay, and silt loam (20.9%, 19.7%, 10.7%, and 10.1%, respectively) (Fig. 2). Sand percentage in soil varied widely across the district from as low as (4.96%) to as high as (88.96%) with a mean value of (37.40%) (Table 2). The coefficient of variation (CV) was 56.08%, skewness and kurtosis were (0.30) and (-0.92), respectively. Based on skewness, distribution was approximately symmetric (< 0.5), and negative kurtosis indicates that the distribution has a lighter tail and adulate peak than a normal distribution (Fig. 4(a)). Silt and clay also varied widely across the district, from as low as (5.00 and 7.04%) to as high as (64.00 and 65.04%) with a mean value of (34.44 and 28.15%). The CV was (38.88 and 54.14%) (Table 1), respectively. Skewness and kurtosis was (-0.26, 0.13) and (-0.46, -1.42), respectively (Fig. 4(b, c)). Sand content in the Kishtwar district was mainly less than 20 percent, and 40 to 60 percent strips were present across the district. The whole tehsil Padder and major area of tehsil Kishtwar of district Kishtwar had sand content between 20-40 percent (Fig. 3(a)). Kishtwar had silt content between 30 to 40 percent on both the east and west ends of the district. In the Central part of the district, silt content was between 20 to 30 percent, with some scattered patches having greater than 40 percent (Fig. 3(b)). Most of the Kishtwar district had 20-30 percent clay, followed by the area on the central and eastern side of the district having 30-40 percent clay content in soils (Fig. 3(c)). Pedogenic and geogenic developments are responsible for distinguishing the textural composition in the soils. Soil texture controls soil organic matter, nutrient contents, and leaching losses of nutrients [5].

3.2 Soil pH

Thirty-six percent of the samples were in the acidic range, having a pH of less than 6.5. Soil pH ranging from 6.5-7.5 constitute 61%, and basic soils constitute only 2.4% of the total soil samples (Table 2). Soil pH varied widely across the district, from as low as 4.80 and as high as 8.00, with a mean value of 6.73 and CV of 8.07% (Table 1). The frequency distribution curve of data was negatively skewed (-0.44) and kurtosis (0.30) (Fig. 4(d)). Soils in the pH range of 6.5-8.7 are well-thought-out and the most appropriate for most crops [24]. Out of a total, 66% of the samples belong to this group. The coefficient of variation of data was recorded at 8.07%. CV of

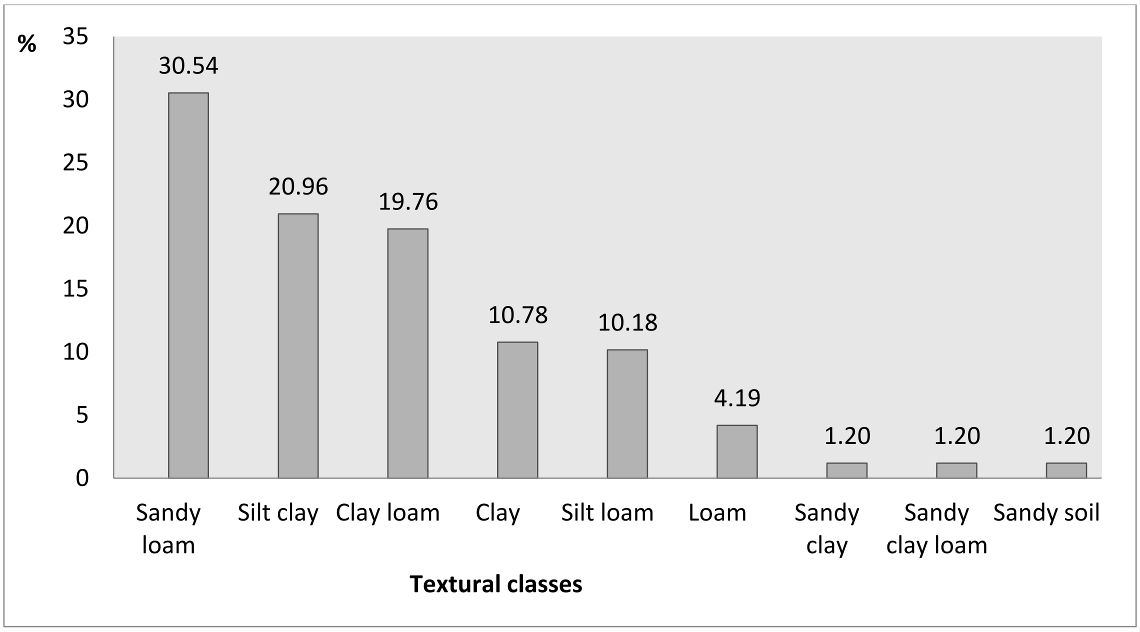

Fig. 2. Percentage distribution of different textural groups

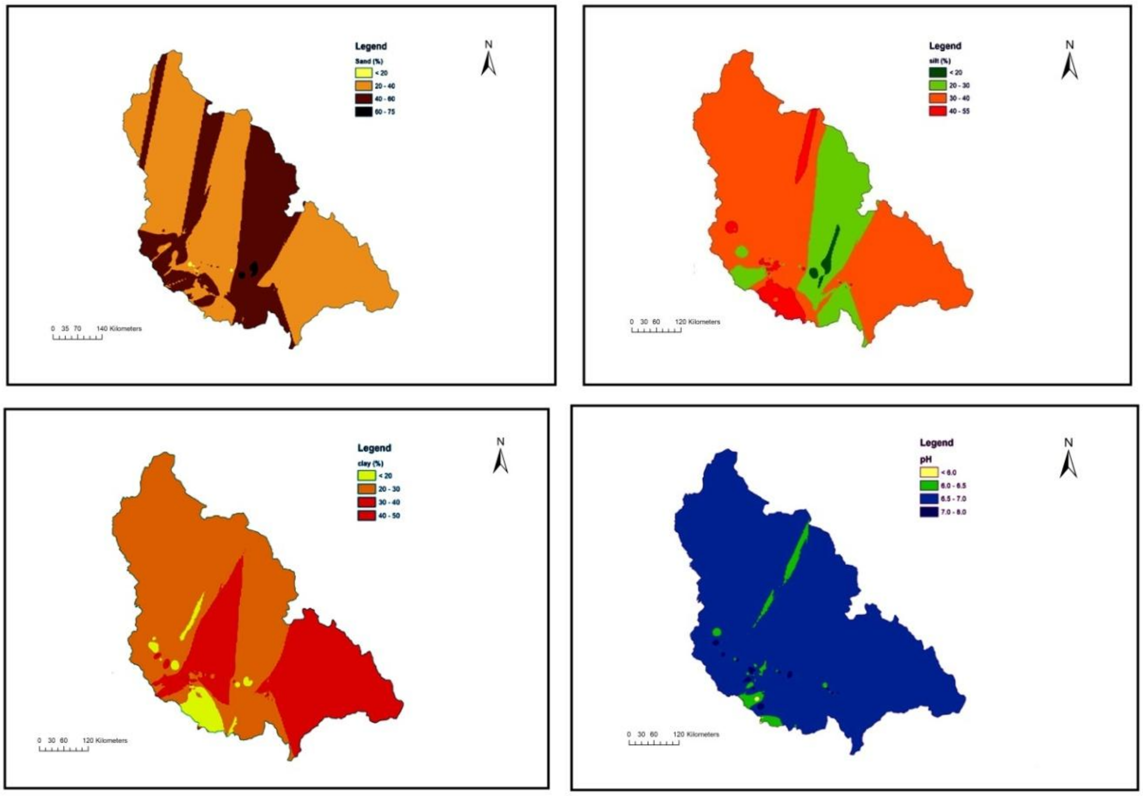

Fig. 3. Thematic maps of sand (a), silt (b), clay (c), and pH (d) of Kishtwar soils

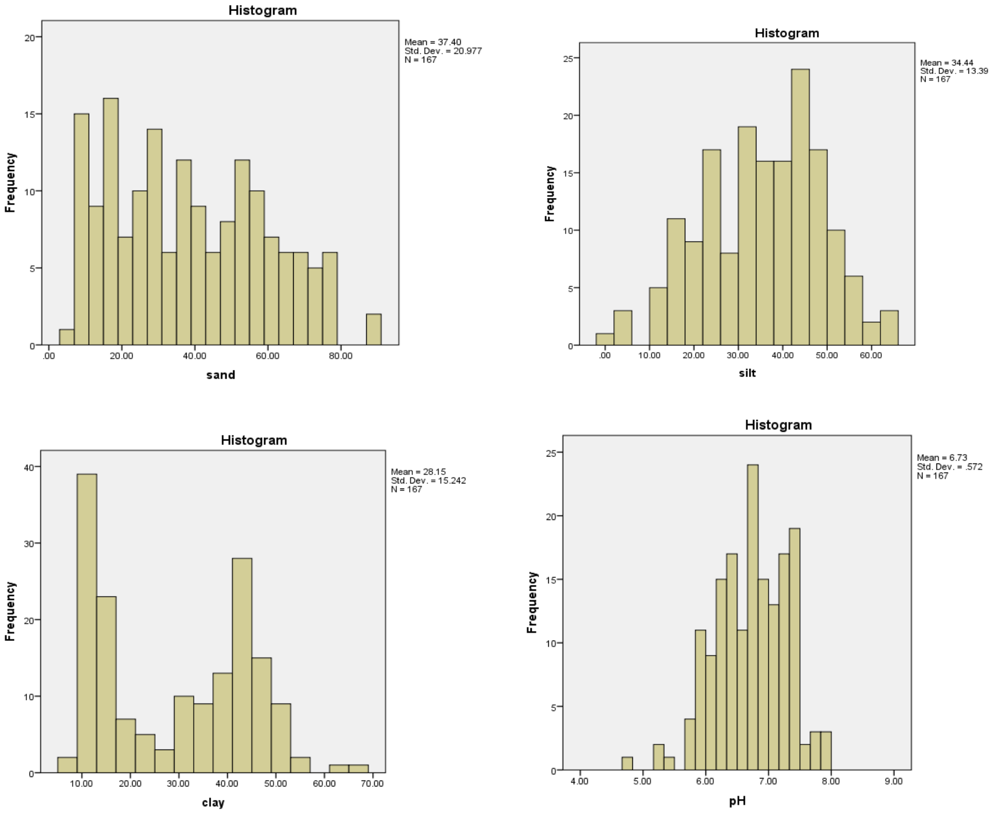

Fig. 4. Frequency distribution of sand (a), silt (b), clay (c), and pH (d) of Kishtwar soils

pH aligns with the findings of [25,26]. Soils in the majority area of district Kishtwar were found to be neutral in reaction, followed by soils having an acidic reaction. Very small patches of the district had soils with basic reactions (Fig. 3(d)). The wide variation in soil pH was mainly observed due to variation in topography [27]. The lower soil pH in forest land also might be due to its higher slope [28,29], higher OM content [30,31,32], and less evaporation from the surface in the study area. Sensible use of nitrogenous fertilizer and implementation of liming may cause higher soil pH in cultivated land.

3.3 Electrical Conductivity

EC of the soils of Kishtwar varied from as low as 0.03 dS m^{-1} to a high of 9.80 dS m^{-1} with a mean value of 1.50 dS m^{-1} high variation as depicted by CV 115.23% was observed (Table 1). The frequency distribution curve of EC was positively skewed (2.44) and kurtosis (7.02) (Fig. 6(a)). Soils with an EC < 0.8 dS m^{-1} and a mean value of 0.37 dS m^{-1} represented 43% of the total samples. This leaching of salts under intensive irrigated agriculture may be the reason for the high percentage of areas with low EC. EC > 0.8 dS m^{-1} and having a mean value of 2.40 dS m^{-1} represented 56.3% of the total samples (Table 2). EC was found to be within safe limits. The western side of Kishtwar had EC ranging from 0.5 to 1.0 dS m^{-1}; on the eastern side, it varied between 1.0 and 1.5 dS m^{-1}. Some strips across the north and south side had EC between 1.5 and 3.0 dS m^{-1} (Fig. 5(a)). Dissolved salts create an ionic imbalance which hinders nutrient uptake. The inability of the plant to compete with ions in soil solution is the primary effect of high [33,34]. Topography employs strong control over the intensity of salinization through its influence on water-table depth [35].

3.4 Calcium Carbonate

$CaCO_3$ content varied widely in the soils ranging from traces to more than 8% with a mean of 0.73%, CV 90.4% (Table 1). The frequency distribution curve of $CaCO_3$ was positively skewed (1.23) and kurtosis (1.43) (Fig. 6(b)). The first category (0.0-1.00% $CaCO_3$) with a mean value of 0.78 and the second category (1.01-5.0% $CaCO_3$) with a mean of 0.79 constituted 73% and 26% of the total samples taken, respectively (Table 2). The area under study was found non-saline, with the lowest mean value in forests and highest in the wasteland, which could be due to the accumulation of $CaCO_3$ and salts in case of wasteland and a more elevated amount of decomposing litter in forests [36]. $CaCO_3$ content affects the soil's availability of both micro and macronutrients through fixation and adsorption [37].

3.5 Organic Carbon

Soil organic matter is considered dynamic and essential for maintaining soil health and productivity and helps enhance soil quality parameters [38]. Organic carbon in soil varied widely across the district, from as low as 0.20% to as high as 2.68%, with a mean value of 1.18%. High variability was noticed in the case of organic carbon, CV 90% (Table 1). The frequency distribution curve of OC was slightly skewed (0.53) (Fig. 6(c)). In the Kishtwar district, Marwah tehsil had a higher content of OC ranging from 1.25 to 2.00%. The rest of the district ranged between 0.75-1.25% (Fig. 5(c)). Many factors such as land use, topography, field management, soil texture, and vegetation may impact the spatial inconsistency of OC [28]. A total of nine textural classes were reported in the district (Fig. 2) with varying topography as the study area consists of hills and valleys. Out of the total samples taken, 8.4% were low, 21% were medium, and 70.7% were in the high range. The majority of the area recorded higher values of OC (Table 2); 70.7% of total samples were in a high range, mainly in the forest area. Lower temperatures at higher altitudes result in limited carbon decomposition, resulting in increased carbon build-up [39]. Litterfall, higher root mass density, and root exudates in forest soil floors lead to high soil OC [40]. Therefore, land use/land cover is a significant factor regulating soil OC storage because it affects the quality and amount of litter input, the litter decomposition rate, and processes of organic matter maintenance in soil. Tillage is usually practiced in cultivated land use, resulting in higher mineralization and decomposition of OM. As tillage proceeds, more OM is broken down [41]. Furthermore, aeration in the soil is upsurged by tillage and causes a flush of microbial action, which rapids up the decomposition of OM [42]. Consequently, there is high OM in forests and pastures due to fewer soil disturbances compared to cultivated land where common tillage is practiced [43].

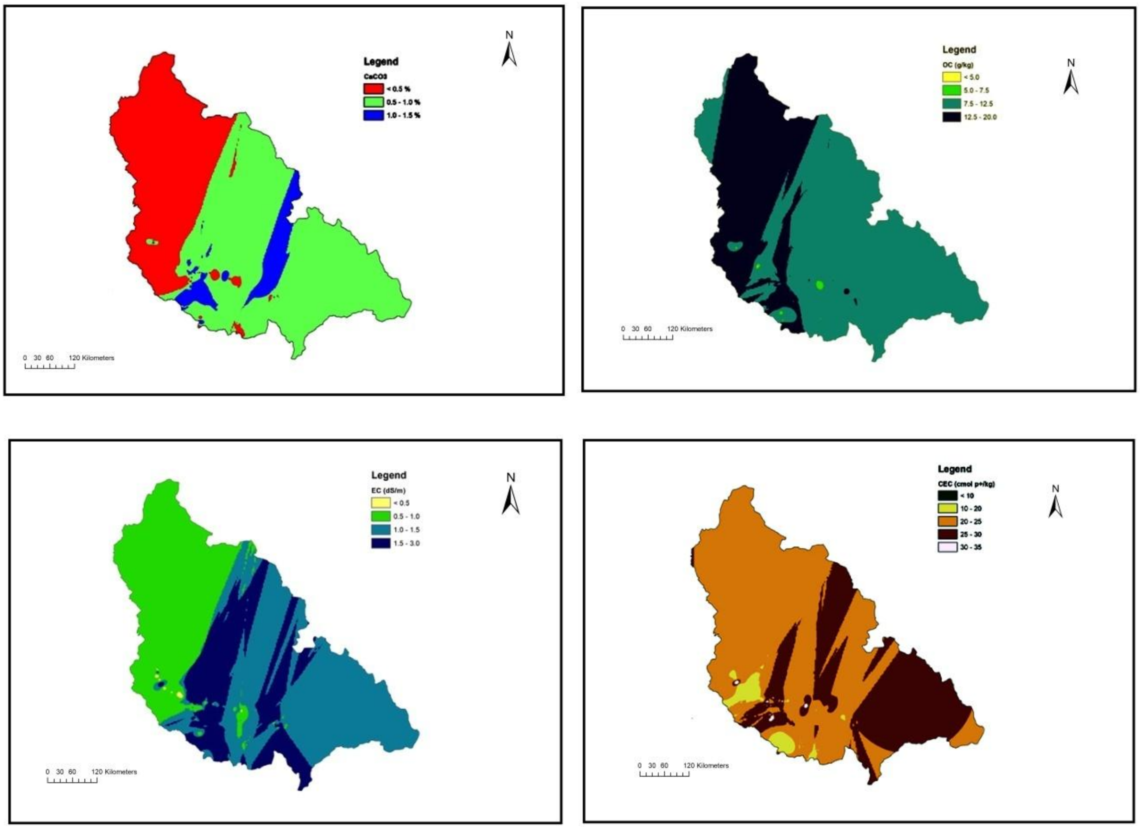

Fig. 5. Thematic maps of EC (a), $CaCO_3$ (b), OC (c), and CEC (d) of Kishtwar soils

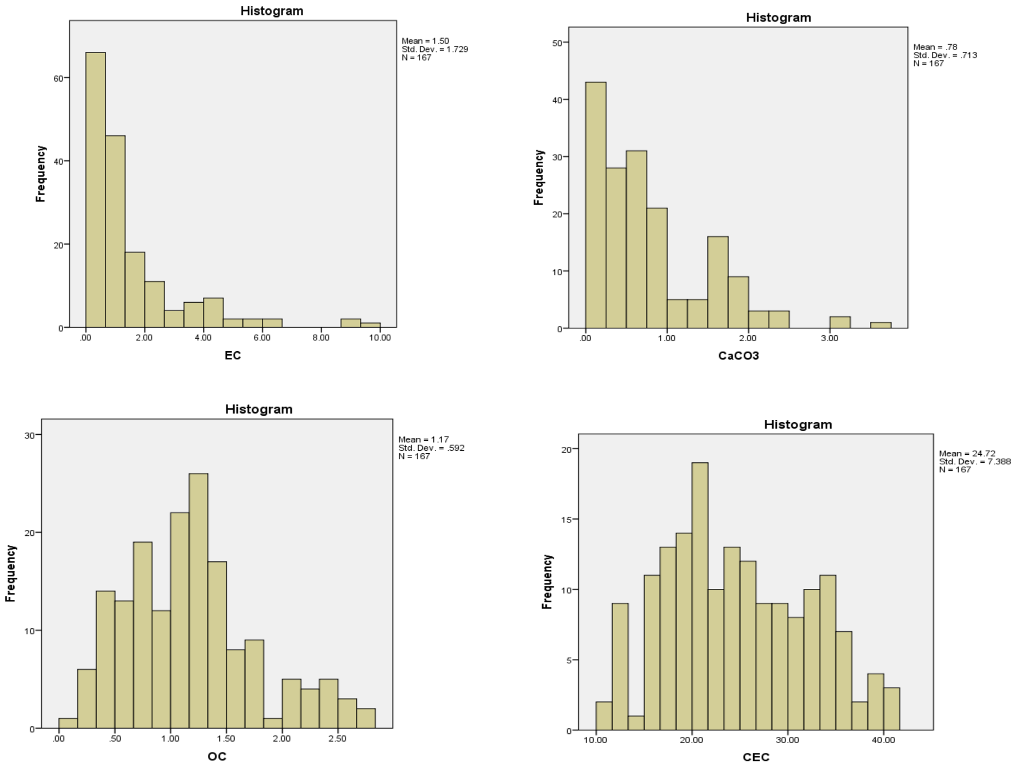

Fig. 6. Frequency distribution of EC (a), $CaCO_3$ (b), OC (c), and CEC (d) of Kishtwar soils

Table 1. Descriptive statistics of sand, silt, clay, pH (1:2.5), electrical conductivity (dS m^{-1}), calcium carbonate (%), Organic carbon (%) and Cation Exchange Capacity (cmol p^{+}/kg) of soils of Kishtwar District

Name of parameter	Minimum	Maximum	Range	Mean	Coefficient of variation (%)	Standard Error	Skewness	Kurtosis
Sand (%)	4.96	88.96	4.9-88.96	37.40	56.08	1.62	0.30	-0.92
Silt (%)	5.00	64.00	5.00-64.00	34.44	38.88	1.04	-0.26	-0.46
Clay (%)	7.04	65.04	7.04-65.04	28.15	54.14	1.18	0.13	-1.42
pH	4.80	8.00	4.80-8.00	6.73	8.07	0.04	-0.44	0.30
EC (dS m^{-1})	0.03	9.80	0.03-9.80	1.50	115.23	0.13	2.44	7.02
OC (%)	0.20	2.68	0.20-2.68	1.18	48.14	0.04	0.53	-0.09
$CaCO_3$ (%)	0.00	3.60	0.00-3.60	0.79	90.38	0.06	1.23	1.43
CEC(cmol p^{+}/kg)	2.50	29.40	2.50-29.40	17.14	39.79	0.53	-0.12	-0.96

EC (Electrical conductivity), CEC (Cation exchange capacity), OC (Organic Carbon)

Table 2. Critical ranges and distribution of pH (1:2.5), electrical conductivity (dS m^{-1}), calcium carbonate (%), Organic carbon (%), and Cation Exchange Capacity (cmol p^+/kg) of soils of the Kishtwar district

Categories range	Mean	Percentage out of total samples
pH		
Normal (6.5-7.5)	7.00	61.7
Acidic (< 6.5)	6.11	35.9
Basic (> 7.5)	7.63	2.4
EC		
Normal (< 0.8)	0.37	43.7
Saline (> 0.8)	2.40	56.3
$CaCO_3$		
0.0–1.00	0.78	73.7
1.01–5.00	0.79	26.3
Organic carbon		
Low < 0.40	1.17	8.4
Medium 0.40–0.75	1.16	21.0
High > 0.75	1.18	70.7
CEC		
Low < 20	16.50	61.7
High > 40	40.75	35.9

EC (Electrical conductivity), CEC (Cation exchange capacity)

3.6 Cation Exchange Capacity

CEC exhibited wide variation as shown by texture and organic carbon ranging from 2.5 to 29.40 (cmol p^+/kg) with a mean value of 17.14 and CV of 39.7% (Table 1). Wide variation in soil CEC value may be due to different soil types, soil fertility management, and land use type. The frequency distribution curve of CEC was slightly negatively skewed (-0.12) (Fig. 6(d)). CEC less than 20 cmol p^+/kg with a mean value of 16.50 and another class more significant than 20 cmol p^+/kg with a mean value of 40.7 cmol p^+/kg constitute about 61% and 39% of total samples taken, respectively (Table 2). Soil buffering capacity and soil nutrient conservation are reflected by soil CEC, as it is the main indexing parameter for buffering capacity and soil fertility [44,45].

4. CONCLUSION

The district's soil was mainly neutral in reaction, followed by acidic and alkaline soils. The majority of the samples recorded high OC content because of the reason that carbon mineralization at higher altitudes is limited by lower temperatures, which leads to carbon accumulation. Moderate CEC was registered in most samples, followed by high CEC samples. Almost all recorded physicochemical properties of Kishtwar district soils were conducive to crop cultivation. However, the major area of the district was either barren or challenging to cultivate sloppy topography making it difficult to cultivate. With the help of maps generated, we can plan resource allocation and distribution in the region. It will also aid policymakers and state agencies in drafting suitable development plans.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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