Original Research Article

Geo-Spatial Assessment and Micronutrient Mapping of Calcareous Soils in Muzaffarpur District, Bihar

ABSTRACT:

The soil fertility maps developed using Geographic Information Systems (GIS) serves as an important tool and the soil samples geo-coordinates were recorded in a Garmin GPS device and imported to the base map in ArcGIS software. The analysed soil fertility data for sampling sites includes Minapur, Kanti and Marwan block of Muzaffarpur district of Bihar in which, altogether 40 (forty) geo-referenced composite soil samples were collected from the various locations and various soil fertility parameters analysed using prescribed standard methods. The results depicted that the soils reaction was alkaline in nature with pH value more than 7.5. The content of soil organic was low to medium and DTPA-extractable available zinc cation ranged from 0.14 to 0.79 ppm with the mean value of 0.42 ppm and Copper (Cu) showed below critical limits while and Iron (Fe) and Manganese (Mn) were found to be in relatively medium content.

Keywords: GIS, GPS, Muzaffarpur, Micro nutrients, Soil Fertility Maps

INTRODUCTION

Soil fertility is a cornerstone of agricultural productivity, as it directly influences the growth, health, and yield of crops. Fertile soils supply essential nutrients, support water retention, and promote a healthy balance of microorganisms (Kumar *et al.*, 2024) all critical for sustaining high agricultural outputs. As global food demand rises, maintaining and improving soil fertility becomes paramount for ensuring food security and promoting sustainable farming practices (Kumar *et al.*, 2023). In this context, Geographic Information Systems (GIS) and Global Positioning Systems (GPS) technologies are revolutionizing soil management by offering precise, data driven solutions to monitor and enhance soil health (Singh *et al.*, 2023). These technologies enable detailed mapping and analysis of soil properties, allowing for site-specific nutrient management. This precision agriculture approach ensures that each area of land receives the optimal amount of fertilizers and amendments, reducing waste and environmental degradation while maximizing crop yields (Kumar *et al.,* 2024a). GIS technology helps to develop thematic soil fertility maps, which provide farmers with a comprehensive view of the nutrient levels, pH, organic matter content, and micronutrient distribution across their fields. These maps, combined with GPS data, pinpoint exact locations where soil samples are taken, facilitating more accurate monitoring and interventions. By tailoring soil management strategies to the specific needs of each section of land, GIS and GPS reduce the blanket application of fertilizers and promote more efficient resource use. Furthermore, these technologies support long-term soil health monitoring by allowing farmers and researchers to track changes in soil properties over time. This helps in identifying trends, such as declining nutrient levels or increasing soil acidity and enables proactive measures to restore soil fertility before significant crop losses occur.

As the wellspring of all life, soil is the most important and valuable natural resource (Das *et al.,* 2020). Land use and soil management strategies have an impact on soil fertility, which varies spatially from field to field (Sun *et al*., 2003). Maintaining soil's fertility status is necessary for sustainable crop production through efficient nutrient management (Sinha *et al.,* 2024). Fertility management based on soil tests has been shown to be a successful method for boosting the productivity of agricultural soils with substantial geographical variability brought on by a combination of physical, chemical and biological processes. Soil test based fertility management is an effective tool for an agricultural soil that has high degree of spatial variability (Meena *et al.,* 2024). The basic indicators of soil fertility are the physical characteristics of the soil (texture, structure, and colour), pH, organic matter, primary nutrients, secondary nutrients and micronutrients (B, Fe, Zn, Cu, and Mn), among others (Brady and Weil, 2002). Understanding the state of the soil's fertility is essential for creating effective soil management plans that support crop cultivation design (Kumar, 2015; Upadhyay *et al*., 2020). Remote sensing tool like Global Positioning System (GPS) and Geographic Information Systems (GIS) is an emerging tool for assessing the spatial variability of the soil. GIS are used to gather, store, retrieve, transform, and display spatial data. Agriculture-related thematic maps generated through GPS aids immensely in developing site-specific nutrient management strategies (Hemalatha *et al.,* 2020). Among the technologies, emerging for the study natural resources, remote sensing and GIS are effective technologies. A thematic map generated which reflecting the level of fertility. Moreover, GIS based soil fertility maps for precision agriculture also serves as a decision support tool for solving resource management issues (Habibie *et al.,* 2021). The present study was undertaken to assess the soil fertility status especially with reference to the micronutrients and to generate the soil fertility maps for micronutrients using remote sensing and GIS for Minapur, Kanti and Marawan blocks of Muzaffarpur district of Bihar. The integration of GIS and GPS in soil management is thus essential for optimizing agricultural productivity, minimizing environmental impacts and supporting the sustainable use of agricultural lands.

MATERIALS AND METHODS

Location of the Study Area

The study area Minapur, Kanti and Marwan is situated in the North-Central of Muzaffarpur district of Bihar. The study area lies between 26.050475° to 26.371451° North Latitude and 84.160084° to 85.452076° East Longitude. The river mainly Burhi Gandak, Baghmati, and Baya flow across the district. The average annual rainfall of the study area received during the year 2021 was around 1830.06 mm and around 85% of its rainfall is received during the period of monsoon. The maximum amount of rainfall is received through the south-westerly monsoon during summer while a small quantity from the North Easterly monsoon during winter. The climate during the summer season lasts from April to June and is extremely hot and humid, with temperatures reaching 40°C, whilst winter lasts from mid-November to March with temperatures ranging from 6°C to 20°C. The location of the study area is depicted in Fig.1.

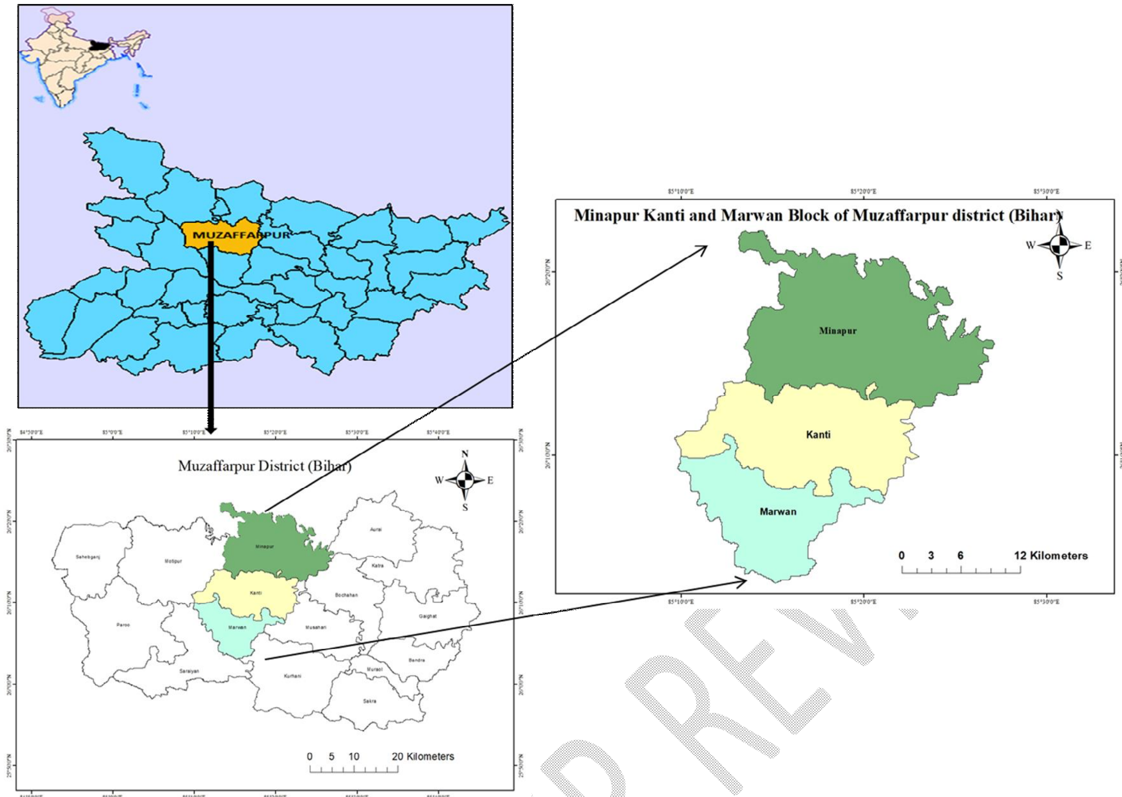

Fig.1: Location map of the study area (Minapur, Kanti and Marwan) in Muzaffarpur district.

Soil Sampling

The soil survey was carried out systematically using field sampling. The soil sampling locations were decided based on the land system units, morphology, land use condition, geology, etc. The Global Positioning System (GPS) instrument was used to locate particular soil sampling points. The places that best represent the various units of the morphology, land system, land use, and geology were considered for soil sampling. Soil samples collected with GPS data can help in making critical decisions on nutrients management. Soil sampling was carried out in such a way that each of the land types was equally represented. A total of 40 soil samples (0-20 cm depth) were collected from the study area (Minapur, Kanti and Marwan) in Muzaffarpur district of Bihar for laboratory analysis of various soil parameters. The collected soil samples were air-dried ground with wooden pestle and mortar & sieve through 2 mm sieve levelled and stored. The thematic maps an available nutrient status were generated by categorising the fertility status as low, medium and high by showing appropriate legend for organic carbon. The geo-coordinates of the sampling location were recorded with the help of a handheld GPS device and imported to the GIS environment for the preparation of thematic soil fertility maps. Locations of the sampling points are represented in Fig. 2.

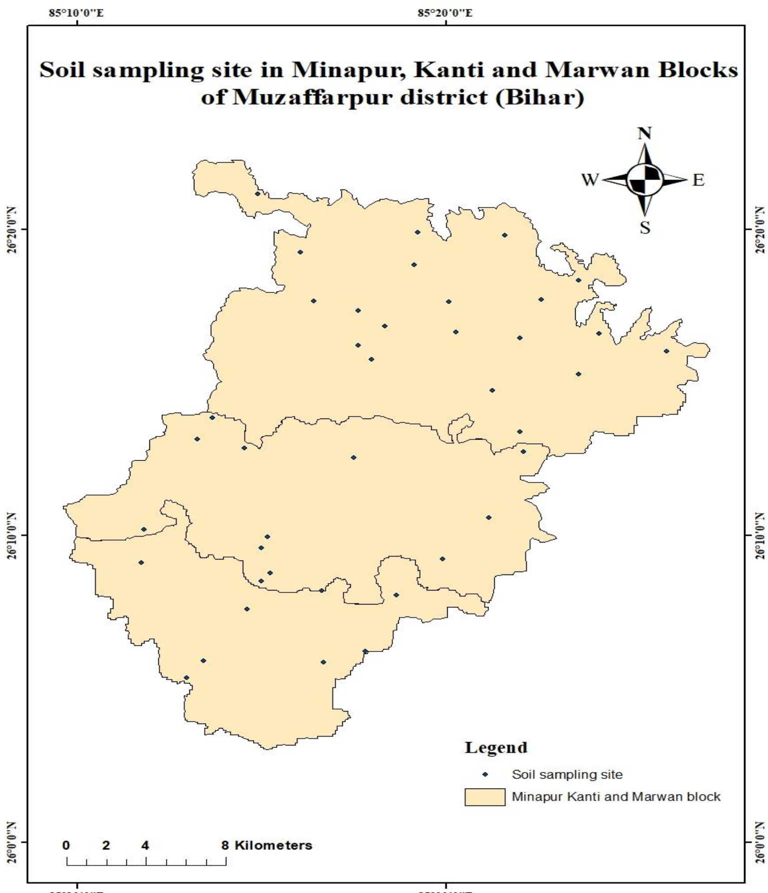

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Fig. 2: Location of soil sampling points in Minapur, Kanti and Marwan block of Muzaffarpur

Laboratory Soil Analysis

The collected soil samples from the field were air dried, ground with wooden pestle and mortar and sieved through 2mm size levelled, stored and used for laboratory analysis of various soil parameters that include soil pH, organic matter, micronutrients viz. manganese, copper, iron, and zinc respectively. For the assessment of soil parameters the following prescribed standard methods were followed are summarised in Table 1.

Table 1: Soil test parameters and methods used for analysis

Soil test parameters	Methods	Reference
pH	Glass electrode pHmeter	Jackson, 1973
Organic carbon (%)	Wet oxidation method	Walkley and Black, 1934
Available micronutrients Zn, Fe, Cu and Mn (ppm)	DTPA extractant	Lindsay and Norvell, 1978

***Generation of thematic soil fertility maps for micronutrients*:**

Soil maps were prepared with the help of a Geographical Information System (Arc GIS 10.8.2). The soil sampled geo-coordinates were recorded in a Garmin GPS device and the geo-coordinates were imported to the base map in ArcGIS software. The Arc GIS software used for reference coordinate system utilized was the World Geodetic System 1984 (WGS84) for locating and geo-referencing the sampling locations in GIS software. Using the Arc toolbox, the interpolation of data was carried out. The latitude and longitude information along with the soil Physico-chemical parameters were imported to the base map in ArcGIS. The thematic soil fertility maps were classified as per soil analysis results. MS Excel and SPSS packages were employed for descriptive statistics of soil parameters.

RESULTS AND DISCUSSION

The samples received for determination of various soil parameters like pH, electrical conductivity, organic matter, available nitrogen, available phosphorus, available potassium, available sulphur, and micronutrients. The status of soil fertility and variability in data from laboratory analysis are summarised in Table 2 and 3.

Table 2: Micro-nutrient content of Minapur, Kanti and Marwan Block in Muzaffarpur district of Bihar

Sl. No.	Soil parameters	Unit	Minimum	Maximum	Mean	Standard Deviation
1	pH	pH	7.54	8.96	7.92	0.28
2	Soil Organic Carbon	%	0.20	0.98	0.55	0.10
7	DTPA-Zinc (Zn)	ppm	0.14	0.79	0.42	0.14
8	DTPA-Copper (Cu)	ppm	0.21	2.36	0.57	0.16
9	DTPA-Iron (Fe)	ppm	2.21	12.01	6.30	1.75
10	DTPA-Manganese (Mn)	ppm	1.48	5.33	3.37	0.42

Table 3: Percent Distribution of pH, Soil Organic Carbon and micronutrients with reference to soil fertility in Minapur, Kanti and Marwan Block of Muzaffarpur district, Bihar.

Soil parameters	Class	Limit	No. of sample	Distribution (%)
	Acidic	<6.5	0	0%
pH	Neutral	6.5-7.5	0	0%
	Alkaline	>7.5	100	100%
Soil Organic Carbon (%)	Low	<0.5	18	45%
	Medium	0.5-0.75	16	40%

	High	>0.75	6	15%
	Low	<0.6	39	97.5%
DTPA-Zinc (ppm)	Medium	0.6-1.8	1	2.5%
	High	>1.8	0	0%
	Low	<4.5	15	37.5%
DTPA-Iron (ppm)	Medium	4.5-9	13	32.5%
	High	> 9	12	30%
	Low	<0.2	28	70%
DTPA-Copper (ppm)	Medium	0.2-0.8	11	27.5%
	High	>0.8	1	2.5%
	Low	<3.5	15	37.5%
DTPA-Manganese (ppm)	Medium	3.5 - 5.0	23	57.5%
	High	>4	2	5%

Soil pH and Soil Organic matter (%)

The soil pH is a measure of the soil's acidity or alkalinity and regulates the availability of its nutrients (Neina, 2019). In the present study the soil pH value across the study area was found to be in the alkaline range. Most of the soils were alkaline with a minimum pH value of 7.54 and maximum 8.96 (Table 3). Earlier similar results were also reported by Singh *et al.*, 2012. The high pH showed in the area value may be due to natural systems like mineralogy, climate, weathering, excess use of basic-forming fertilizers, etc. The generating soil fertility thematic map showing the distribution of soil pH in the study area is depicted in Fig 3. The soil map clearly indicates the distribution of pH value greater than 8.0 in northern part of the study area while the remaining area falls under soil pH value 7.5 – 8.0 (Fig. 3.). The similar results were also reported by Tagung *et al.*, (2022a) which is alkaline in nature having pH value more than 7.5.

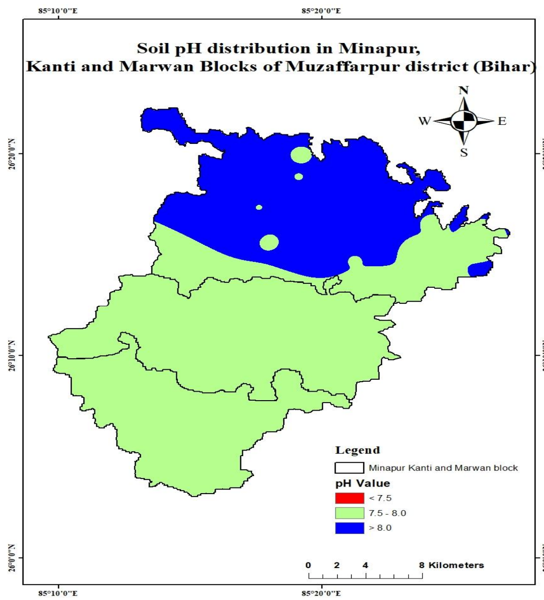

Fig. 3 Soil pH distribution in Minapur, Kanti and Marwan Block of Muzaffarpur district

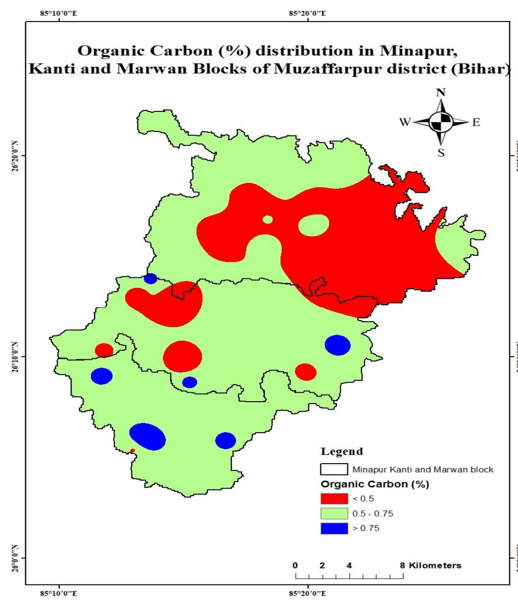

Fig. 4 Organic carbon distribution in Minapur, Kanti and Marwan Block of Muzaffarpur district

Similarly, Soil organic matter is a vital component of soil fertility ranged from 0.20 to 0.98% with a mean value of 0.55% (Table 2). The distribution of organic carbon revealed around 45%, 40% and 15% of the study area considered low, medium, and high organic carbon content respectively (Table 3). The deviation in carbon across the area clearly showed in soil fertility map (fig. 4). The map depicts the wide distribution of organic carbon falls under low content particularly in the north-eastern region, while the remaining study area contains medium organic carbon. The low organic carbon content found in the area may be due to fast decomposition at elevated temperature during summer season rises to 40°C and scanty use of organic residues. Soil organic carbon also obtaining low to medium in a major of sites (Singh, *et.al.*, 2024).

Availability Cationic micronutrients (ppm)

DTPA extractable--Zinc

Micronutrients is an important essential nutrients required in trace quantity and plays very crucial role in plant growth. The DTPA-extractable available zinc cation ranged from 0.14 to 0.79 ppm with the mean value of 0.42 ppm depicted in Table 2. The thematic map showed the spatial distribution of Zn reveals about 97.5% of the study area containing lower about Zn-concentration (Table 3). The deficient content recorded may be due to the intensive growing of crops and imbalanced use of fertilizer. The study site contains low Zn in the region may also be attributed to lower organic carbon content. The zinc status in the study area reflected in the thematic map depicted in Fig. 5. The soil nutrient mapping provided crucial informations for sustainable agricultural practices (Borkotoki, *et al.*, 2024). The finding of the study found around 90% of area falls in low content (Tagung *et al.*, 2022b).

DTPA extractable - Fe

Iron (Fe), while not being a component of chlorophyll, causes chlorosis, which is the yellowing or whitening of leaves when there is a lack of iron. The analysed data regarding iron concentration ranged in the study area varied from 2.21 to 12.01 ppm with a mean value of 6.30 ppm in given the Table 2. The spatial distribution of DTPA-extractable Fe content in the study area is depicted though developed map showed in Fig. 10. The map clearly indicates the medium range of Fe content distributed in majority of the study area while low content observed in patches in the study area (Fig. 6). The low proportion of available iron may be due to the absence of numerous primary and secondary iron minerals, including olivine, siderite, goethite, and magnetite. Proper care must be taken for antagonistic elements of the iron like K, Zn. as low iron availability may end up iron deficiency symptoms in crops.

DTPA extractable -Mn

The status of DTPA extractable manganese (Mn) content in the study area is presented in Table 2 ranged from 1.48 to 5.33 (ppm) with a mean value of 3.37 ppm. The finding also reveals nearly 37.5% and 57.5% of the study area falls under low and medium status few areas recorded about 5% under high manganese content (Table 3). The thematic map showed the distribution of DTPA-Mn cations depicted in Fig.7. The deficient content widespread found in the region may be due to well drained neutral or calcareous soils depicted in Table 2. It can also be attributed to heavy applications of lime and heavy fertiliser dosage in the region. Similar results were also report by Tagung *et al.*, 2022b.

DTPA extractable -Cu

Another micronutrient that is crucial for plant growth and development is copper, which acts as an enzyme activator. The enzyme involved in the oxidation-reduction processes is found in the chloroplasts of leaves. The existence of copper is required for the activity of this enzyme. The available copper (Cu) content in analysed samples varied from 0.21 to 2.36 ppm with the mean value of 0.57 ppm in the investigated area (Table 2). The finding of the study reveals that the majority of the study area falls under low to medium copper concentration (Table 3). Figure 8 depicts the soil fertility map showing the distribution of DTPA-Cu content in the study area. The reason for low Cu content may be due to accumulation of copper over time by the application of sewage sludge, slag and commonly through persistent use of copper-containing fungicides or fertilisers in the region.

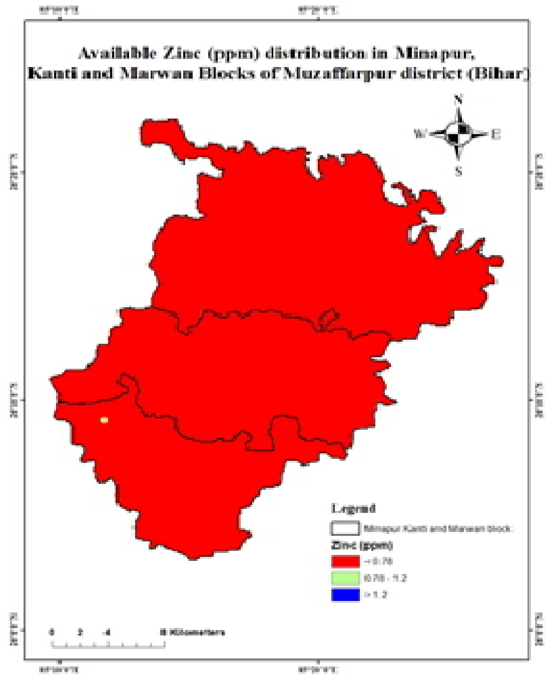

Fig. 5: DTPA-extractable zinc (ppm) distribution in the Minapur, Kanti and Marwan Block of Muzaffarpur district

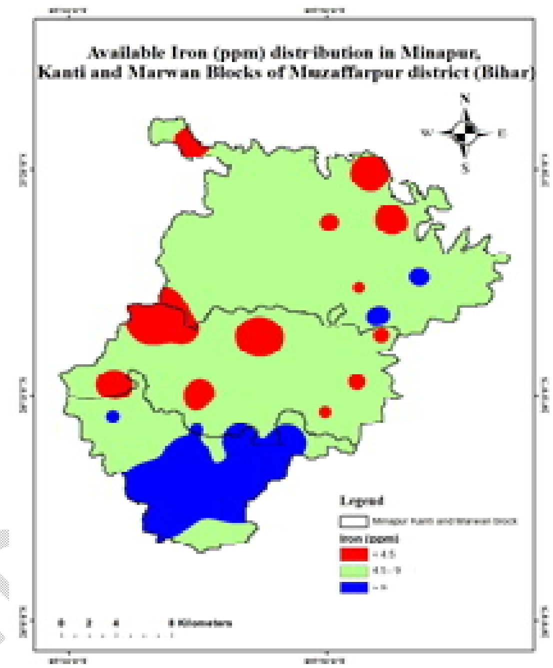

Fig. 6: Distribution of DTPA-Fe (ppm) in the Minapur, Kanti and Marwan Block of Muzaffarpur district

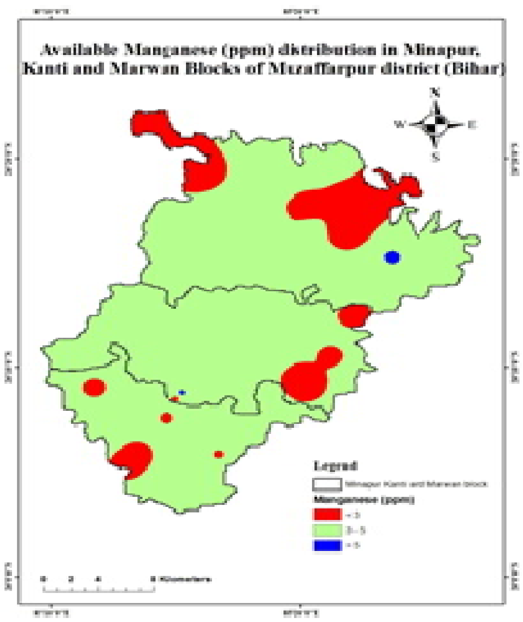

Fig 7: Distribution of DTPA-Mn (ppm) in the Minapur, Kanti and Marwan Block of Muzaffarpur district

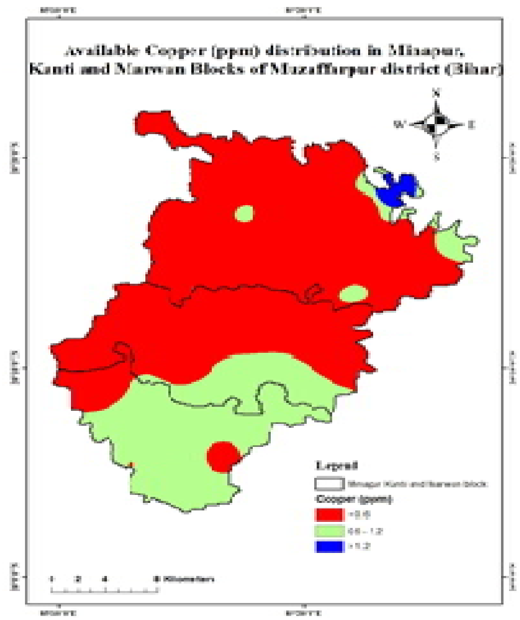

Fig. 8: Distribution of DTPA-Cu (mg/kg) in the Minapur, Kanti and Marwan Block of Muzaffarpur district

CONCLUSION

The conclusion is made on the results of the study area that the soils of Minapur, Kanti and Marwan Block under Muzaffarpur district of Bihar has showed the status of various soil properties and nutrients like organic carbon low to medium category. Soil pH was found to be under strongly alkaline in soil reaction while, micronutrients in the most of the area. Among micronutrients the zinc, and copper content was found deficit in the region while manganese and iron were found to be in medium content. In order to attain the highest degree of crop production, the soils in the research area need to receive the right care and balanced fertilisation.

RECOMMENDATIONS:

The potential recommendations based on the study are as below:

1. Balanced Fertilizer Application: Given the low levels of Zinc and Copper in the study area, it is essential to recommend micronutrient-enriched fertilizers to address the deficiencies, particularly Zinc and Copper, to improve crop productivity. Encourage farmers to use site-specific nutrient management, applying fertilizers based on soil test results rather than blanket applications.

2. Organic Matter Enrichment: Promote the use of organic amendments like compost, farmyard manure or green manures to enhance soil organic carbon levels, which were found to be low to medium in much of the study area. Train farmers on incorporating organic residues into the soil after harvest and rotating crops with legumes to boost organic matter.

3. Soil pH Management: Implement liming practices or soil conditioners to address the strongly alkaline soils, which may limit the availability of essential nutrients like Iron and Phosphorus. Offer guidelines to farmers on selecting suitable crops that can tolerate alkaline conditions or suggest amendments to lower soil pH, such as sulphur or gypsum.

4. Micronutrient Supplementation: Regularly supplement soils with micronutrients like Zinc and Copper, particularly in the areas identified as deficient, to prevent yield losses and improve crop quality. Introduce government or NGO-supported micronutrient distribution programs to provide affordable nutrient solutions to farmers.

5. Adopt Precision Agriculture Technologies: Encourage the adoption of precision agriculture tools like GIS and GPS for continuous monitoring of soil health and tailored nutrient management strategies. Collaborate with agricultural institutions to provide training on using GPS and GIS tools for creating fertility maps and managing nutrient variability.

6. Capacity Building and Training: Establish training programs to educate farmers about soil testing, balanced fertilization, and the benefits of using organic inputs to maintain long-term soil fertility. Organize regular workshops and field demonstrations in collaboration with agricultural universities and local extension services.

7. Long-Term Soil Monitoring: Implement regular soil testing and mapping every 2-3 years to monitor changes in soil fertility and adjust nutrient management practices as needed. Encourage government agencies to subsidize soil testing services to ensure wider access for farmers.

8. Collaborative Research: Promote collaborative research between agricultural universities and local farmers to develop customized soil fertility management practices that are suitable for specific regions. Support partnerships between farmers, academic institutions and policymakers to design site-specific nutrient solutions based on geospatial soil data. By implementing these recommendations, farmers can optimize soil fertility, enhance crop production and ensure sustainable land use for future generations.

FUTURE SCOPE OF STUDY

The nutrients status particularly the micronutrients which affects food security and livelihood, is influenced by the management of nutrients and soil fertility. Determination of available soil micronutrients in the different blocks of Muzaffarpur district and research could help farmers, researchers and students. Furthermore, this study can potentially serve as a basis for sustainable soil management, integrated plant nutrient management, land use planning and site-specific nutrient management in near future. Suggest future studies could explore deeper soil layers (beyond the top 0-20 cm) or focus on a broader range of nutrients or trace elements and also it would be better to mention the potential for long-term monitoring using GIS technologies to track changes in soil health over time.

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