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Characterization of Spatial Variability of Soil Fertility Parameters Using Geo-Spatial Techniques

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Authors' contributions

This work was carried out in collaboration between all authors. Author GST designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PSK and GDS managed the analyses of the study. Author AS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

GPS based surface soil samples were collected from Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks of Rewa district, Madhya Pradesh, India during off season of 2011-2012. Geographically, it is situated between 24°18' and 25°12' north latitudes and 81°2' and 82°18' east longitudes. and analyzed for soil physiochemical properties using standard method. Results obtained from the laboratory analysis, were studied using standard statistical software. Further, the data were normalized and maps were created using geo-statistical tool in Arc GIS environment. Classical results and maps indicated that the soil samples of studied blocks were found to be slightly acidic to slightly alkaline in reaction, normal in soluble salts, low to medium in organic carbon content and non-calcareous in nature. Result revealed that the nutrient index of sulphur indicated that the low NI value (1.45) in soils of Naigarhi and other blocks showed medium. Similarly, S was deficient to be 61.3% in Naigarhi and followed by 52.93% Sirmour. However, the highest deficiency of Zn (87.30 and 80.95) and lowest NI status (1.13 and 1.21) in Huzur and Mangawan blocks, respectively. NI value of Zn was medium in soils of other blocks. Fe deficiency was found only 4.74 and 8.33 per cent in Mangawan and Raipur Karchuliyan block, respectively.

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Only 7.94, 2.38, 9.09 and 5.26 were found deficient in B soils of Huzur, Mangawan, Naigarhi and Sirmour blocks, respectively. The Cu, Fe, Mn and B NI value rated high in soils of all studied blocks. The organic carbon content exhibited significant positive correlation with available Zn (r =0.278**) and S (r = 0.149*). However, available boron content exhibited positive correlation with pH. The $CaCO_3$ contents had significant negative correlation with available Zn (r = - 0.140*) and Mn (r = -0.146*). The maps prepared using GIS also suggested the major variability of S, Zn, Fe and B in study area.

Keywords: GPS; GIS; sulphur; micronutrients; variability.

1. INTRODUCTION

Nutrients status in soil directly influences the soil health and productivity potential. Characterization of nutrients status of soil in any region provides a basic foundation for selecting crop/cropping system in sustainable manner. Soil micronutrients are essential to plants growth; maintain ecosystems and high crop productivity. However, imbalance fertilization, deteriorate the precious soil environment and subsequently deteriorate soil fertility and crop productivity [1]. Information related to spatial variability and distribution of nutrients in soil is critical for farmers to enhance the crop productivity and use efficiency of applied fertilizers [2]. Fertilizer is one of the costliest inputs in agriculture and the use of right amount of fertilizer is fundamental for farm profitability and environmental protection [3]. Application of fertilizers based on large scale maps with recommendations related to soil fertility may also be used as a tool for minimizing the requirement of fertilizer inputs without surrendering the yield.

Information about the extent of nutrient status and variability is necessary for the scientists, administrators, farmers and fertilizer manufacturers to determine the kind and quantity of fertilizer required for the particular region. There is a need to blend the traditional knowledge with frontier technologies. Geo-positioning system is the tool of such frontier technology, which, would help in generation of agricultural management system and formulating plans for sustainable agricultural development. The geo referenced sampling sites can be revisited with the help of GPS, which helps in monitoring the changes in the status of micronutrients over a period of time, which otherwise is not possible by traditional methods of sampling. Geo-statistics is a useful tool for analyzing spatial variability, interpolating between point observations, and ascertaining the interpolated values with a specified error using a minimum number of observations.

The modern day space age technologies can be adopted for speedy dissemination of the research results on optimum doses of nutrients for maximum farm profitability to scientists, industry personnel, extension workers and farmers. One of them is the use of soil fertility maps for fertilizer recommendation with a support to calculate fertilizer doses based on soil test values interactively. In soil survey, global positioning system and geographic information system (GIS) technologies have been adopted for better management of soil and other resources for sustainable crop production [4]. Hence the present study was undertaken for analysis of spatial distribution, as well as its status using geo-statistical tool.

2. MATERIALS AND METHODS

2.1 Description of Study Area

Rewa district is located in Madhya Pradesh having semi-arid and sub-tropical climate. Geo referenced two hundred surface soil samples were collected during off season of 2011-12. Locations of sampling sites were decided using geo-positioning system. Location map is given in Fig. 1.

2.2 Soil Sampling and Their Analysis

The soil samples (two hundred) were randomly collected from Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks of Rewa district during off season of 2010-11 under AICRP on MSN project. The pH, EC, OC, and $CaCO_3$ analyzed using standard laboratory methods. Zn, Fe, Mn and Cu were extracted with DTPA as outlined by [5] and reading taken by using Atomic Absorption Spectrophotometer, where as hot water soluble B content in soil was determined by Azomethine-H method [6] and estimated by using spectrophotometer. Further, data were processed and interpreted sing standard statistical software (SPSS-16). The limits of micronutrients were used for various categories (low, medium and high) as suggested by [7].

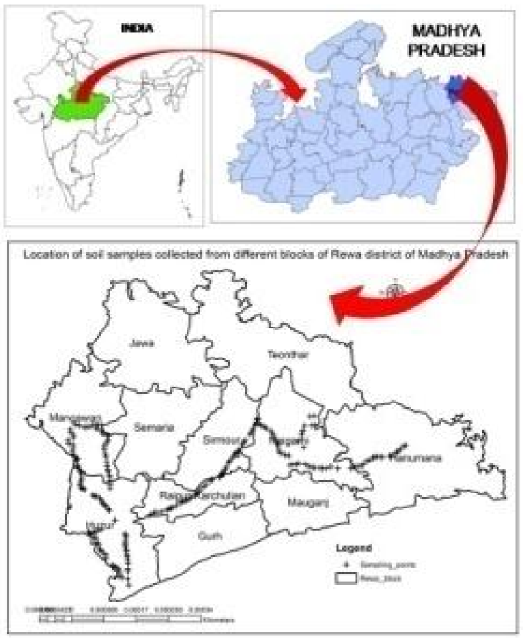


Fig. 1. Location map of study area

2.3 Geo-statistical Analysis

The presence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) is a prerequisite to the application of geo-statistics. The experimental variogram measures the average degree of dissimilarity between unsampled values and a nearby data value and thus can depict autocorrelation at various distances. The value of the experimental variogram for a separation distance of h (referred to as the lag) is half the average squared difference between the value at z(xi) and the value at z(xi+h):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i + h) - z(x_i)]^2$$

Where: N (h) is the number of data pairs within a given class of distance and direction. If the values at z (xi) and z (xi+h) are auto correlated the result of Eq. (1) will be small, relative to an uncorrelated pair of points. From analysis of the experimental variogram, a suitable model is then fitted, usually by weighted least squares, and the parameters (e.g. range, nugget and sill) are then used in the Kriging procedure. Several distribution maps are created with different interpolation algorithms.

3. RESULTS AND DISCUSSION

3.1 Spatial Variability Maps Generated Using Geo-statistical Tool

The spatial distribution maps of all fertility parameters prepared by ordinary Kriging using best fitted exponential models. [8] Reported that strong spatial dependency of soil characteristics can be attributed to intrinsic factors and weak spatial dependency can be attributed to extrinsic factors. Maps obtained from geo-statistical are presented in Fig-3-11 depicted the variability of nutrients in soils of selected block of district.The results and maps prepared by authors were also corroborated by the works of [9].

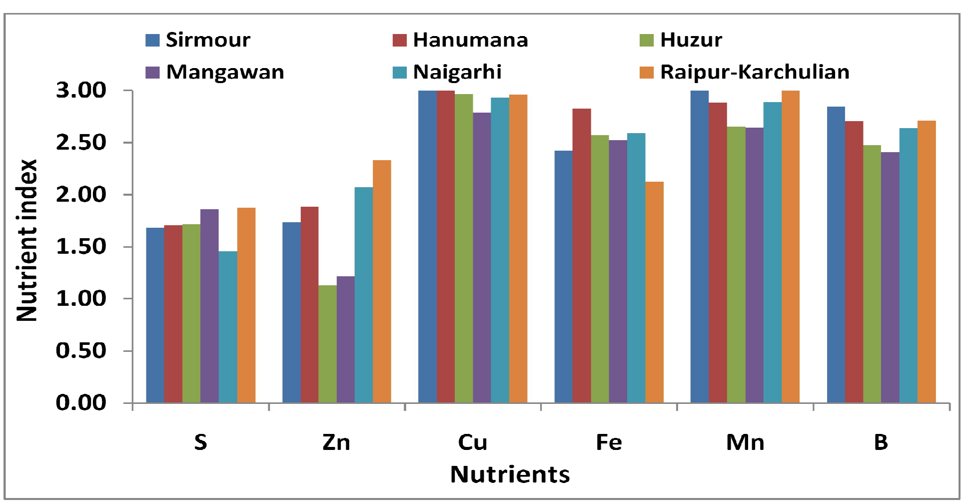
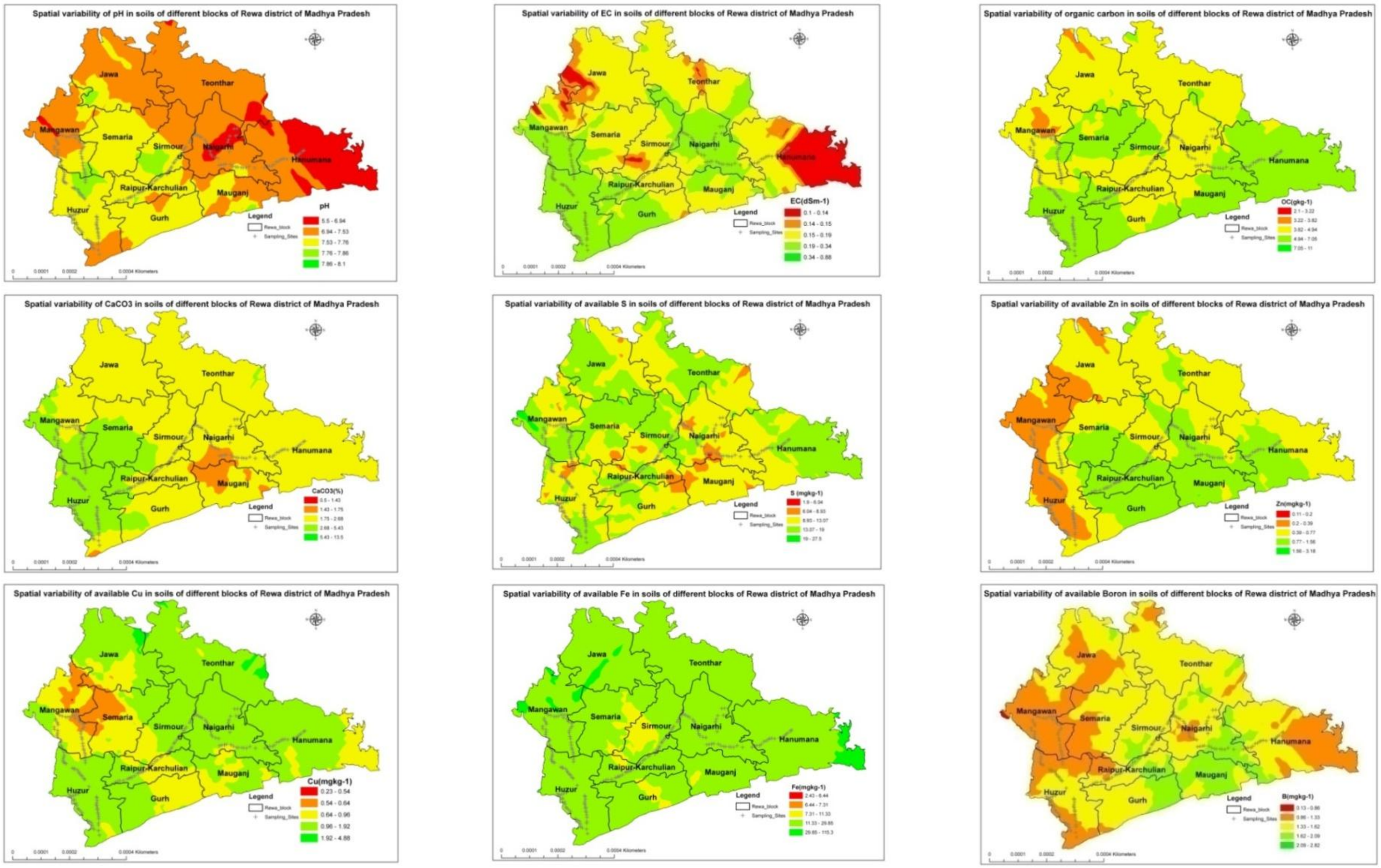


Fig. 2. Nutrient index in soils of different blocks of Rewa district



Figs. 3-11. Spatial variability maps of pH, EC, OC, $CaCO_3$, S, Zn, Cu, Fe and B in soils of different blocks of Rewa district of Madhya Pradesh

3.2 Spatial Variability of Physico-Chemical Properties Using Classical and GEO-statistical Approach

3.2.1 Soil reaction

Data presented in Table 1 and maps indicated that the soil pH varied from 5.9 to 7.7, 6.3 to 8.10, 5.9 to 8.0, 5.5 to 8.0, 6.5 to 8.1 and 5.5 to 8.0 with mean value of 6.87, 7.65, 7.46, 7.20, 7.72 and 7.49 in Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks of Rewa district. Thus, the soil samples were found to be slightly acidic to neutral and somewhere it was slightly alkaline in reaction. Similar results were also reported by [10].

3.2.2 Electrical conductivity

Electrical conductivity ranged from 0.10 to 0.41, 0.12 to 0.79, 0.10 to 0.88, 0.10 to 0.87, 0.11 to 0.42 and 0.10 to 0.37 with mean value of 0.16, 0.21, 0.22, 0.23, 0.18 and 0.16 dSm^{-1} in soils of Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks, respectively. All the samples were found to be in safe limit which indicates salinity is not at all a problem in these areas. Similar results were reported by [11].

3.2.3 Organic carbon

Organic carbon content in soils varied from 3.40 to 11.00,2.60 to 9.60,2.10 to10.30,2.10 to 8.00,3.60 to 7.70 and 3.60 to 7.50 g kg^{-1} with mean value 6.37,5.39, 4.54,4.50, 5.06 and 4.65 g kg^{-1} in Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks, respectively. Considering the critical limit of 0.50 g kg^{-1}, 35.29 and 39.68% (<50 %), soil samples from Hanumana and Huzur were found to be deficient in organic carbon, respectively. However 54.17, 61.36, 63.16 and 71.34 (>50 but <75%) soil samples from Raipur-karchulian, Naigarhi, Sirmour and Mangawan were found to be deficient, respectively. This indicated that deficiency of OC is less in soils of Hanumana and Huzur. However, it was highly deficient in soils of Raipur-karchulian, Naigarhi, Sirmour and Mangawan (Table 2 and maps). It might be due to unbalanced fertilization and high summer temperature and good aeration in the soil, resulting in rapid decomposition of it. [12] Also reported medium organic carbon content in soils of Varanasi, India. This was supported by [13].

3.2.4 Calcium carbonate

Data given in Table 1 indicated that the mean calcium carbonate content were 19.71, 34.60, 30.95, 20.45, 27.50 and 17.11 gkg^{-1} in soils of Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks, respectively. Overall, the calcium carbonate varied from 5 to 95 g kg^{-1} in the study area. It is indicating that the mixed red and black soils were non-calcareous in nature.

3.3 Spatial Variability of Sulphur and Micronutrients in Soils

3.3.1 Available sulphur

The available S content varied from 8.90 to 17.40 mg kg^{-1}, 1.90 to 27.50 mg kg^{-1}, 2.30 to 27.50 mg kg^{-1}, 1.40 to 24.60 mg kg^{-1}, 2.7 to 24.60 mg kg^{-1} and 3.00 to 25.00 mg kg^{-1} with mean value of 12.25, 12.37, 14.44, 13.23, 13.22 and 12.17 mg kg^{-1} in soils of Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks, respectively. The coefficient of variation, which is the ratio of the standard deviation to mean expressed, as a percentage is a useful measure of overall variability. Considering CV <10% as low, 10 to 100% as moderate, >100% as high variability, the highest variability of Sulphur (CV= 59.28% was observed in soils of Sirmour followed by Naigarhi (CV=56.51%), Huzur (CV=54.49%), Raipur-Karchulian (CV=48.00%), Mangawan (CV=43.43%) and Hanumana (CV=22.76%).Considering 10.0 mg kg^{-1} 0.15 % $CaCl_2$ extractable sulphur as the critical level about 29.41, 46.03, 38.10,61.36, 33.33 and 52.63 per cent soil samples were found deficient in Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks, respectively. Similar finding was reported by [14] and [10].

3.3.2 Available Zn

The available Zn content in soils varied from 0.15 to 3.18 mg kg^{-1}, 0.13 to 0.99 mg kg^{-1}, 0.11 to 2.77 mg kg^{-1}, 0.23 to 2.48 mg kg^{-1}, 0.76 to 1.88 mg kg^{-1} and 0.11 to 1.95 mg kg^{-1} with mean value of 1.09, 0.32, 0.41, 1.02, 1.11 and 0.79 mg kg^{-1} in Hanumana, Huzur, Mangawan, Naigarhi, Raipur-Karchulian and Sirmour blocks, respectively. The data presented in Table 2 also indicated that the highest variability of Zn (CV=107.23%) in soils was found in Mangawan and followed by Hanumana, Naigarhi, Sirmour, Huzur and the lowest variability (CV=28.05) in soils of Raipur-Karchulian. Considering 0.6 mg kg^{-1} DTPA extractable Zn as the critical limit about 35.29, 87.30, 80.95, 25.00 and 42.11 per cent samples were found deficient in Hanumana, Huzur, Mangawan, Naigarhi and Sirmour blocks, respectively. None of soil samples were found deficient in Raipur Karchulian. Recently 60% soils samples were found deficient reported by [15] substantiate our results. Lower content of zinc in black soils is due to its fixation by clay [16]. Similar results were supported by [1,10].

3.3.3 Available Cu

The available Cu content in soils varied from 0.44 to 4.11 mg kg^{-1} (mean 0.96 mg kg^{-1}), 0.34 to 4.22 mg kg^{-1} (mean 1.28 mg kg^{-1}), 1.37 to 4.33 mg kg^{-1} (mean 0.76mg kg^{-1}), 0.34 to 4.77 mg kg^{-1} (mean 1.28 mg kg^{-1}) ,0.35 to 4.15 mg kg^{-1} (mean 1.02 mg kg^{-1}) and 0.46 to 4.88 mg kg^{-1} (mean 1.44 mg kg^{-1}) in Hanumana, Huzur, Mangawan, Naigarhi and Sirmour blocks, respectively. The highest variability of Cu (CV=111.81%) in soils of Mangawan followed by Naigrahi, Raipur-Karchulian, Sirmour and Hanumana. The lowest variability of Cu (CV=86.67%) in Huzur block. None of the samples were tested low in Cu.Similar results were reported by [17-19].

3.3.4 Available Fe

The available Fe content in soils varied from 6.12 to 74.20 mg kg^{-1} (mean 21.50 mg kg^{-1}), 4.64 to 101.30 mg kg^{-1} (mean 21.58 mg kg^{-1}), 4.34 to 106.20 mg kg^{-1} (mean 28.75 mg kg^{-1}), 4.61 to 115.30 mg kg^{-1} (mean 17.92 mg kg^{-1}), 2.43 to 99.30 mg kg^{-1} (mean 14.19 mg kg^{-1}) and 4.88 to 18.30 mg kg^{-1} (mean 9.06 mg kg^{-1}) block of Hanumana, Huzur, Mangawan, Naigarhi and Sirmour blocks of Rewa district respectively. The highest and lowest variability of Fe was found to be CV=174.80 and CV=40.40% in soils of Raipur-Karchulian and Sirmour, respectively. Only 4.74 and 8.33 per cent soil samples were found deficient in Mangawan and Raipur Karchuliyan block, respectively. None of the samples were tested low in other blocks.

3.3.5 Available Mn

Data showed that the available Mn content in soils varied from 2.23 to 92.30 mg kg-1, 2.27 to 97.30 mg kg^{-1}, 2.76 to 99.00 mg kg^{-1}, 4.34 to 11.46 mg kg^{-1}, 4.18 to 56.30 mg kg^{-1} and 2.05 to 88.30 mg kg^{-1} with mean value of 12.28, 13.31, 11.28, 7.71, 9.57 and 18.67 in Hanumana, Mangawan, Naigarhi, Raipur-Karchulian, Sirmour and Huzur blocks, respectively. Amongst the studied nutrients the Mn content in soils was highly variable as compared to other. None of the samples were tested low in Mn.

3.3.6 Available Boron

The available B content varied from 0.55 to 2.32 mg kg^{-1} (mean 1.34 mg kg^{-1}), 0.21 to2.82 mg kg-1 (mean 1.22 mg kg^{-1}) , 0.39 to 2.32 mg kg^{-1} (mean 1.08 mg kg^{-1}) , 0.13 to 2.82 mg kg^{-1} (mean 1.54 mg kg^{-1}), 0.79to 2.66 mg kg^{-1} (mean 1.50 mg kg^{-1}) and 0.13 to 2.66 mg kg^{-1} (mean 1.62 mg kg^{-1}) in soils of Hanumana, Huzur, Mangawan, Naigarhi and Sirmour blocks, respectively. The highest variability of B was found in soils of Huzur and the lowest in soils of Sirmour block. None of the samples were tested low in Boron in soils of Hanumana and Raipur-Karchlian. However, 7.94, 2.38, 9.09 and 5.26 percent soil samples were found deficient in soils ofHuzur, Mangawan, Naigarhi and Sirmour blocks, respectively. Similar work has been carried out by [20,10].

Table 1. Spatial distributions of physicochemical properties in soils of different blocks of Rewa district Madhya Pradesh

Blocks (n)	Parameter	pH	EC(dSm^{-1})	$CaCO_3$(gkg^{-1})
Hanumana	Range(mean)	5.90-7.70(6.87)	0.10-41(0.16)	10.00-35.00(19.71)
(17)	CV	9.33	52.53	36.41
Huzur	Range(mean)	6.30-810(7.65)	0.12-0.79(0.21)	10.00-90(34.60)
(63)	CV	4.71	50.24	52.50
Mangawan	Range(mean)	5.90-8.00(7.46)	0.10-0.88(0.22)	10.00-95.00(30.95)
(42)	CV	7.02	74.54	61.10
Naigarhi	Range(mean)	5.50-8.00(7.20)	0.10-0.87(0.23)	5.00-75.00(20.45)
(44)	CV	10.32	69.46	59.13
Raipur-Karchulian	Range(mean)	6.50-8.10(7.72)	0.11-0.42(0.18)	10.00-75.00(27.50)
(24)	CV	4.45	45.96	65.67
Sirmour	Range(mean)	5.50-8.00(7.49)	0.10-0.37(0.16)	10.00-30.00(17.11)
(19)	CV	8.14	49.92	41.70

Table 2. Spatial distribution of sulphur and micronutrients in soils of different blocks of Rewa district Madhya Pradesh

Blocks(n)	Dominant soil groups	Parameter	OC(gkg^{-1})	S(mgkg^{-1})	Micronutrients (mgkg^{-1})				
					Zn	Cu	Fe	Mn	B
Hanumana	TypicHaplustalfs	Range(mean)	3.40-11.00(6.37)	8.90-17.40(12.25)	0.15-3.18(1.09)	0.44-4.11(0.96)	6.12-74.20(21.50)	2.23-92.30(12.28)	0.55-2.32(1.34)
(17)	TypicUstochrepts	CV	37.92	22.76	87.56	86.67	104.84	168.88	40.39
	VerticUstochrepts	PSD	35.29	29.41	35.29	0.00	0.00	0.00	0.00
		PSM	35.29	70.59	41.18	0.00	17.65	11.76	29.41
		PSH	29.41	0.00	23.53	100.00	82.35	88.24	70.59
		NI	1.94	1.71	1.88	3.00	2.82	2.88	2.71
Huzur	TypicHaplustalfs	Range(mean)	2.60-9.60(5.39)	1.90-27.50(12.37)	0.13-0.99(0.32)	0.34-4.22(1.37)	4.64-101.30(21.58)	2.05-88.30(18.67)	0.21-2.82(1.22)
(63)	VerticUstochrepts	CV	25.16	54.49	63.18	85.17	126.26	145.07	53.36
	TypicUstochrepts	PSD	39.68	46.03	87.30	0.00	0.00	0.00	7.94
		PSM	52.38	36.51	12.70	3.17	42.86	34.92	36.51
		PSH	7.94	17.46	0.00	96.83	57.14	65.08	55.56
		NI	1.68	1.71	1.13	2.97	2.57	2.65	2.48
Mangawan	VerticUstochrepts	Range(mean)	2.10-10.30(4.54)	2.30-27.50(14.14)	0.11-2.77(0.41)	0.23-4.33(0.76)	4.34-106.20(28.75)	2.27-97.30(13.31)	0.39-2.32(1.08)
(42)	TypicHaplustalfs	CV	33.53	43.43	107.23	111.81	114.03	188.87	41.63
		PSD	71.43	38.10	80.95	0.00	4.76	0.00	2.38
		PSM	23.81	38.10	16.67	21.43	38.10	35.71	54.76
		PSH	4.76	23.81	2.38	78.57	57.14	64.29	42.86
		NI	1.33	1.86	1.21	2.79	2.52	2.64	2.40
Naigarhi	VerticUstochrepts	Range(mean)	2.10-8.00(4.50)	1.90-24.60(10.05)	0.23-2.48(1.02)	0.34-4.77(1.28)	4.61-115.30(17.92)	2.76-99.00(11.28)	0.13-2.82(1.54)
(44)	TypicHaplustalfs	CV	25.44	56.51	64.82	100.42	136.37	146.00	45.60
		PSD	61.36	61.36	25.00	0.00	0.00	0.00	9.09
		PSM	36.36	31.82	43.18	6.82	40.91	11.36	18.18
		PSH	2.27	6.82	31.82	93.18	59.09	88.64	72.73
		NI	1.41	1.45	2.07	2.93	2.59	2.89	2.64
Raipur-Karchulian	Typichaplustalfs	Range(mean)	3.60-7.70(5.06)	2.70-24.60(13.22)	0.76-1.88(1.11)	0.35-4.15(1.02)	2.43-99.30(14.19)	4.34-11.46(7.71)	0.79-2.66(1.50)
(24)	TypicUstochrepts	CV	25.40	48.00	28.05	90.41	174.80	18.96	39.28
		PSD	54.17	33.33	0.00	0.00	8.33	0.00	0.00
		PSM	41.67	45.83	66.67	4.17	70.83	0.00	29.17
		PSH	4.17	20.83	33.33	95.83	20.83	100.00	70.83
		NI	1.50	1.88	2.33	2.96	2.13	3.00	2.71
Sirmour	TypicHaplustalfs	Range(mean)	3.60-7.50(4.65)	3.00-25.00(12.30)	0.11-1.95(0.79)	0.46-4.88(1.44)	4.88-18.30(9.06)	4.18-56.30(9.57)	0.13-2.66(1.62)
(19)	TypicUstochrepts	CV	23.79	59.28	64.39	87.43	40.40	120.50	33.08
	TypicRhodustalfs	PSD	63.16	52.63	42.11	0.00	0.00	0.00	5.26
		PSM	36.84	26.32	42.11	0.00	57.89	0.00	5.26
		PSH	0.00	21.05	15.79	100.00	42.11	100.00	89.47
		NI	1.37	1.68	1.74	3.00	2.42	3.00	2.84

Table 3. Correlations matrix

Parameters	pH	EC	OC	$CaCO_3$	S	Zn	Cu	Fe	Mn
EC	-0.167*	1							
OC	0.106	-0.054	1						
$CaCO_3$	0.297**	-0.018	0.094	1					
S	0.059	0.114	0.149*	-0.048	1				
Zn	-0.071	0.018	0.278**	-0.140*	-0.068	1			
Cu	0.091	-0.109	0.012	0.098	0.043	-0.062	1		
Fe	0.04	0.062	0.08	0.08	0.03	-0.036	0.002	1	
Mn	-0.027	-0.036	0.018	-0.146*	-0.063	-0.167*	0.073	0.014	1
B	0.291**	-0.106	0.061	0.036	0.066	0.158*	0.058	-0.068	-0.012

**. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed)*

3.4 Categorization of Soils Using Nutrient Index

The nutrient index (NI) values for available nutrients present in the soils were calculated utilizing the formula suggested by [21]. Data given in Table 2 and Fig 2 showed that the nutrient index of sulphur indicated that soils of Naigarhi block showed the lowest NI value (1.45) and other blocks showed medium nutrient index (>1.67 but <2.33). The nutrient index value of Zn was found to be lowest 1.13 and 1.21 (<1.67) in soils of Huzur and Mangawan blocks, respectively. However, it was medium in soils of other studied blocks. The Cu, Fe, Mn and B status in soils of all studied blocks were rated as high (>2.33) except Raipur-karchulian in case of Fe which was medium status. The S status in all the blocks of study area was low to medium. Similar finding was reported by [22,12,23,10].

3.5 Relationships of S and Micronutrients with Soil Properties

The relationship of soil pH, OC and $CaCO_3$ with micronutrients is presented Table 3. The Zn and Mn contents had negative association with soil pH thereby indicating that availability of these micronutrients decreases with increase in soil pH. However, the available Boron content in soils correlated positively and significant correlation was found with soil pH (r=0.29**). Such behavior of soil was also reported by [24].

The organic carbon content exhibited significant positive correlation with available Zn (r =0.278**) and S (r = 0.149*). The availability of boron increased due to formation of strong complex of boron with organic matter in soil [25]. The positive correlation with organic carbon suggested that the micronutrients form complexes with organic matter and consequentially remained in the forms, easily available to the plants. Further, the $CaCO_3$ contents had significant negative correlation with available Zn (r = - 0.140*) and Mn (r = -0.146*) contents in soil. Similar results reported by [19].

4. CONCLUSIONS

Based on findings it can be concluded that the soils were slightly acidic to slightly alkaline in reaction, normal in soluble salts, low to medium in organic carbon content and non-calcareous in nature. The highest deficiency of S in Naigarhi and followed by Sirmour. However, Zn deficiency was more in Huzur and Mangawan blocks. Fe and B deficiency was noticed in Mangawan and Raipur Karchuliyan blocks. The maps prepared using GIS also suggested the major variability of S, Zn, Fe and B in these blocks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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