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Spatial variability assessment and mapping of soil properties for sustainable agricultural production using remote sensing technology and Geographic Information Systems (GIS)

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Abstract

Low knowledge of the suitability of land in agricultural production is a major problem for land users. To better assess soil distribution structures, remote sensing and the use of geographic information systems (GIS) are considered the most effective tools to achieve this goal. In this paper, we investigated the spatial variability of some soil chemical and fertility properties in the Ridhora watershed of Nagpur, Maharashtra region, India. From the study area 59 Soil samples were collected using a systematic sampling strategy from 0 to 15 cm below the surface at a regular grid spacing of 1km× 1km with different vegetation cover and all the samples were transported to the laboratory After the creation of standard data, Statistical analysis was used to describe the soil structure, geostatistical statistical analysis was used to describe the spatial correlation of soil properties, and the spatial distribution of these structures was adjusted using mapping techniques. The results showed that in the study area the variability of soil fertility was low to moderate N; Available P ranges from low to high and available K ranges from moderately high to very high. Available Zn and Fe showed deficiency in 60.9% and 7.40% of the study area, respectively.

Keywords crop rotations, kharif crop, soil properties

Introduction

India's agriculture mainly relies on rainwater, which accounts for 45% of total food and grain production. Of the 141 million hectares (M ha) of total arable land, 61% (86 million hectares) is rainwater agriculture. [1-2].
Cultivation systems play an important role in sustainable agriculture and environmental conservation. The manager's procedures have a huge impact on understanding and changing the level of soil structure. The transition from atmospheric to arable land can lead to soil erosion and further degradation. Along with tillage, fertilization, and excessive irrigation, soil care packages regularly make small changes to soil levels. Other researchers [3-8] reported changes in soil quality and their consequences in our ecosystem. Tillage has the most significant effect on cation exchange capacity (CEC), which lowers the SOM [7]. Tillage raises the pH, base charge, and phosphorus release [7] of the soil. In comparison to pasture, overall soil nitrogen and soil organic carbon (SOC) were lower [9].

The spatial distribution of soils varies from area to larger regional scales, extending over miles with a wide range of factors and external factors, primarily soil-forming entities, which can be termed soil management

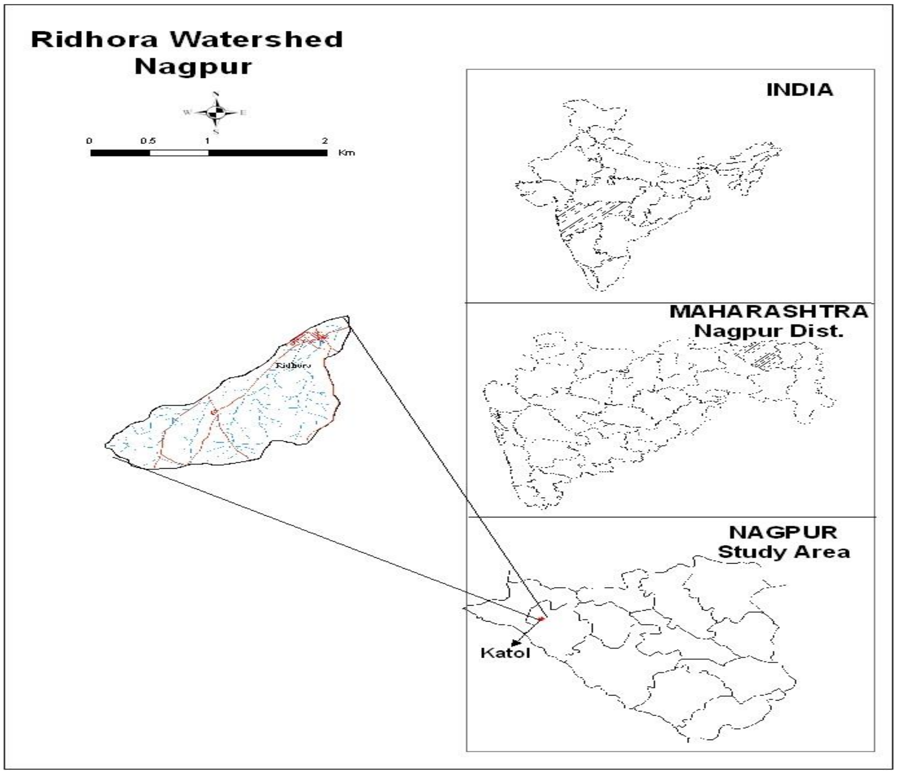

Figure 1. Location Map of study area with IRS-P6 LISS-IV data

strategies, fertility reputations, crop rotations, etc. [10]. Deformation may also be the result of a gradual exchange of soil properties due to topography, topographic features, soil-forming factors, and soil management practices [11]. Soil properties models must be monitored and quantified to understand the impact of soil use and management systems on the soil.

Soil surveys provide accurate and scientific inventories with a variety of soil, types, personality, and amounts of accurate and scientific inventories to predict personality and abilities. This offers a good fact for the verses of the earth, terrace, and plants [12]. These statistics are required when implementing effective control methods for soil to obtain spatial records of soil characteristics, and military statistics cannot be mentioned well and implement effective control methods for sustainable agricultural production. Geographical recording device (GIS) technology has opened a more suitable opportunity to improve soil statistics because it has the potential of filtering straight in soil discipline and provides rising, repeat, space, and temporary weather forekys. The price is also a powerful and accurate alternative to the data panorama dynamics. GIS is a means of providing output information and can assist in spatial statistical assessment, so it may cause enormous amounts to increase the accuracy of soil surveys through GIS technology software.

It the vital manner to accumulate knowledge of this. Gio-detection is to prepare a card for spatial interpolation of points based on the full measurement of the soil residence. Because the Geostatistical strategy was well developed in the spatial version of the soil characteristics, it was successful because of the spatial version of the space home of the 1970s to participate in the spatial version of the soil housing. Although a small study was achieved in small [14], it was pretty little in Large-scale [15]. The nature of the Ridhora watershed and analyzes the identity of the nutritional deficit section of the spatial volatility of soil characteristics and the clean part of the correct power control.

Methodology

The Ridhora watershed in the Nagpur district of Maharashtra is located between 21010l to 21014l N latitude and 78033l to 78038l E longitude. Toposheet No.55K/12, was taken into consideration for the study area of the Ridhora watershed. WGS 84 zones 44 N datum, ground control points (GCPs), and Universal Transverse Mercator (UTM) projection were used for geo-referencing and gathering topographic information. The area under the observation was occupied with Deccan basalts followed by limestone, the conglomerate of

Table 1. Descriptive statistics of soil chemical and fertility properties

Soil properties	Minimum	Maximum	Mean	Standard deviation	CV	Skewness	Kurtosis
Soil pH	6.75	8.33	7.57	0.37	0.05	0.46	-0.52
OC (%)	0.22	1.39	0.76	0.29	0.38	0.67	-0.29
CaCO3	0	16.46	2.95	3.38	1.14	5.6	35.6
Available N (kg ha^{-1})	159.17	385.38	263.09	59.3	0.22	0.41	0.16
Available P (kg ha^{-1}) (ln)	10.2	35	17.38	6.84	0.39	0.70	-0.32
Available K (kg ha^{-1}) (ln)	118.4	645.6	317.2	107.2	0.33	0.57	0.18
Available S (kg ha^{-1}) (ln)	7.09	24.64	13.3	4.40	0.33	0.66	-0.29
Available Fe (mg kg^{-1})	2.47	18.93	9.43	4.37	0.46	0.71	0.23
Available Mn (mg kg^{-1}) (ln)	6.52	16.98	10.6	2.35	0.22	0.44	0.19
Available Cu (mg kg^{-1})	0.17	6.29	2.27	1.26	0.55	0.21	-0.78
Available Zn (mg kg^{-1}) (ln)	0.06	0.98	0.49	0.23	0.46	0.76	0.21

cretaceous period, clay, and sandstone. The watershed area was separated into six major landform units, viz., plateau, escarpment, lower valley, upper valley, upper pediment, and isolated mound. The particular area varies from 420 to 540 m above from MSL (mean sea level) accompanying with 3-8% slope to 15-30% slope.

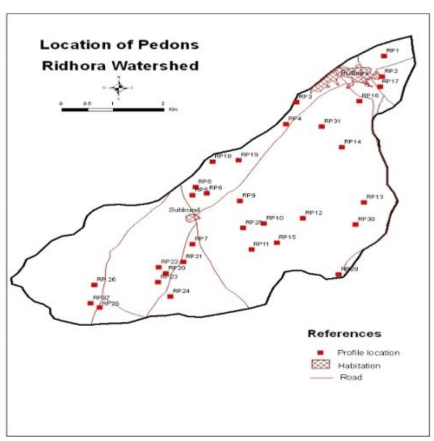

Figure 2. Soil sampling experimental design

The area under the study has a very typical sub-tropical climate with an average rai fall of 1051.5 mm with dominant in ustic soil moisture regime and hyperthermic soil temperature regime. The vegetation in this area includes evergreen as well as deciduous plant species including khair (*Acacia catechu*), babul (*Acacia arabica*), shivan (*Gmelina arborea*), behra (*Terminalia bellirica*), tendu (*Diospyros melanoxylon*), palas (*Butea monosperma*), neem (*Azardirachta indica*) and teak (*Tectona grandis*), etc.

Table 2. Characterization of the spatial distribution of chemical and fertile properties of the soil

Class	**Range (kg ha-1)**	**Area (ha)**	**% of TGA**
Soil pH			
Neutral soil	6.5-7.5	866.92	34.92
Slightly alkaline	7.5-8	1579.55	63.63
Soil OC			
Low	(0.2 – 0.4 %)	2.78	0.11
Medium	(0.4 – 0.6 %)	1104.89	44.51
Moderately high	(0.6 – 0.8 %)	478.56	19.28
High	(0.8 – 1.0 %)	854.77	34.43
Very high	(>1.0 %)	5.47	0.22
Calcium Carbonate ($CaCO_3$)			
Slightly calcareous	(0.5-2%)	386.78	15.58
Moderately calcareous	(2-4%)	2059.69	82.97
Available N			
Low	140-280	1875.39	75.55
Medium	280-420	571.08	23.00
Available P			
Low	(7 – 14 kg ha^{-1})	608.20	24.50
Medium	(14 – 21 kg ha^{-1})	1287.47	51.86
Moderately high	(21 – 28 kg ha^{-1})	516.65	20.81
High	(28 – 35 kg ha^{-1})	34.15	1.38
Available K			
Moderately high	(240 -300 kg ha^{-1})	1107.34	44.61
High	(300 – 360 kg ha^{-1})	934.87	37.66
Very high	(> 360 kg ha^{-1})	404.26	16.28
Available Sulphur			
Low	(5.0 -10.0 mg kg^{-1})	21.14	0.86
Marginal	(10.0 – 15.0 mg kg^{-1})	2291.54	92.30
Adequate	(15.0 - 20.0 mg kg^{-1})	133.79	5.39
Available Zn			
Very low	(< 0.30 mg kg^{-1})	6.45	0.26
Low	(0.30 -0.60 mg kg^{-1})	1505.36	60.64
Marginal	(0.60 – 1.20 mg kg^{-1})	934.66	37.65
Available Fe			
Low	(2.5 – 4.5 mg kg^{-1})	183.80	7.40
Marginal	(4.5 - 9.0 mg kg^{-1})	1041.81	41.96
Adequate	(9.0 – 18.0 mg kg^{-1})	1111.65	44.79
Moderately high	(18.0-27.0mg kg^{-1})	109.21	4.40
Available Cu			
Adequate	(1.5 – 2.0 mg kg^{-1})	425.76	17.15
High	(> 2.0 mg kg^{-1})	2020.71	81.40
Available Mn			
Adequate	(4.0 – 8.0 mg kg^{-1})	1042.35	41.99
Moderately high	(8.9-16.0mg kg^{-1})	1262.86	50.87
High	(>16.0 mg kg^{-1})	141.26	5.69

While the herbaceous crops include kural (*Heteropogon contortus*), kundu (*Schema pilosum*), and dub (*Impara cuplinatrica*). The kharif crop was dominant in this observed are including the commercial crops of pigeon pea (*Cajanus cajan*), ground nut (*Arachis hypogea* L), maize (*Zea mays*) cotton (*Gossypium spp.*), and soybean (*Glycine max*), similarly the main rabi crops were chickpea (*Cicer arentium*) and wheat (*Triticum spp.*). Mandarin (*Citrus reticulata*) was the foremost fruit crop in the watershed region. The data during October 2003 was collected using IRS-P6 LISS-IV (spatial resolution of 5.8 m), while during February 2005 it was collected through LISS-III (spatial resolution of 23.5 m). Both the data were analyzed using ArcGIS 10.3 software. the same old false-color Composite (FCC) became generated with the aggregate of green, crimson, and close to Infra purple (NIR) bands. Cartosat-1 virtual Elevation model (DEM) (30 m resolution) turned into used. During February 2011 soil samples were collected from 0-15 cm depth using Georeference and grid method, after the harvest of winter crops.

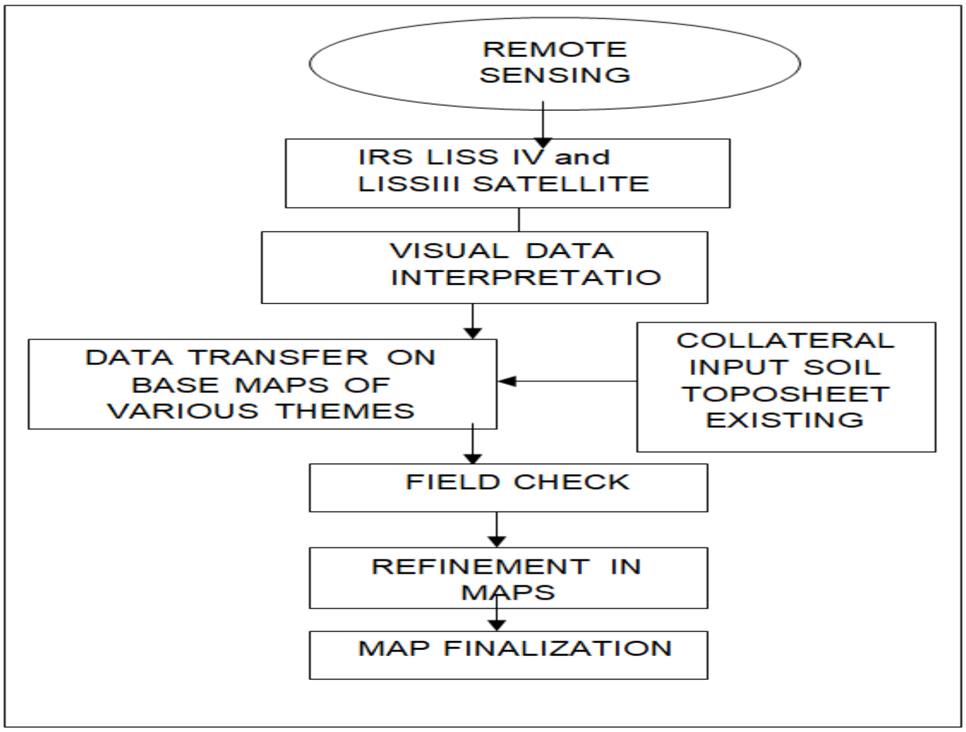

Figure 3. Methodology for deriving resource map using remote sensing data

The grid program language period was stabilized based on the effective recommendations given with the aid of the Department of Agriculture and Cooperation, Ministry of Agriculture, authorities of India (DoAC, 2014; nmsa.dac.gov.in). A total of 59 samples were collected covering the grids area of 2482.59 ha (325_325 m interval) (Figure 1, 2). The soil samples were further processed for physic-chemical observation. To determine organic carbon, the soil sample was sieved through a hundred mesh sieve (0.5 mm) [16]. Soil pH was measured with a 1:25 soil water ratio. Soil available nitrogen ($KMnO_4$-N), phosphorus (Olsen-P), and potassium (NH_4OAc-K) were assessed as per the methodology given by Subiah and Asija [17], Olsen [18], and 1 N ammonium acetate, respectively. To determine CEC for calcareous soil and Non-calcareous soil, 1N sodium acetate (pH 8.2) and 1N sodium acetate (pH 7.0) were used, respectively, by saturating the soil overnight. Available micronutrient cations (Fe, Mn, Cu, and Zn) were extracted by DTPA-$CaCl_2$ extractant at pH 7.3 [19]. Methodology for deriving resource maps using remote sensing data is present in Figure 3.

The collected data were tabulated in Excel and analyzed using SPSS version 11.5 software. Wherever the data sets of soil attributes were non-normal, logarithmic transformations provided in Geostatistical Analyst of ArcGIS software (version 10.1) were used to normalize the data. Surface maps of basic soil qualities were created using semi-variogram parameters and digital cadastral boundaries overlay during map building in ArcGIS software's geostatistical analyzer.

Table 3. Evaluation parameters of kriged map of soil chemical and fertility properties

Soil property	RMSE	R2
PH	0.32	0.57
Organic carbon	0.38	0.61
$CaCO_3$	5.24	0.31
Available N	14.82	0.24
Available P	7.05	0.33
Available K	198.6	0.74
Available Fe	5.77	0.49
Available Mn	8.34	0.66
Available Cu	13.22	0.62
Available Zn	0.21	0.46

Results and Discussion

Descriptive statistics of soil chemical properties are given in (Table 1). The pH ranges from 6.75 to 8.33, with an average of 7.57. The organic carbon content was 0.22 to 1.39%, with an average of 0.76. Calcium carbonate ($CaCO_3$) ranges from 0 to 16.46% with an average value of 2.95%. Among the chemical properties studied, $CaCO_3$ was found to be highly variable (CV = 1.14), followed by OC (CV = 0.38). On the other hand, pH was found to be the most variable (CV = 0.05). Normality was tested for each chemistry of the soil. Soil OC and $CaCO_3$ were found to be abnormal due to their high skewness and kurtosis. A logarithmic function was used to match a normal distribution.

Descriptive information for soil fertility parameters is given in Table 1. Available N, P, K, and S ranges are 159.17 to 385.38, 10.2 to 35, 118.4 to 645.6, 7.09 to 24.64 kg ha1 with an average value of 263.09 kg ha., 17.38 kg ha1, 317.2 kg ha1, and 13.3 kg ha1. Available trace elements Fe, Mn, Cu and Zn range from 2.47 to 18.3, 6.52 to 16.98, 0.17 to 6.29 and 0.06 to 0.98 mgkg1, with mean values of 9.43, 10.6, 2.27 and 0.49 mgkg1, respectively. Among macronutrients, available phosphorus was found to be very diverse (CV = 0.39), followed by available K (CV = 0.33). Available nitrogen was found to be the most variable (CV = 0.22). All trace elements were moderately variable with CVs ranging from 0.22 to 0.55. Check that the soil fertility indicators are normal. Among the soil fertility indicators, available P, K, Fe, Cu, and Zn were found to be abnormal due to their high skewness and kurtosis values. A logarithmic function was used to match a normal distribution.

Spatial maps of soil pH variability range from 6.75 to 8.33. Spatial maps of soil pH have been reclassified. Commissionerate of Agriculture, 2002) viz., nearly neutral (6.5-7.5) and slightly alkaline (7.5-8.0). The highest area of about 1579.55 ha (63.63 % of TGA) (Table 2) shows a slightly alkaline soil reaction the lowest area 866.92 ha (34.92 % of TGA) shows a nearly neutral reaction. The spatial variability maps of soil organic carbon varied from 0.38% to 1.94%. Reclassified organic carbon spatial variability map (PDKV, 2008) viz., Low (0.2–0.4%), Moderate (0.4–0.6%), Moderate (0.6–0.8%), High (0.8–1.0%), and Very High (>1.0%). It is high in about 854.77 ha (34.43 % of TGA), moderately high in 478.56 ha (19.28 % of TGA), medium in 1104.89 ha (44.51 % of TGA), and low in about 2.78 ha (0.11 % of TGA). The data revealed that (Table 2), about 5.47 ha (0.22 % of TGA) have a very high content of organic carbon. Spatial variability map of calcium carbonate indicates that (Commissionerate of Agriculture, 2002) viz., slightly calcareous (0.5 to 2 %) and moderately calcareous (2 to 4 %) The highest area of about 2059.69 ha (82.97 % of TGA) (Table 2) shows slightly calcareous. The lowest area 386.78 ha (15.58 % of TGA) shows moderately calcareous. A reclassified map of soil pH, OC, and CaCO3 is shown in Figure 4 respectively. The Kriged map of available N, P, K, and S shows that the available N ranges are 159.17 to 385.38 kg ha^{-1}, 10.2 to 35 kg ha^{-1}, 118.4 to 645.6 kg ha^{-1}, and 7.09 to 24.64 kg ha^{-1}, respectively. Maps of available nitrogen

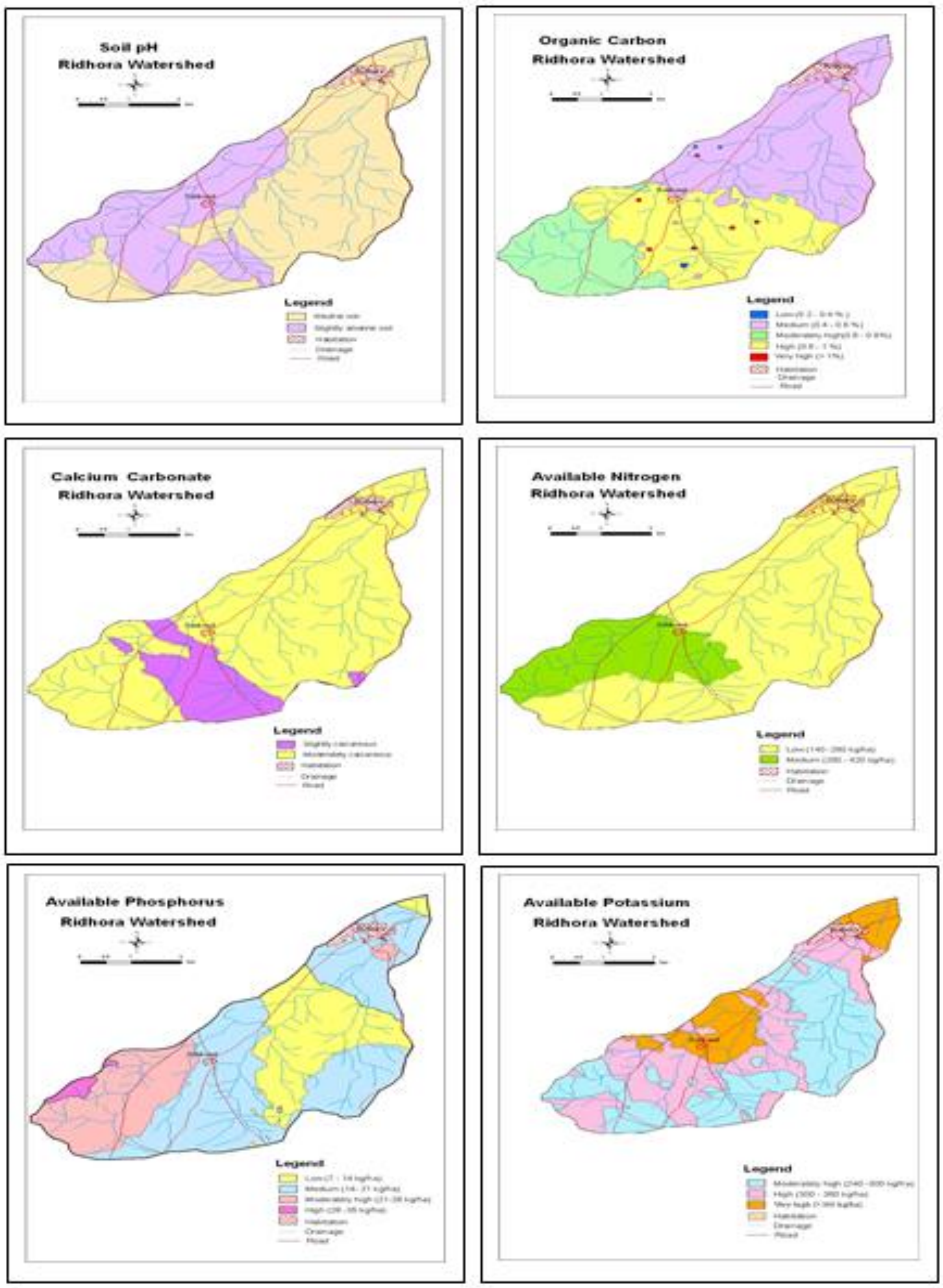

Figure 4. Krigged map of Soil pH, Organic Carbon, Catiaon Exchange Capacity and Available N, P, K

in Krieg are low (140 – 280 kg/ha^{1}), medium (281-420 kg ha^{-1}) [20]. A reclassified Krieg map of available nitrogen indicates that available nitrogen was found to be low across the catchment area.

(Table 2). Calling for the supplemental application of nitrogenous fertilizers and organic matter. Available phosphorus's kriged maps have been reclassified as Low (7- 14 kg ha^{-1}), medium (14.1-21.0 kg ha^{-1}), moderately high (21.1-28.0 kg ha^{-1}), high (28.1-35.0 kg ha^{-1}). The reclassified kriged map of available P. This indicates that most of the watershed area was found as a medium in the available P is low covering 608.20 ha (24.50 % of TGA) and medium in 1287.47 ha representing 51.86 percent area of the total watershed area. It was moderately high in 516.65 ha (20.81 % of TGA). However, it is high in 34.15 ha (1.38 % of TGA) of the watershed area. The distribution of P also calls for an additional supply of P through fertilizers, organic matter, etc. (Table 2). Potassium maps available in Kriged have been reclassified as moderately high (240-300 kg ha^{-1}), high (300-360 kg ha^{-1}), and very high (>360 kg ha^{-1}).

The reclassified kriged map of available K indicates that the majority of the area is moderately high with an area of 1107.34 ha (44.61% of TGA) followed by high with an area of 934.87 ha (37.66 % of TGA). Followed by a very high 404.26 ha (16.28%) The kriged map of available S was three classes [21], AICRP report on secondary and micronutrients) viz., low (5.0 -10.0 mg kg-1), marginal (10.0 – 15.0 mg kg^{-1}) and adequate (15.0 -20.0 mg kg^{-1}).It is seen to be marginal in the major part of the watershed covering an area of about 2291.54 ha (92.30 % of TGA), low in 21.14 ha (0.86 % of TGA), and adequate in 133.79 ha representing 5.39 percent of the total watershed area. Similar results were found by [23]. A reclassified map of available N, P, K, and S is shown in Figure 4, respectively.

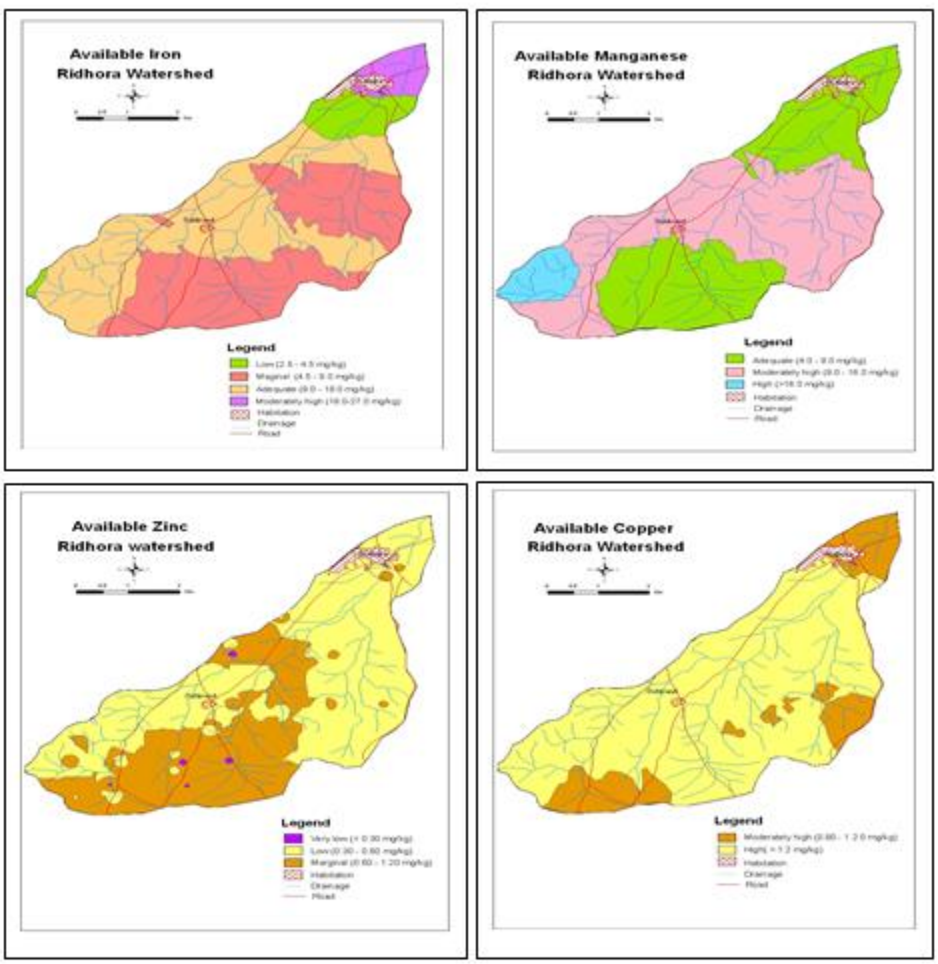

Figure 5. Krigged map of Available Fe, Mn, Zn and Cu

Spatial maps of usable Mn show that usable Mn varies spatially from 6.52 to 16.98 mg kg^{-1} and is well above the critical level of 3.0 mg kg^{-1} [22-23]. A spatial map of available copper shows how much copper is available 0.17 to 6.29 mg $kg^{-1}$and the situation was found to be quite normal in the major part of the watershed and quite above threshold 0.2 mg kg^{-1} [23-24]. Spatial maps of available Zn show that available Zn ranged from 0.06 to 0.98 mg kg^{-1} and reclassified into scarce and sufficient regions at the critical level of 0.6 mg kg^{-1} [23-25].

It has been found that available zinc is scarce in most regions covering an area of 1511.81 (60.9% of TGA), whereas, the nutrient was found sufficient in 934.66 ha (37.65% of TGA) (Table 2). Spatial maps of available Fe show that available Fe spatially varied from 2.47 to 18.93 mg kg^{-1} and reclassified into scarce and sufficient regions at the critical level of 4.5 mg kg^{-1} [19]. The majority of the area was found sufficient in available Fe covering an area of 2262.67 (91.15% of TGA), whereas, the nutrient was found deficient in 183.80 ha (7.40% of TGA) in all the soils (Table 2). A reclassified spatial Krig map of the available micronutrients (Fe, Mn, Cu, and Zn) is shown in Figure 5, respectively.

Cross validation of soil chemical properties

Evaluation parameters of kriged map of soil chemical properties are presented in (Table 3). The RMSE values for soil pH, OC, and $CaCO_3$ were 0.32, 0.38, and 5.24, respectively. The coefficient of determination (R^2) for soil pH, OC, and $CaCO_3$were 0.57, 0.61, and 0.31, respectively. The kriged maps were also validated with observed values.

Evaluation parameters of kriged map of soil fertility parameters are presented in (Table 3). The available N, P, K, and RMSE values are 14.82, 7.05, and 198.6, respectively. The coefficient of determination (R^2) for available N, P, and K were 0.24, 0.33, and 0.74, respectively. The RMSE values for the available Fe, Mn, Cu, and Zn were 5.77, 8.34, 13.22, and 0.21, respectively. The coefficients of determination (R^2) for the available Fe, Mn, Cu and Zn were 0.49, 0.66, 0.62, and 0.46, respectively. A higher coefficient of determination (R^2) was observed for available Mn followed by available Cu Fe, and Zn, similar results were closely painted by [23].

Conclusion

The findings of this study indicate the efficacy and use of GIS, particularly in the analysis and interpolation of soil data utilized in the creation of themed maps. The initial stage in precision agriculture is soil nutrient mapping, which will serve as a foundation for measuring and regulating geographical variability. It also aids in reducing the amount of additives put into the soil, ensuring that the soil is not overburdened, which can lead to pollution and land deterioration. The available N, P, and K on the spatial map were medium, low, high, medium-high, and very high, respectively. A zinc deficit was discovered in 60.9 percent of catchment regions. The research also assisted in identifying and isolating crucial areas of malnutrition. The generated map can be used as an effective tool for managing specific site elements.

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