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Mapping of Soil Micronutrients (Fe, Mn, Cu, Zn) in the Transition Zone of Northwestern Foothill of Shivaliks of Kathua District Using GIS

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Authors' contributions

This work was carried out in collaboration among all authors. Author VV designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KRS and VS edited the analyses of the study. Authors VMA and RB edited and managed the literature and analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To analyze and map the soil micronutrient status in the transition zone of NW foothills of Shivaliks of Kathua Region using GIS.
Methodology: Composite surface soil samples from two hundred and six (206) locations distributed randomly due to undulated topography across the whole of the district were collected at the depth of 0-15 cms using global positioning system (GPS). Inverse distance weighting (IDW) technique was adopted to generate prediction maps of the soil properties. The process of digitization and generation of maps was carried out with ArcGIS 10.3.
Results: After soil sample analysis, the available copper content in the soil of hilly areas varies from 0.4 to 14.4 mg kg^{-1} with a mean value of 3.75 mg kg^{-1}. Available Zinc content ranged from 0.25 to 5.60 mg/kg respectively. The available Manganese content of the surface soils varied between 5.60 to 78.10 mg kg^{-1} with a mean value of 23.97 mg kg^{-1}. Available Iron content ranged from 11.30 to 92.00 mg/kg with a mean value of 38.57 mg kg^{-1}. The available copper content in the

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soil of plain areas varies from 2.08 to 34.90 mg kg^{-1} with a mean value of 8.94 mg kg^{-1}. The minimum and maximum values of available copper content lies in higher range. Available Zinc content ranged from 0.25 to 5.60 mg kg^{-1} respectively. According to the map, available zinc is visualized lowest in plains due to raised soil pH. The available manganese content of the surface soils varied between 2.500 to 57.40 mg/kg with a mean value of 27.03 mg kg^{-1}. Available Iron content ranged from 0 to 66.10 mg kg^{-1} with a mean value of 41.68 mg kg^{-1}.

Conclusion: The mapping was done successfully with micronutrients varying from low to high range. The technique was found to be effective in identifying the micronutrients availability throughout the study region, thereby helping policy makers to frame fertilizer distribution and application policy for future.

Keywords: Iron (Fe); manganese (Mn); copper (Cu); zinc (Zn); IDW; GPS; ArcGIS.

1. INTRODUCTION

In the early 1960's, India was totally dependent on import of food materials but as soon the advancements were introduced into the Indian Agriculture a lot of things changed. Green Revolution and the introduction of HYV's, Chemical fertilizers, new chemicals to retard the disease and pest growth lead to the beginning of a new era of food security in India. But after 4 decades of beginning of green revolution, the second generation soil problems is now a new challenge to soil researchers. The maximized use of major chemical fertilizers like Urea, DAP, MOP etc. has not only created a huge disturbance in soil nutrient distribution and availability but has also forced crops to be more sensitized towards other minor nutrients or micro nutrients. Concerted efforts have been made through the All India Coordinated Research Project on micronutrients to delineate the soils of India regarding the deficiency of micronutrients as a result of which it has been analyzed that at present about 48.1% of Indian soils are deficient in diethylene triamine penta acetate (DTPA) extractable zinc, 11.2% in iron, 7% in copper and 5.1% in manganese. Apart from the deficiency of above micronutrients, boron and molybdenum deficiencies have also been reported in some areas. The reports of AICRP on micronutrient have also stated that the areas with multi-micronutrient deficiencies are limited and for such areas simple fertilizers are sufficient to exploit the potential of crops and cropping systems. Based on the extent of deficiency, cultivated area, and crop removal, it has been projected that the micronutrient fertilizer demand will rise by 2025, thereby creating a vaccum in sustainable fertilizer usage approach [1].

In Himalayas, the most important micronutrient deficiency to plants is boron, whereas zinc deficiency is a serious problem to both plant production and human nutrition. Deficiencies of selenium, iodine and molybdenum have been reported in several regions. However, the availability of micronutrients in agricultural soils is influenced mainly by: (a) soil with naturally low levels of micronutrients (b) reduction of the soil's natural fertility caused by the crop yield increment, (c) application of lime to soil reduces the availability of micronutrients, except molybdenum. Thus, the study of spatial variability of soil micronutrients content data promotes a supportive approach towards the rational management of soil with the objective of the sustainability of the agricultural environment.

However, information pertaining to such use of GIS-based fertility maps has been meager in India [2,3]. The current study was aimed to evaluate and map the spatial distribution of soil micro nutrients in plains and hilly areas of North Western foothills of Shivaliks of Kathua district under one macro and three micro agro climatic zones.

2. MATERIALS AND METHODS

The present study area which is Kathua district of J&K, U.T, India lies in between 32°17`N to 32°55`N of latitude and 75°70`E to 76°46` E of longitude and experiences wide range of climatic variations from sub-tropical to temperate areas and even alpine in higher regions and is located in the transition zone of foothills of Shivaliks of Jammu province. The district is further distributed into 5 tehsils from where samples have been withdrawn.

Basohli is located at 32.50°N, 75.82°E. It has an average elevation of 460 meters above mean sea level and is situated in the uneven lofty hills of shiwaliks. It is situated in the right bank of Ravi River. Main crops of the area: - Maize & Wheat. Bani is a small glaciated valley located at a height of 4200 ft. from mean sea level in the lap of lofty mountains. It experiences temperate and polar type of climate. Severe winters and moist summer are main climatic phenomenon of this valley. Billawar is located at 32.62°N 75.62°E with an average elevation of 844 m above mean sea level and is situated in the lap of Shivaliks between the banks of Naj and Bhini Rivers. Kathua is located at Jammu to the Northwest, the Doda and Udhampur districts to the north and Pakistan working boundary to the west. Hiranagar is located at 32.45° N, 75.27°E and an average elevation of 1010 feet. Vegetables are mostly the part of the cropping pattern with Paddy and Wheat as cereals in some areas. The annual rainfall in the area is about 1300 mm approximately. The area is mostly irrigated and productive.

Due to the undulated topography of the area, composite surface soil samples from two hundred and six (206) locations distributed randomly across the whole of the area were collected at the depth of 0-15 cms using global positioning system (GPS). The exact sample location was recorded using a handheld GPS receiver and then were analyzed as per the standard procedure for laboratory analysis. ArcGIS 10.3 was used to digitize the nutrient map of the area. Processed soil samples were analyzed for nutrient availability by following standard analytical techniques. Available micronutrients were analyzed through DTPA extractable method [4].

Table 1. Fertility status of Fe, Mn, Cu and Zn was interpreted as deficient and sufficient by following criteria given below

Fertility ratings [5]		
Micro nutrients	**Deficient**	**Sufficient**
Copper	<0.20	>0.20
Zinc	<0.60	>0.60
Manganese	<2.00	>2.00
Iron	<4.50	>4.50

Original data is analyzed using different computer software. Descriptive Statistical analysis which included mean values, Coefficient of variation, Minimum and Maximum Values, standard deviation, standard error of mean, Skewness and Kurtosis was carried out using Graph Pad Prism 5. Traditional statistical analysis is performed using GS+ (version 10.0) while the spatial structural analysis is carried out by using GS+ (version 10.0). Use of indicator *kriging* favors the loss of information. However it is noteworthy that this loss of information is compensated by determining a threshold considered of importance for studies of spatial variability, enabling the inclusion of additional information in the spatial analysis process. The *kriging* technique was used to estimate the values for non-sampled places in the field without trend and with minimum variance.

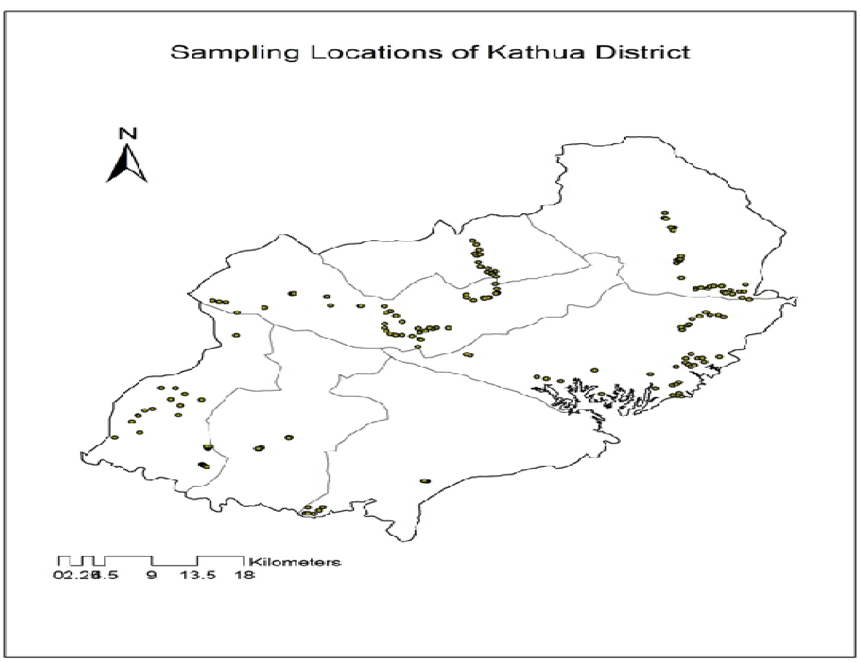


Fig. 1. Sampling locations of Kathua district

Inverse distance weighting (IDW) technique was adopted to generate prediction maps of the soil micro nutrients. The choice of either technique to prepare filled contour maps of soil properties was based upon error analysis. The process of digitization and generation of maps was carried out with ArcGIS 10.3.

3. RESULTS AND DISCUSSION

The available copper content in the soil of hilly areas varies from 0.4 to 14.4 mg kg^{-1} with a mean value of 3.75 mg kg^{-1}. The descriptive statistics of the available copper content in hilly areas is presented in Table 2. From above statements it can be concluded that the available copper content is usually too high. In the hilly areas where 95% of the area is expressing high copper content is because high organic matter content in the soils. It showed a significant and positive correlation with organic carbon, available nitrogen, phosphorus and potassium, DTPA-Fe and Zn. The increased availability of Copper may be due to the fact that, DTPA being organic chelating agent extracts micronutrient cations from different pools and the higher amount of organic carbon coupled with low pH values is further likely to increase the solubility of micronutrient cations [6].

Available Zinc content ranged from 0.25 to 5.60 mg kg^{-1} respectively. The higher sufficient content of available zinc might be due to highest content of organic carbon as well as finer fractions of soils leading to increase in the surface ion exchange and hence contributed to the higher amount of DTPA-Zn in those soils [7].

The available Manganese content of the surface soils varied between 5.60 to 78.10 mg kg^{-1} with a mean value of 23.97 mg kg^{-1}. The Mn bearing minerals in the parent material of these soils might be the reason for higher Mn content of soils. Similar results were also reported in Lachimpur series of Jharkhand [8] which may be due to the formation of insoluble higher valent oxides of Mn at high pH [9]. Available Iron content ranged from 11.30 to 92.00 mg kg^{-1} with a mean value of 38.57 mg kg^{-1}. Usually Fe availability is generally high in acid soils but due to antagonistic relation with Cu, Zn, Mn and phosphate ions renders the plant with non-availability of Fe.

The available copper content in the soil of plain areas varies from 2.08 to 34.90 mg kg^{-1} with a mean value of 8.94 mg kg^{-1}. The minimum and maximum values of available copper content lies in higher range. However, if we consider the map, it can be easily noticed that the plains towards south are depicting lower copper content than hills. The lower copper content might be due to diversified cropping patterns in the area.

Table 2. Characterstics of calculated semi-variograms for copper, zinc, manganese & iron in study area

Soil Nutrients	Residual SS	R^2	Proportion (C/[Co+C])	Model	Nugget Variane	Sill (Co+C)	Range (A)
Copper	0.0346	0.94	0.717	Gaussian	7.82	35.63	61799.6
Zinc	0.0793	0.678	0.742	Spherical	1.688	7.207	256516.70(minor), 647960.20(major)
Mangane	0.0142	0.351	0	Spherical	5.1	149.3	1230
Iron	0.11466	0.089	0.945	Spherical	14.7	267.5	1360

Table 3. Statistical parameters of micronutrients in soils of hilly areas of Kathua region

Column Statistics	Copper (mg kg^{-1})	Zinc (mg kg^{-1})	Manganese (mg kg^{-1})	Iron (mg kg^{-1})
Minimum	0.4	0.25	5.6	11.3
Maximum	14.4	5.6	78.1	92
Mean	3.75	0.9	23.97	38.57
SD	2.5	0.71	10.3	15.66
Standard Error	0.21	0.061	0.88	1.343
CV (%)	66.62	79.4	42.96	40.6
Skewness	1.68	2.73	1.69	0.52
Kurtosis	4.26	13	5.58	-0.25

Table 4. Statistical parameters of micronutrients in soils of plain areas of Kathua region

Column Statistics	Copper (mg kg^{-1})	Zinc (mg kg^{-1})	Manganese (mg kg^{-1})	Iron (mg kg^{-1})
Minimum	2.08	0.3	2.5	0
Maximum	34.9	13.1	57.4	66.1
Mean	8.94	2.62	27.03	41.68
SD	4.81	2.05	15.9	17.85
Standard Error	0.57	0.24	1.91	2.14
CV (%)	53.77	78.28	58.83	42.83
Skewness	2.62	2.57	0.36	-0.38
Kurtosis	11.81	9.71	-1	-0.68

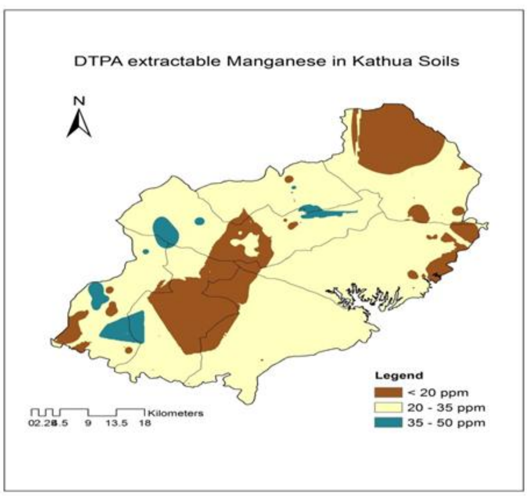
Table 5. Correlation of coefficient among the different micronutrients in soils of hilly areas

	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})
Cu (mg kg^{-1})				
Zn (mg kg^{-1})	-0.13			
Mn (mg kg^{-1})	-0.10	-0.09		
Fe (mg kg^{-1})	0.08	-0.08	0.13	

Table 6. Correlation of coefficient among the different micro nutrients in soils of plain areas

	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})
Cu (mg kg^{-1})				
Zn (mg kg^{-1})	0.15			
Mn (mg kg^{-1})	0.15	0.32**		
Fe (mg kg^{-1})	0.07	0.16	0.37	

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



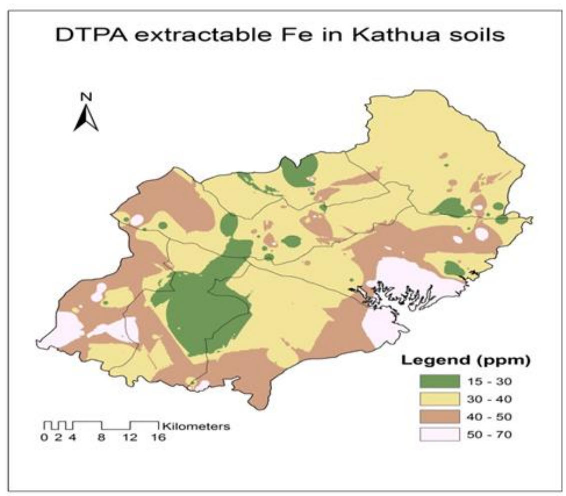


Fig. 2. Spatial distribution maps of soil micro-nutrients (manganese and iron) interpolated by ordinary kriging

Available Zinc content ranged from 0.25 to 5.60 mg kg^{-1} respectively. According to the map, available zinc is visualized lowest in plains due to raised soil pH. The available Manganese content of the surface soils varied between 2.500 to 57.40 mg kg^{-1} with a mean value of 27.03 mg kg^{-1}. This manganese spread is usually normal to high throughout the area because of presence of manganese minerals in soil. Available Iron content ranged from 0 to 66.10 mg kg^{-1} with a mean value of 41.68 mg kg^{-1}. Intensive cropping, particularly with horticultural and cereals in these soils may exhibit Iron deficiency in crops, if maintenance doses are not provided.

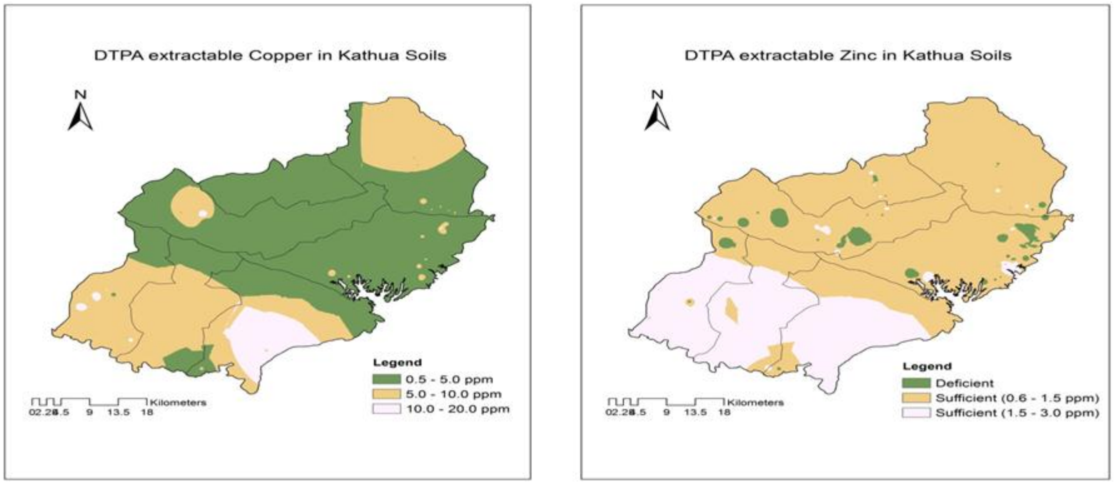


Fig. 3. Spatial distrbution maps of soil micro-nutrients (copper and zinc) interpolated by ordinary kriging

Geo-statistical methods were used to analyze the spatial correlation structures of the available contents of Copper, Zinc, Manganese and Iron in soil and spatially estimate their values at unsampled locations jointly in both hilly and plain areas. Because Kriging assumes the normal distribution for each estimated variable, it is necessary to check whether the available contents of Cu, Mg, Zn and Fe in soil samples are approximately normally distributed or not. The first step in using of Kriging methods is to check the presence of spatial structure among data by variogram analysis. The distribution of data should be normal for the parameter estimation, and the KS test was used to examine the distribution of the data. It can be noticed that the skewness and kurtosis indices of all the micronutrients are close to the standard value of 0 and tend to be normally distributed. The information generated with variograms was used to calculate sample weighing factors for spatial interpolation by ordinary Kriging procedures. Ordinary Kriging was chosen to create the spatial distribution maps of Cu, Mg, Zn and Fe contents, with the maximum search radius being set to the autocorrelation range of the corresponding variable. The exponential model was suitable for estimation of soil properties. The ratio of nugget variance to sill expressed in percentages (C0/C+C0) can be regarded as a criterion for classifying the spatial dependence of the soil parameters. If this ratio is less than 25%, then the variable has strong spatial dependence. Cu, Mg, Zn and Fe showed weak spatial dependence as the ratio of nugget variance exceeded 75% and have moderate spatial structure. So, all experimental variograms were in anisotropic form and were fitted using basic math models, such as Exponential. A filled contour map (prediction map) and a relevant prediction standard error map were created for soil properties using the ArcGIS Geo-statistics tool. The correlation range measures the spatial separate distances within which data are auto correlated. The approximate correlation ranges for Cu, Mg, Zn and Fe are 2.538 km, 2.820, 2.456 and 2.220 km, respectively. This may imply that Cu, Mg, Zn and Fe contents are more sensitive to extrinsic factors such as fertilization. To map the spatial distributions of Cu, Mg, Zn and Fe ordinary Kriging was used to interpolate their respective sample data.

4. CONCLUSION

The mapping technique was found to be effective in identifying and mapping the micronutrients availability throughout the study region, thereby helping policy makers to frame fertilizer distribution and application policies for future. Also, under this context, GIS-based soil fertility mapping has appeared as a promising alternative to mass area testing and generated maps can be used as a decision support tool for nutrient management techniques which will be helpful in adopting a rational approach compared to farmer practices or blanket use of state recommended fertilization.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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