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Geospatial Analysis of Soil Fertility in Muzaffarpur District, Bihar, India: Integrating GPS and GIS Technologies

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Authors' contributions

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

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ABSTRACT

The soil fertility maps generated using Global Positioning System (GPS) and Geographic Information Systems (GIS) serve as crucial tools for effective nutrient management decision-making. However, soil fertility data for the Minapur, Kanti, and Marwan blocks of Muzaffarpur district, Bihar, India was found to be insufficient. Therefore, a soil fertility inventory research was conducted in these three blocks to create thematic soil fertility maps. A total of 40 geo-referenced composite soil samples were collected from various locations within the study area using a handheld GPS device. The processed soil samples were analyzed for various soil fertility parameters using standard methods. Soil nutrient status and fertility maps were then created using ArcGIS software with Inverse Distance Weighted (IDW) interpolation techniques. The results clearly indicated that the soil reaction was alkaline, with a pH value exceeding 7.5. The content of soil organic matter, potassium, and sulphur was found to be low to medium, while available nitrogen and phosphorus levels were recorded as very low in these blocks. Finally it is concluded that the study generated thematic soil fertility maps for Minapur, Kanti, and Marwan blocks of Muzaffarpur district, Bihar, revealing alkaline soil with low to medium organic matter, potassium, and sulphur and very low nitrogen and phosphorus levels.

Keywords: GIS; GPS; Muzaffarpur; soil fertility maps.

1. INTRODUCTION

As the wellspring of all life, soil is the most important and valuable natural resource [1]. Land use and soil management strategies have an impact on soil fertility, which varies spatially from field to field [2,3]. Maintaining soil's fertility status is necessary for sustainable crop production through efficient nutrient management [4,5]. 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 [6-9]. Soil test based fertility management is an effective tool for a agricultural soils that have high degree of spatial variability [10]. 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 [11]. Understanding the state of the soil's fertility is essential for creating effective soil management plans that support crop cultivation design [12,13]. 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 [14]. Agriculture-related thematic maps (soil fertility, land usage, land cover, soil erosion *etc.*) generated through GPS tool aids immensely in developing site-specific nutrient management strategies [15]. Among the technologies, emerging for the study natural resources, remote sensing and GIS are effective technologies for detecting, assessing, mapping and monitoring the land degradation. A thematic map generated which reflecting the level of fertility. Moreover, Geographic Information Systems (GIS)-based soil fertility maps for precision agriculture also serves as a decision support tool for solving resource management issues like land management, soil erosion, soil degradation, water quality, and urban planning [16]. The present study was undertaken to assess the soil fertility status and to generate soil fertility maps using remote sensing (RS) and GIS for Minapur, Kanti and Marawan blocks of Muzaffarpur district of Bihar.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

The study area Minapur, Kanti and Marwan is situated in the North-Central of Muzaffarpur district of Bihar, India. 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.

2.2 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 and available N, P and K. 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.

2.3 Laboratory Soil Analysis

Soil samples collected from the field were air dried in shade and thereafter processed samples were taken various soil parameters that include soil pH, organic matter, available nitrogen, phosphorus, potassium and sulphur using the processed following standard method are summarised in Table 1.

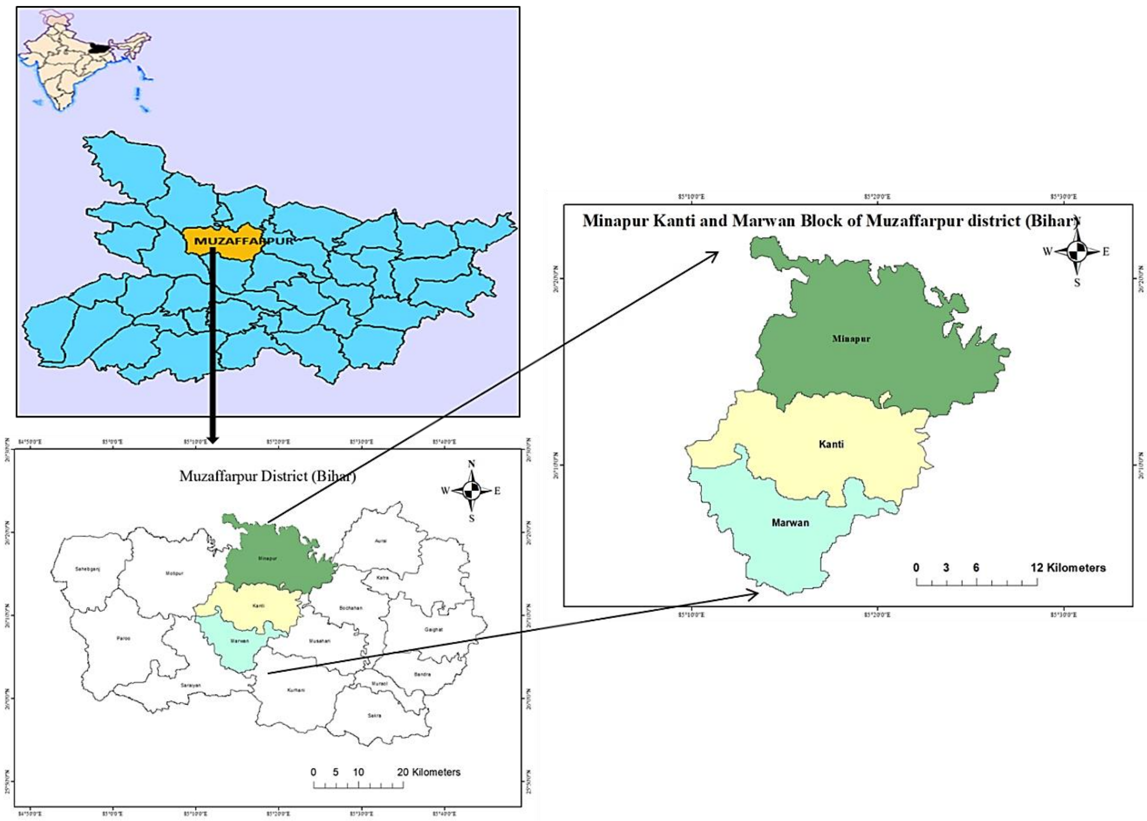

Fig. 1. Location map of the study area (Minapur, Kanti and Marwan) in Muzaffarpur district

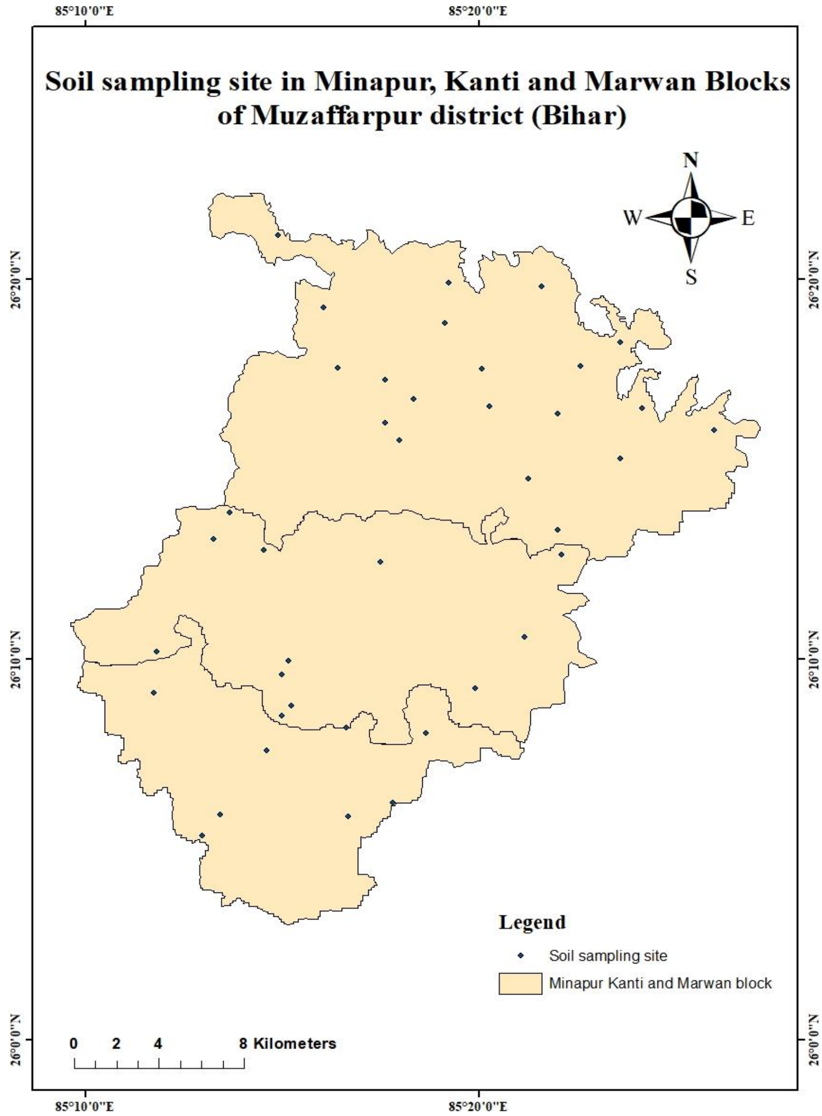

Fig. 2. Location of soil sampling points in Minapur, Kanti and Marwan block of Muzaffarpur

Table 1. Soil test parameters and methods used for analysis

Soil test parameters	Methods	Reference
pH	Glass electrode pH meter	[17]
Organic carbon (%)	Wet oxidation method	[6]
Available Nitrogen (kg ha^{-1})	Alkaline KMnO4 method	[18]
Available Phosphorus (kg ha^{-1})	Olsen's method	[19]
Exchangeable Potassium (kg ha^{-1})	Ammonium Acetate method	[20]
Available Sulphur (kg ha^{-1})	Calcium chloride method	[21]

2.4 Soil Fertility Mapping

The location coordinates of each soil collected sample were recorded in a Garmin GPS device and the geo-coordinates were imported to the base map in ArcGIS software. GPS & GIS technologies i.e. the global positioning system and geographical information system are widely utilized to delineate fertility maps of soil nutrients. The 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 kriging interpolation technique is based on regression of observed Z-value of point data and weighted mean as per spatial covariance. The interpolation observes the values of unsampled variables from sampled variables. The latitude and longitude information along with the soil Physico-chemical parameters were imported to the base map in ArcGIS. The ordinary kriging interpolation method was used to generate the soil fertility maps. The thematic soil fertility maps were classified as per soil analysis results.

3. RESULTS AND DISCUSSION

Collected soil samples were subjected for analysis of pH, electrical conductivity, organic matter, available nitrogen, phosphorus, potassium, and sulphur. The status of soil fertility and percent distribution obtained from laboratory analysis are summarised in Tables 1 and 2.

3.1 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 [22]. 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 2). Earlier similar results were also reported by Singh et al., [23]. 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. [24] which is alkaline in nature having pH value more than 7.5.

Table 2. Soil fertility status of Minapur, Kanti and Marwan Block in Muzaffarpur district of Bihar

Sl. No.	Soil parameters	Minimum	Maximum	Mean	Standard Deviation
1	pH	7.54	8.96	7.92	0.28
2	Soil Organic Carbon (%)	0.20	0.98	0.55	0.10
3	Available Nitrogen (kg ha^{-1})	201.8	279.9	237.5	9.96
4	Available Phosphorus (kg ha^{-1})	3.22	17.3	10.9	1.69
5	Available Potassium (kg ha^{-1})	88.8	684.6	199.4	52.4
6	Available Sulphur (kg ha^{-1})	7.20	25.18	12.54	1.54

Table 3. Percent distribution of soil fertility in Minapur, Kanti and Marwan Block of Muzaffarpur district

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%
Available Nitrogen (kg ha^{-1})	Low	<280	39	97.5%
	Medium	280-560	1	2.5%
	High	>560	0	0%
Available Phosphorus (kg ha^{-1})	Low	<14	35	87.5%
	Medium	14-28	5	12.5%
	High	>28	0	0%
Available Potassium (kg ha^{-1})	Low	<150	11	27.5%
	Medium	150-250	23	57.5%
	High	>250	6	15%
Available Sulphur (kg ha^{-1})	Low	<10	9	22.5%
	Medium	10-20.0	30	75%
	High	>20	1	2.5%

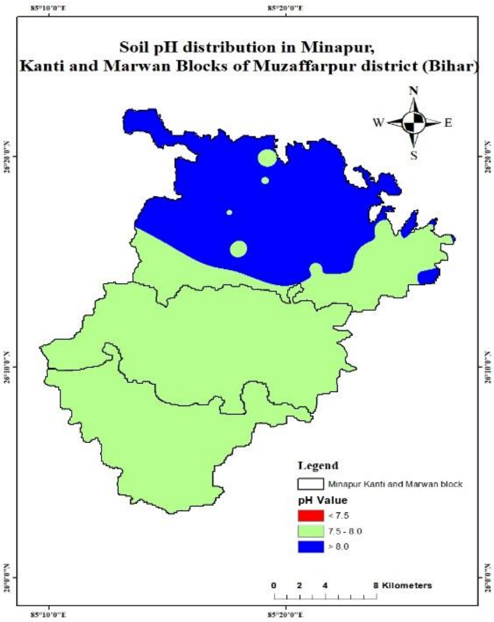

Fig. 3. Soil pH distribution in Minapur, Kanti and Marwan Block of Muzaffarpur district

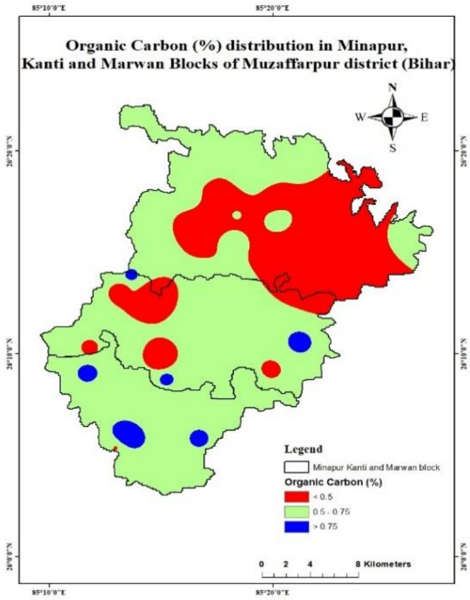

Fig. 4. Organic matter distribution in Minapur, Kanti and Marwan Block of Muzaffarpur district

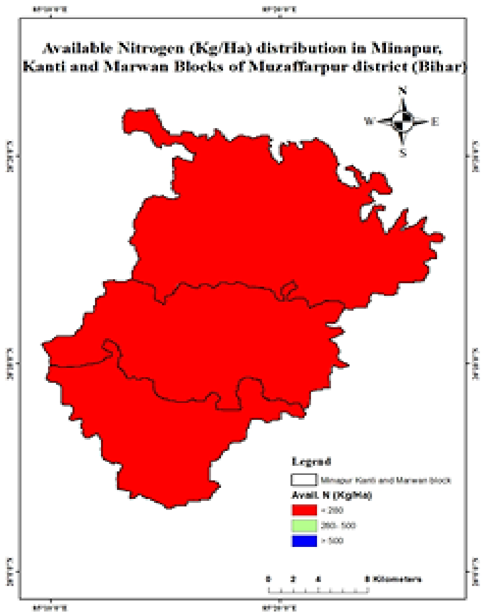

Fig. 5. Distribution of available Nitrogen (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

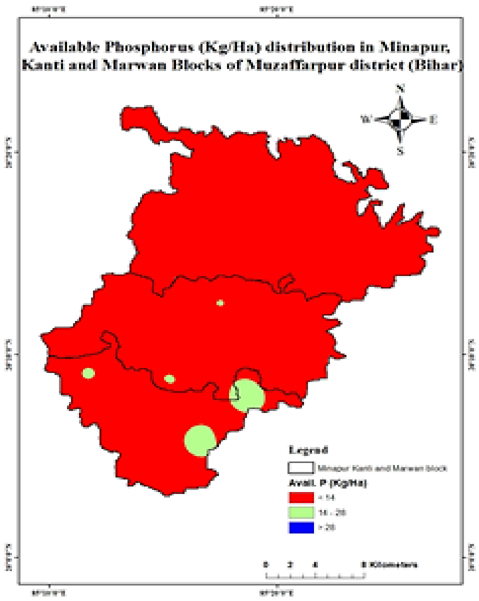

Fig. 6. Distribution of available Phosphorus (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

Similarly, the soil organic matter ranged from 0.20 to 0.98 % with a mean value of 0.55% which is depicted in the Table 1. The study also revealed with respect to spreading of organic carbon content that around 45%, 40% and 15% falls under low, medium, and high organic carbon content respectively (Table 3). The soil fertility map also generated showing the distribution of soil organic carbon covering the entire study area is depicted in Fig. 4. The low distribution of organic carbon distinctly showed in the map covering widespread in the map north-eastern region however, remaining portion of the study area associated with the medium range of organic carbon. Lower organic carbon content obtained in the area might be due to the high rate of organic matter decomposition as the temperature in the summer season rises to 40°C and the restricted use of organic residues. Given its significance in physical, chemical, and biological processes, the distribution of soil organic carbon can be viewed as a key component of the soil.

3.2 Available Nitrogen and Phosphorus (kg ha^{-1})

The assessed available nitrogen content of the study area varied from 201.8 to 279.9 kg/ha with a mean value of 237.5 kg/ha is depicted in the Table 1. The study reveals around 87.5% of samples found to be deficient across the study area in terms of nitrogen content (Table 3).

Few samples falls under medium range which is reveals in the generated soil map was distributed entirely in the study area (Fig. 5). The generated soil fertility map clearly depicting the distribution of soil available nitrogen in the study area in Fig. 5. The low nitrogen content in the study area may be possibly due to low organic matter content in soils as evident from low OC content (Table 2). Similar results were reported by Singh et al., 2019 in rice-wheat growing soils. The nitrogen deficit in the region may also be attributed to crop removal and high temperatures that facilitate faster degradation and removable of organic matter. The variability in soil available phosphorus in the study area ranged from 3.22 to 17.3 (kg/ha) with a mean value of 10.9 kg/ha given in the Table 2. The percentage distribution of nutrients consider in the study area categorized around 87.5% and 12.5% falls under low and medium phosphorus content respectively depicted in the Table 3. The generated soil fertility map of phosphorus reveals that patches in southern region fall under medium P content while the remaining area depicting Phosphorus deficient content. Overall distribution of soil available phosphorus in the study area is depicted in Fig. 6. Low phosphorus availability may be due to poor soil management leading to runoff, precipitation, soil erosion, adsorption and immobilization in the region. Singh et al. [25] also reported the available phosphorus were found in the low to medium range 4.34 to 18.4 (kg ha^{-1}) in this area.

3.3 Available Potassium and Sulphur (kg ha^{-1})

The soil samples were received from the study location, analysed with following standard procedure, the available potassium ranged from 88.8 to 684.6 (kg/ha) with a mean value of 194.4 kg/ha given in the Table 1. The percentage distribution of available K content got around 27.5% and 57.5% which is falls under low and medium potassium content as depicted in Table 2. The higher proportion of low to medium potassium content in the study area justifies that recommended dose of potassium should be reviewed for increasing the production of crops. The thematic map of soil fertility map showing the distribution of soil available potassium across the study area is depicted in Fig. 7. Map of K distribution reveals to available K value of 150 to 250 Kg/ha, covered maximum area (57.5%). It is also showed that the patches in the southern and central region is distributed sparsely with K content lower than 150 kgha^{-1}. The available K content having higher than 250 kgha^{-1} is observed in patches in the southern and eastern region of the study area. Similar results were reported by Singh et al., [25] in rice-wheat growing soils. Low K content in the region may be influenced by the presence of lower amount of clay and soil organic matter in the region which in turn strongly influences the degree of K leaching in soil.

The status of available sulphur content is presented in Table 1. The data regarding available sulphur content in the study area ranged from 7.20 to 25.18 (kgha^{-1}) with a mean value of 12.54 kgha^{-1}given in the Table 1. The finding of the study reveals that around 22.5% and 75% of the study area falls under low and medium sulphur content respectively depicted in Table 3. Similar kind of result has been reported by parmar et al. [26]. Half of the study area falls under medium sulphur content. Tagung et al., [24] also reported the status of available sulphur content ranged from 6.20 to 22.1 (kgha^{-1}) with a mean value of 12.2 kgha^{-1}. The thematic map generated on soil fertility which is showing the distribution of soil available sulphur content in the study area is depicted in Fig. 8. Low status of organic matter might be the cause of lower content of available sulphur in the region. Moreover, sulphur mining also results from overlooking the fact that crops regularly absorb sulphate nutrients from the soils.

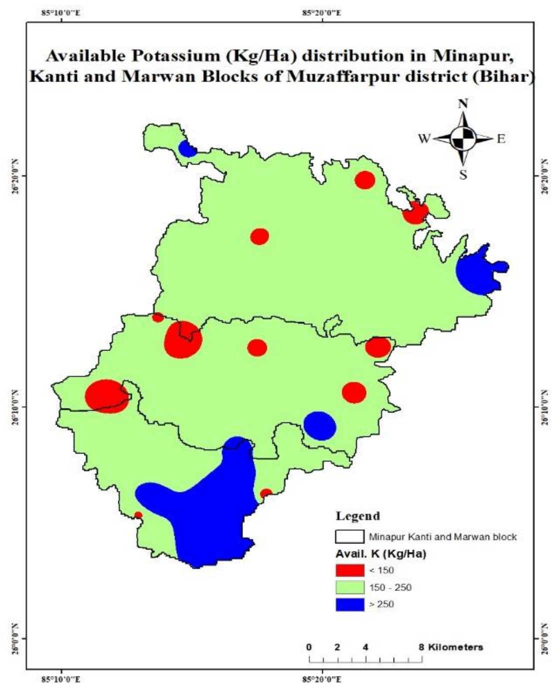

Fig. 7. Distribution of available Potassium (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

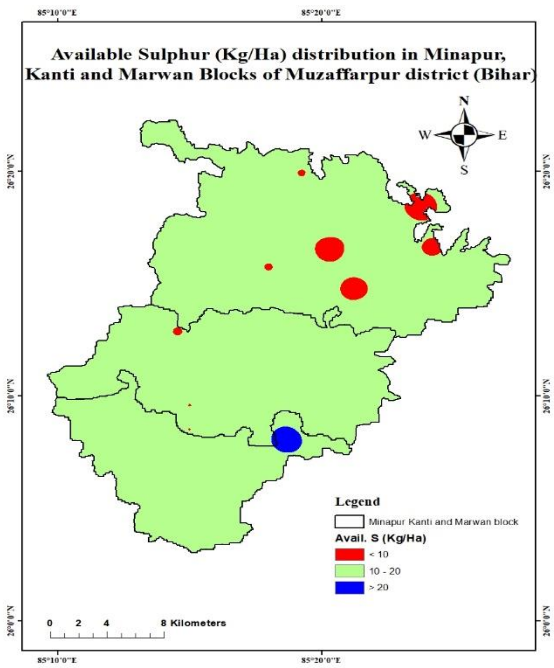

Fig. 8. Distribution of available Sulphur (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

4. CONCLUSION

It is concluded from the above results that the soils of Minapur, Kanti and Marwan Block under Muzaffarpur district of Bihar has showed the status of organic carbon low to medium category however, 97.5 per cent low available nitrogen. Soil pH was found to be under strongly alkaline in soil reaction while the available phosphorus and potassium content was at low and medium level respectively.

5. RECOMMENDATIONS

Based on the soil fertility analysis of Minapur, Kanti and Marwan blocks in Muzaffarpur district, Bihar, the following recommendations are proposed: *Soil pH Management*: Alkaline Soil: Given the predominantly alkaline soil (pH > 7.5), it is recommended to apply soil acidifying amendments such as gypsum or sulphur to lower the pH and enhance nutrient availability. *Organic Matter Enhancement*: Low Organic Carbon: With 45% of samples showing low organic carbon, incorporating organic matter such as compost, green manure and crop residues can improve soil structure and nutrient content. *Nitrogen Management*: Low Available Nitrogen: To address the very low nitrogen levels (97.5% samples), apply nitrogen-rich fertilizers like urea or ammonium sulphate and consider leguminous cover crops to enhance nitrogen fixation. *Phosphorus Management*: Low Available Phosphorus: Given the low phosphorus levels (87.5% samples), use phosphorus fertilizers such as superphosphate or rock phosphate and consider mycorrhizal inoculants to improve phosphorus uptake. *Potassium Management*: Low to Medium Potassium: With 27.5% of samples low and 57.5% medium in potassium, apply potassium fertilizers like muriate of potash (MOP) and integrate potassium-rich organic materials. *Sulphur Management*: Low to Medium Sulphur: To address the sulphur deficiency (22.5% low and 75% medium), apply sulphur-containing fertilizers such as ammonium sulphate or elemental sulphur to the soil. *Regular Soil Testing*: Conduct regular soil testing to monitor changes in soil fertility and adjust fertilizer application rates accordingly to ensure balanced nutrient management. *Integrated Nutrient Management*: Implement integrated nutrient management (INM) practices, combining chemical fertilizers with organic amendments to maintain soil health and fertility sustainably (Sinha et. al., 2024). By addressing these specific nutrient deficiencies and managing soil pH, the fertility and productivity of the soils in these blocks can be significantly improved.

6. FUTURE SCOPE OF STUDY

The future scope of this study in Minapur, Kanti and Marwan blocks of Muzaffarpur district, Bihar, can be expanded in several directions like: *Longitudinal Studies*: Conduct long-term monitoring to assess the impact of implemented soil management practices on soil fertility and crop yields over multiple growing seasons. *Advanced Soil Health Indicators*: Include additional soil health indicators such as microbial activity, enzyme activities and soil biodiversity to gain a comprehensive understanding of soil health. *Precision Agriculture*: Utilize precision agriculture technologies such as remote sensing and drones for real-time monitoring and site-specific soil management, improving efficiency and reducing input costs. *Climate Change Impact*: Study the effects of climate change on soil fertility parameters and develop adaptive soil management strategies to mitigate potential adverse impacts. *Nutrient Cycling and Sustainability*: Investigate nutrient cycling processes and the sustainability of nutrient management practices, focusing on minimizing nutrient losses and environmental impacts. *Soil Amendments and Biochar*: Explore the potential of innovative soil amendments, including biochar, for improving soil fertility, carbon sequestration and overall soil health. *Integrated Crop Management*: Develop integrated crop management practices that incorporate soil fertility data with pest and disease management, irrigation and crop selection to optimize overall farm productivity. *Policy Development*: Use the findings to inform policymakers and contribute to the development of region-specific guidelines and policies for sustainable soil and nutrient management. *Farmer Training and Outreach*: Implement training programs and workshops for local farmers to disseminate knowledge and best practices derived from the study, enhancing community engagement and practical application of research findings. *Collaborative Research*: Foster collaborations with agricultural research institutions, universities and government agencies to expand the scope and scale of soil fertility research and its applications.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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