Journal of Scientific Research and Reports

Volume 30, Issue 11, Page 155-165, 2024; Article no.JSRR.125296
ISSN: 2320-0227

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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jsrr/2024/v30i112543

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Cite as: *Singh, Sanjay Kumar, Techi Tagung, Ajeet Kumar, Pankaj Singh, Harendra Singh, Sumedh R. Kashiwar, Sanjay Tiwari, A.K. Singh, Shweta Kumari, and Y. V. Singh. 2024. "Geo Spatial Assessment and Micronutrient Mapping of Calcareous Soils in Muzaffarpur District, Bihar, India". Journal of Scientific Research and Reports 30 (11):155-65. https://doi.org/10.9734/jsrr/2024/v30i112543.*

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/125296

Original Research Article

Received: 17/08/2024
Accepted: 24/10/2024
Published: 28/10/2024

ABSTRACT

The soil fertility maps created using GIS are valuable tools, with the geo-coordinates of soil samples recorded using a Garmin GPS device and then imported into the base map through ArcGIS software. The analyzed soil fertility data covers sampling sites in the Minapur, Kanti, and Marwan blocks of Muzaffarpur district, Bihar. A total of 40 geo-referenced composite soil samples were collected from various locations, with multiple soil fertility parameters assessed using standard prescribed methods. The results indicated that the soil had an alkaline reaction, with a pH value above 7.5. The soil organic content ranged from low to medium. DTPA-extractable available zinc (Zn) levels varied between 0.14 and 0.79 ppm, with an average of 0.42 ppm. Copper (Cu) levels were below the critical limits, while iron (Fe) and manganese (Mn) were found in relatively medium concentrations.

Keywords: Soil fertility maps; GPS; muzaffarpur; micro nutrients; GIS.

1. 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, GIS and 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.

Soil, the foundation of all life, is one of the most essential and valuable natural resources (Das *et al*., 2020). Its fertility is influenced by land use and soil management practices, which can vary significantly from one field to another (Sun *et al.,* 2003). Maintaining soil fertility is crucial for sustainable crop production, achieved through effective nutrient management (Sinha *et al.,* 2024). Fertility management based on soil testing has proven to be a successful strategy for enhancing the productivity of agricultural soils, which often exhibit significant spatial variability due to a mix of physical, chemical, and biological factors. This approach is particularly effective for soils with high degrees of spatial variability (Meena *et al*., 2024). The fundamental indicators of soil fertility include physical characteristics such as texture, structure, and color, along with factors like pH, organic matter content, primary and secondary nutrients, and micronutrients (such as boron, iron, zinc, copper, and manganese) (Brady and Weil, 2002). Understanding soil fertility is crucial for developing effective soil management strategies that enhance crop cultivation (Kumar, 2015; Upadhyay et al., 2020). Emerging tools like GPS and GIS-based remote sensing offer valuable insights into assessing the spatial variability of soil. GIS is used to collect, store, retrieve, transform, and display spatial data. Thematic maps related to agriculture, generated through GPS, play a crucial role in developing site-specific nutrient management strategies (Hemalatha et al., 2020). Among the various technologies emerging for studying natural resources, remote sensing and GIS are particularly effective. Thematic maps generated through these technologies reflect soil fertility levels. Additionally, GIS-based soil fertility maps for precision agriculture serve as valuable decision support tools for addressing resource management challenges (Habibie et al., 2021). The current study aimed to assess the soil fertility status, particularly concerning micronutrients, and to create soil fertility maps for micronutrients using remote sensing and GIS. This research focused on the Minapur, Kanti, and Marawan blocks of Muzaffarpur district in Bihar. Integrating GIS and GPS in soil management is crucial for optimizing agricultural productivity, reducing environmental impacts, and promoting the sustainable use of agricultural lands.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

The study area is located in the Minapur, Kanti, and Marawan blocks of Muzaffarpur district in Bihar. The study area lies between 26.050475° to 26.371451° North Latitude and 84.160084° to 85.452076° East Longitude. This region is characterized by diverse agricultural practices and varying soil types, making it an ideal setting for assessing soil fertility and micronutrient levels. The geographical features and climatic conditions of this area contribute to its agricultural productivity, providing a unique opportunity to evaluate the effectiveness of remote sensing and GIS technologies in soil management. The average annual rainfall in the study area for the year 2021 was approximately 1,830 mm, with about 85% of this precipitation occurring during the monsoon season. The majority of rainfall is received from the southwest monsoon during the summer months, while a smaller amount comes from the northeast monsoon during winter. The summer season in the study area extends from April to June and is characterized by extremely hot and humid conditions, with temperatures reaching up to 40°C. In contrast, winter lasts from mid-November to March, with temperatures ranging from 6°C to 20°C. The location of the study area is illustrated in Fig. 1.

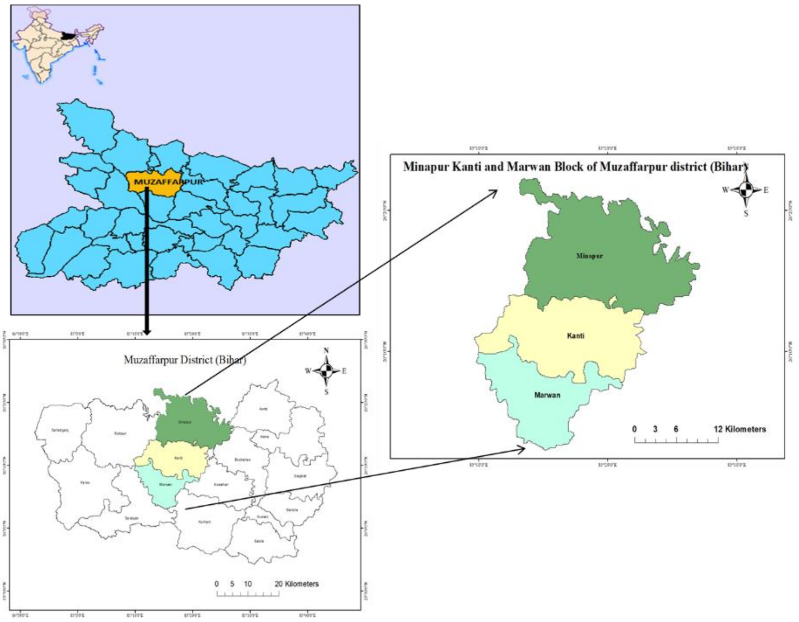

Fig. 1. Location map of the study area (Minapur, Kanti and Marawan) in Muzaffarpur district

2.2 Soil Sampling

The soil survey was conducted systematically using field sampling techniques. Soil sampling locations were determined based on various factors, including land system units, soil morphology, land use conditions, and geological characteristics. GPS instruments were utilized to accurately identify specific soil sampling points. Locations that best represented the different units of morphology, land systems, land use, and geological features were selected for soil sampling. Soil samples collected along with GPS data can facilitate informed decision-making regarding nutrient management. The soil sampling was done to ensure that each land type was adequately represented. A total of 40 soil samples were collected from the study area (Minapur, Kanti, and Marawan) in Muzaffarpur district, Bihar, at a depth of 0-20 cm for laboratory analysis of various soil parameters. The collected soil samples were air-dried, ground using a wooden pestle and mortar, and then sieved through a 2 mm sieve for leveling and storage. Thematic maps depicting the available nutrient status were created by categorizing the fertility levels as low, medium, and high, accompanied by an appropriate legend for organic carbon. The geo-coordinates of the sampling locations were recorded using a handheld GPS device and imported into a GIS environment for the creation of thematic soil fertility maps. Locations of the sampling points are represented in Fig. 2.

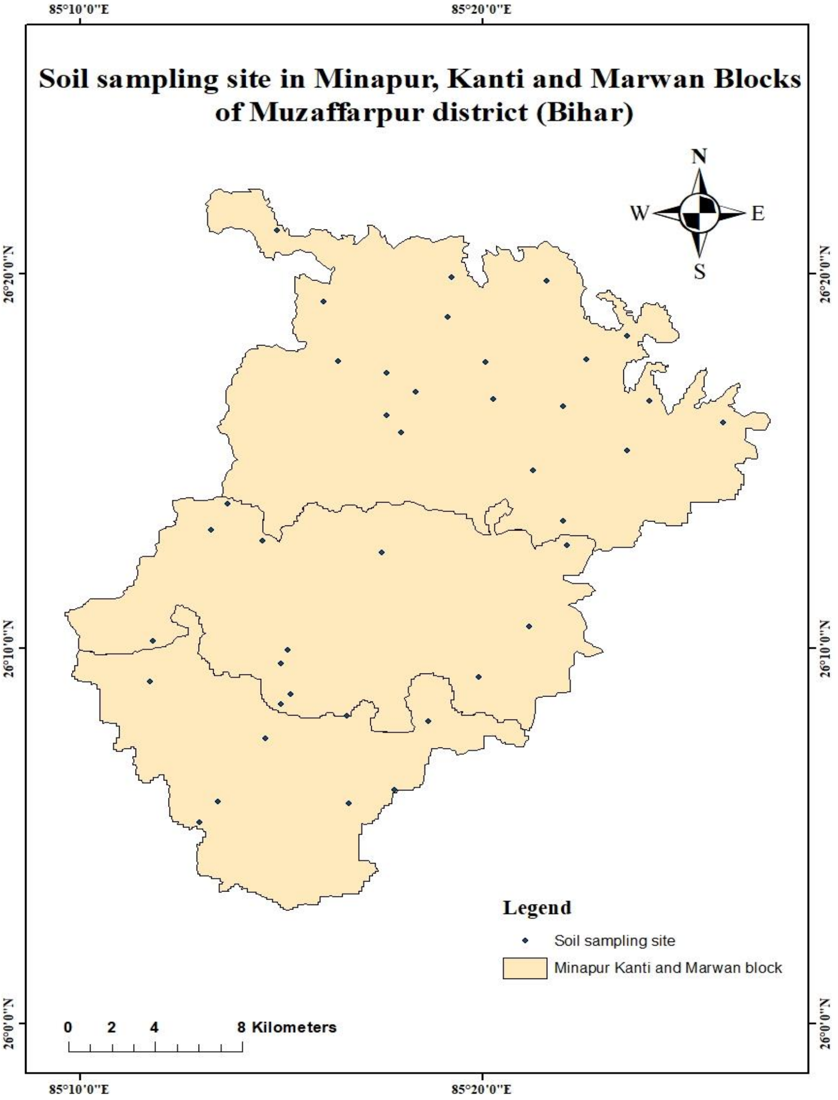

Fig. 2. Soil sampling location points in Minapur, Kanti and Marwan block of Muzaffarpur

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

2.3 Soil Analysis in Laboratory

The collected soil samples from the field were air-dried, ground with a wooden pestle and mortar, and then sieved through a 2 mm sieve. The samples were levelled, stored, and used for laboratory analysis of various soil parameters, including soil pH, organic matter, and micronutrients such as manganese, copper, iron, and zinc. For the assessment of soil parameters, the following prescribed standard methods were employed, as summarized in Table 1.

Creation of thematic soil fertility maps for micronutrients: Soil maps were created using GIS (ArcGIS 10.8.2). The geo-coordinates of the sampled soil locations were recorded with a Garmin GPS device and then imported into the base map in ArcGIS software. The ArcGIS software utilized the World Geodetic System 1984 (WGS84) as the reference coordinate system for locating and geo-referencing the sampling locations within the GIS environment. Using the Arc Toolbox, data interpolation was performed. The latitude and longitude information, along with the soil physicochemical parameters, was imported into the base map in ArcGIS. The thematic soil fertility maps were classified according to the results of the soil analysis. Microsoft Excel and SPSS software were used for conducting descriptive statistics on the soil parameters.

3. RESULTS AND DISCUSSION

The samples were collected for the analysis of various soil parameters, including pH, electrical conductivity, organic matter, available nitrogen, phosphorus, potassium, sulphur, and micronutrients. The soil fertility status and data variability from the laboratory analysis are summarized in Tables 2 and 3.

Soil pH and Soil Organic Matter (%): Soil pH is a measure of the soil's acidity or alkalinity, which plays a key role in regulating the availability of nutrients (Neina, 2019). In the current study, the soil pH values across the study area were found to fall within the alkaline range. Most soils were alkaline, with a minimum pH value of 7.54 and a maximum of 8.96 (Table 3). Similar findings were previously reported by Singh et al. (2012) and Kiran et al. (2021). The high pH values observed in the area may be attributed to natural factors such as mineralogy, climate, weathering, and the excessive use of base-forming fertilizers. A thematic map illustrating the distribution of soil pH across the study area is shown in Fig. 3. The soil map clearly shows that pH values greater than 8.0 are predominantly distributed in the northern part of the study area, while the remaining areas have soil pH values ranging between 7.5 and 8.0 (Fig. 3). Similar results were also reported by Tagung et al. (2022a) and Reddy et al. (2021), where the soils were found to be alkaline, with pH values exceeding 7.5.

Similarly, soil organic matter is a crucial component of soil fertility, ranging from 0.20% to 0.98%, with a mean value of 0.55% (Table 2). The distribution of organic carbon indicated that approximately 45% of the study area had low

Table 2. Micro-nutrient Content of Minapur, Kanti, and Marwan Blocks 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 in Relation to Soil Fertility in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District, Bihar

Soil parameters	Class	Limit	No. of sample	Distribution (%)
pH	Acidic	<6.5	0	0%
	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%
DTPA-Zinc (ppm)	Low	<0.6	39	97.5%
	Medium	0.6-1.8	1	2.5%
	High	>1.8	0	0%
DTPA-Iron (ppm)	Low	<4.5	15	37.5%
	Medium	4.5-9	13	32.5%
	High	> 9	12	30%
DTPA-Copper (ppm)	Low	<0.2	28	70%
	Medium	0.2-0.8	11	27.5%
	High	>0.8	1	2.5%
DTPA-Manganese (ppm)	Low	<3.5	15	37.5%
	Medium	3.5 - 5.0	23	57.5%
	High	>4	2	5%

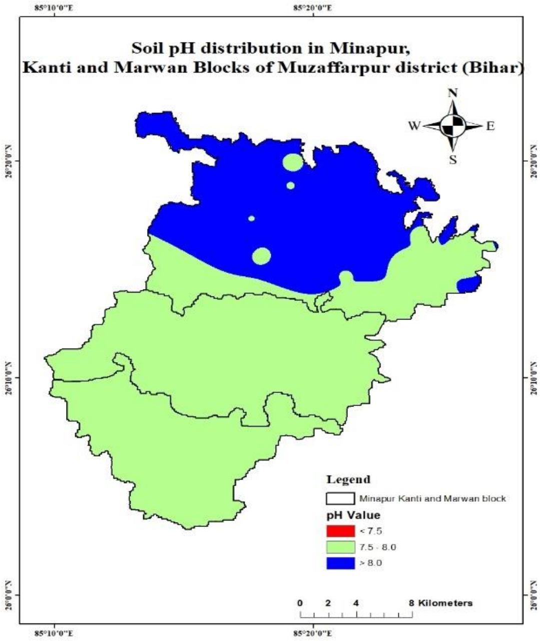

Fig. 3. Soil pH Distribution in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District

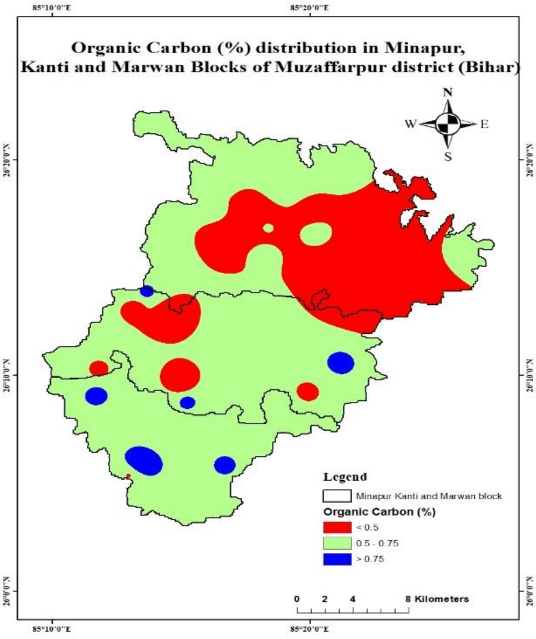

Fig. 4. Organic Carbon Distribution in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District

organic carbon content, 40% had medium, and 15% had high organic carbon content, as shown in Table 3. The variation in carbon content across the area is clearly illustrated in the soil fertility map (Fig. 4). The map shows that the north-eastern region exhibits a wide distribution of low organic carbon content, while the rest of the study area predominantly contains medium organic carbon levels. The low organic carbon content in this area may be attributed to rapid decomposition due to high summer temperatures, which can reach up to 40°C, as well as limited use of organic residues. Additionally, soil organic carbon levels are found to be low to medium in many sites, as noted by Singh *et al*. (2024).

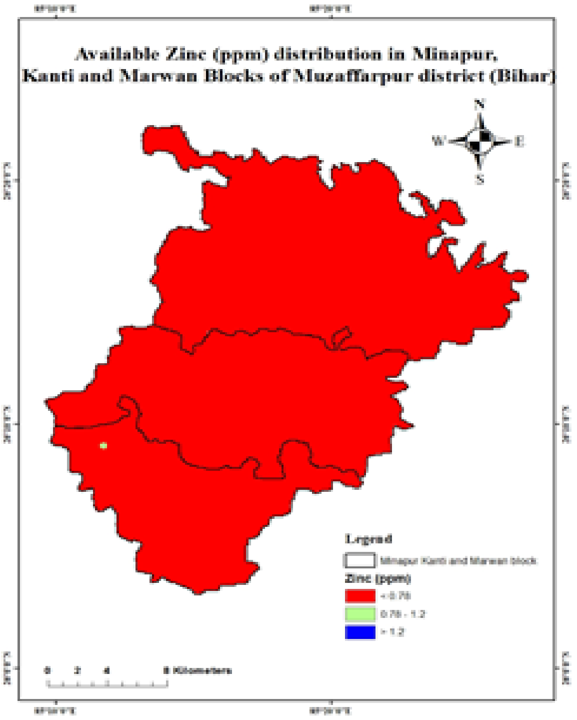

Fig. 5. Distribution of DTPA-Extractable Zinc (ppm) in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District

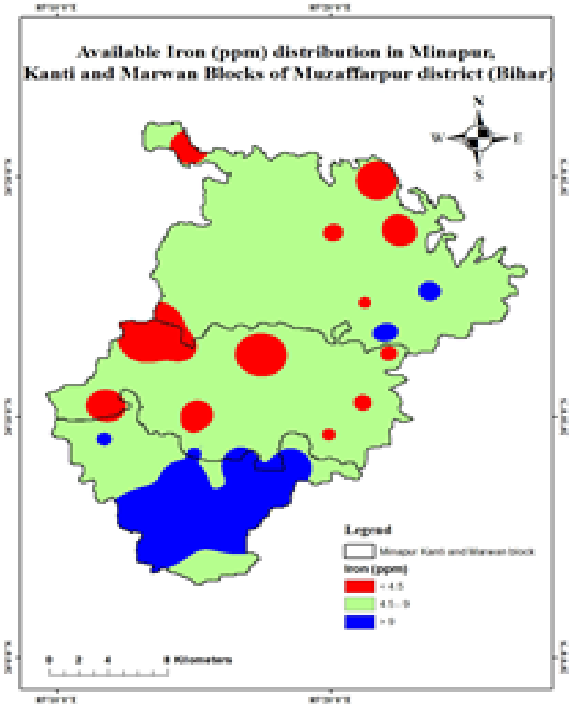

Fig. 6. Distribution of DTPA-Extractable Iron (Fe) (ppm) in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District

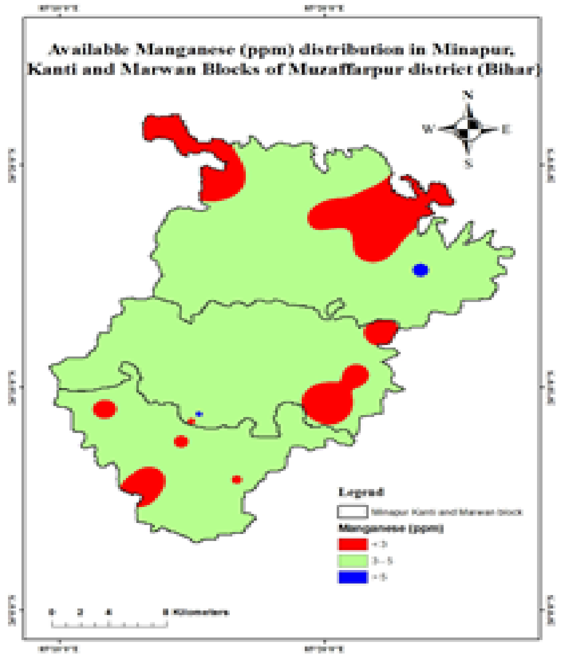

Fig. 7. Distribution of DTPA-Extractable Manganese (Mn) (ppm) in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District

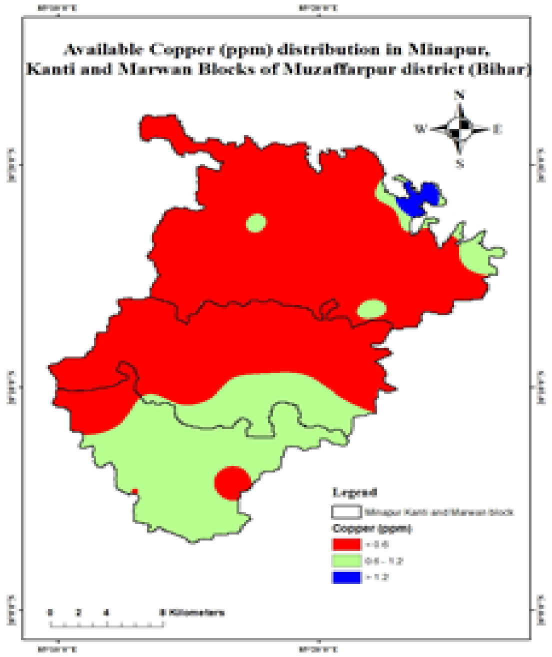

Fig. 8. Distribution of DTPA-Extractable Copper (Cu) (mg/kg) in Minapur, Kanti, and Marwan Blocks of Muzaffarpur District

3.1 Availability of Cationic Micronutrients

DTPA extractable—Zn: Micronutrients are essential nutrients required in trace amounts and play a crucial role in plant growth. The DTPA-extractable available zinc concentration ranged from 0.14 to 0.79 ppm, with a mean value of 0.42 ppm, as shown in Table 2. The thematic map illustrates the spatial distribution of zinc (Zn), indicating that approximately 97.5% of the study area has low Zn concentrations (Table 3). This deficiency may be attributed to the intensive cultivation of crops and the imbalanced use of fertilizers. The low zinc levels in the region may also be linked to the lower organic carbon content. The zinc status in the study area is reflected in the thematic map presented in Fig. 5. Soil nutrient mapping provides critical information for sustainable agricultural practices (Borkotoki *et al*., 2024). Additionally, the findings of the study indicate that around 90% of the area falls within the low zinc content category (Tagung *et al*., 2022b).

DTPA extractable – Fe: Iron (Fe), although not a component of chlorophyll, can lead to chlorosis, which is characterized by the yellowing or whitening of leaves due to iron deficiency. The analyzed data for iron concentration in the study area ranged from 2.21 to 12.01 ppm, with a mean value of 6.30 ppm, as shown in Table 2. The spatial distribution of DTPA-extractable Fe content in the study area is illustrated in the map presented in Fig. 6. This map clearly indicates that medium levels of Fe are distributed throughout the majority of the study area, while low Fe content is observed in patches across the region (Fig. 6). The low levels of available iron may be attributed to the absence of various primary and secondary iron minerals, such as olivine, siderite, goethite, and magnetite. It is important to manage antagonistic elements such as potassium (K) and zinc (Zn), as low iron availability can lead to iron deficiency symptoms in crops.

DTPA extractable -Mn: The status of DTPA-extractable manganese (Mn) content in the study area, as presented in Table 2, ranged from 1.48 to 5.33 ppm, with a mean value of 3.37 ppm. The findings reveal that approximately 37.5% of the study area falls under low manganese status, while 57.5% is categorized as medium, with a few areas (about 5%) recorded as having high manganese content (Table 3). The thematic map illustrating the distribution of DTPA-extractable Mn is depicted in Fig. 7. The widespread deficiency in manganese may be due to well-drained neutral or calcareous soils, as indicated in Table 2. This deficiency can also be attributed to heavy applications of lime and high fertilizer usage in the region. Similar results were reported by Tagung *et al*. (2022b).

DTPA extractable -Cu: Copper is another crucial micronutrient for plant growth and development, acting as an enzyme activator. The enzymes involved in oxidation-reduction processes are located in the chloroplasts of leaves, and the presence of copper is essential for their activity. In the analyzed samples, the available copper (Cu) content ranged from 0.21 to 2.36 ppm, with a mean value of 0.57 ppm in the investigated area (Table 2). The study's findings indicate that the majority of the study area falls within the low to medium copper concentration categories (Table 3). Fig. 8 illustrates the soil fertility map, showing the distribution of DTPA-extractable Cu content in the study area. The low copper content may be attributed to the accumulation of copper over time due to the application of sewage sludge, slag, and the frequent use of copper-containing fungicides or fertilizers in the region.

4. CONCLUSION

The conclusion drawn from the study indicates that the soils of the Minapur, Kanti, and Marwan Blocks in the Muzaffarpur District of Bihar exhibit various soil properties and nutrient statuses, with organic carbon levels falling within the low to medium range. The soil pH was found to be strongly alkaline, while most areas showed deficiencies in certain micronutrients. Specifically, zinc and copper were identified as deficient, whereas manganese and iron were present in medium concentrations. To achieve optimal crop production, it is essential for the soils in the research area to receive appropriate management and balanced fertilization.

5. 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.

6. 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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ACKNOWLEDGEMENT

The author(s) gratefully acknowledge the Department of Soil Science, Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India for providing the research facilities for this research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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