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Assessment of the spatial distribution of soil nutrients and mapping using GPS and GIS in blocks of Muzaffarpur District, Bihar

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Abstract
Soil fertility is one of the crucial factors which maintain soil production and productivity. A special variability in nutrients through a field can be detected using tools such as soil testing. In order to do that, monitoring work regarding soil fertility inventory research was carried out in the Aurai and Katra block in the Muzaffarpur district of Bihar using GPS and Geographic Information Systems (GIS). A total of 40 (forty) geo-referenced composite soil samples from a depth of 0-20 cm were collected from the various locations of the blocks using a GPS instrument. These soil samples were processed in the laboratory and soil attributes were analyzed prescribed using standard methods of procedures. Based on obtained data regarding soil parameters, a soil map thematic layers were created for block boundaries. Soil fertility maps were created by superimposing block unit polygons and the base map using the standard ordinary Kriging interpolation method. The results indicated that the majority of the soils belong to moderately alkaline in reaction. Soil organic matter values also obtained low to medium in a majority of the soils whereas available nitrogen, phosphorus, and potassium were recorded low in the blocks. In the case of micronutrients, value showed below critical limits.

Keywords: GIS, GPS, Muzaffarpur, ordinary Kriging, soil fertility maps

1. Introduction
Natural resources are considered important components *viz.* soil, land, and water which support agricultural growth and sustain human life quality (Das *et al.* 2020) [3]. Execute planning for better land use through inventory on limited available soil resources. In agricultural soils bearing a high degree of spatial variability, soil test-based fertility management is an efficient technique for determining the soil fertility-related production limits of the study area and suggesting corrective actions for the best crop output. Maintaining sustainable agriculture is the characterization of the soil concerning the assessment of the soil fertility of an area (Singh and Mishra, 2012) [15]. Soil fertility status identification requires maintaining soil productivity for particular crops to implement effective soil management practices (Kavitha and Sujatha, 2015) [8]. Characterizing the soil nutrient status can assist farmers in making decisions on fertilizer management efficiency where occurs nutrient deficiencies (Schröder *et al.*, 2018) [14]. Before the development of new technologies like Global Positioning Systems (GPS) and Geographic Information Systems (GIS), it was challenging to describe the spatial diversity of soil fertility throughout a field. Remote sensing (RS), geographic information systems (GIS), global positioning systems (GPS), and information technology (IT) are examples of contemporary geospatial technologies that have enormous promise for managing and developing soil and water resources (Das, 2004) [4]. Recently, agriculture-related thematic maps, such as those showing soil fertility, land usage, and land cover, have been created using a GPS tool. It aids in developing site-specific nutrient management strategies for the area (Mishra *et al.*, 2013) [10]. To develop solutions to resource management problems like land management, soil erosion, soil degradation, water quality, and urban planning, soil fertility maps based on Geographic Information Systems (GIS) are helpful (Parmar *et al.*, 2022) [13]. The maps of soil fertility produced by GIS can be used as a decision support tool for nutrient management (Habibie *et al.* 2021) [5]. Considering the above discussions, the present study was undertaken to assess the soil fertility status and generate GPS and GIS-based soil fertility maps of Aurai and Katra blocks of Muzaffarpur district of Bihar. The main objective of the study was to prepare a scientific and comprehensive soil map helping in the land use plan of the particular area.

2. Materials and Methods
2.1 Location of the Study Area
The Muzaffarpur district is situated in the North of Bihar consisting of a geographical area of 3122.56 km2 and is located on the Survey of India's 72 B, 72C, 72F, and 72 G degree sheets. The study area Aurai and Katra lies between 26.1639° to 26.3959° North Latitude and 85.4380° to 85.7256° East Longitude. The river mainly Burhi Gandak, Baghmati, and Baya flow across the district. The study area receives annual rainfall on an average of 1187 mm while, 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.

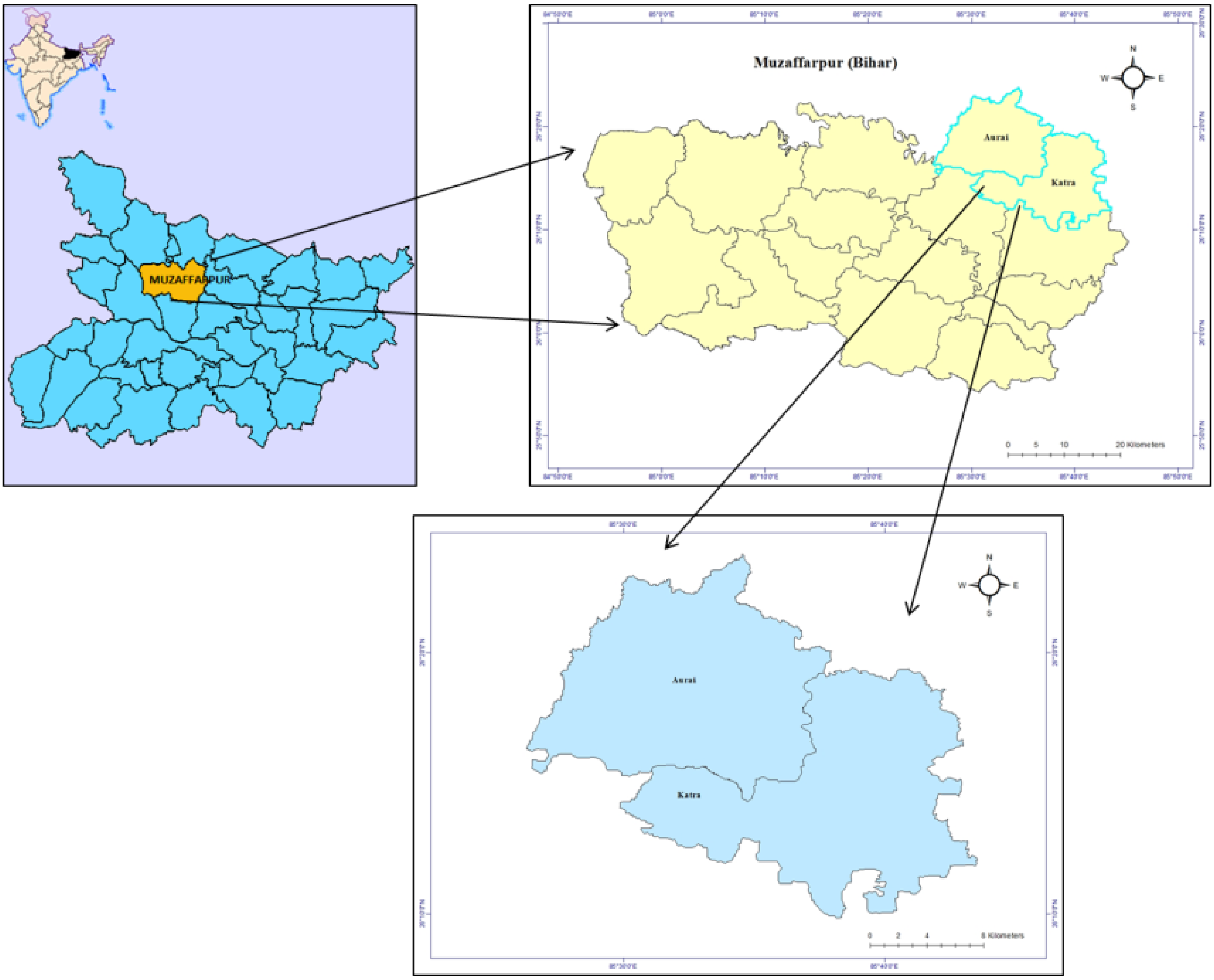

Fig 1: Location map of the study area (Aurai and Katra block) in Muzaffarpur district of Bihar

2.2 Soil Sampling
The soil survey was carried out systematically and scientifically using field sampling. The Global Positioning System (GPS) instrument was widely used to locate particular soil sampling points. The soil sampling locations were decided based on the land system units, morphology, land use condition, geology, etc. The soils were sampled from the places that best represent the various units of the morphology, land system, land use, and geology. 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 two blocks (Aurai and Katra tehsil) of Muzaffarpur district of Bihar for laboratory analysis of various soil parameters. 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.

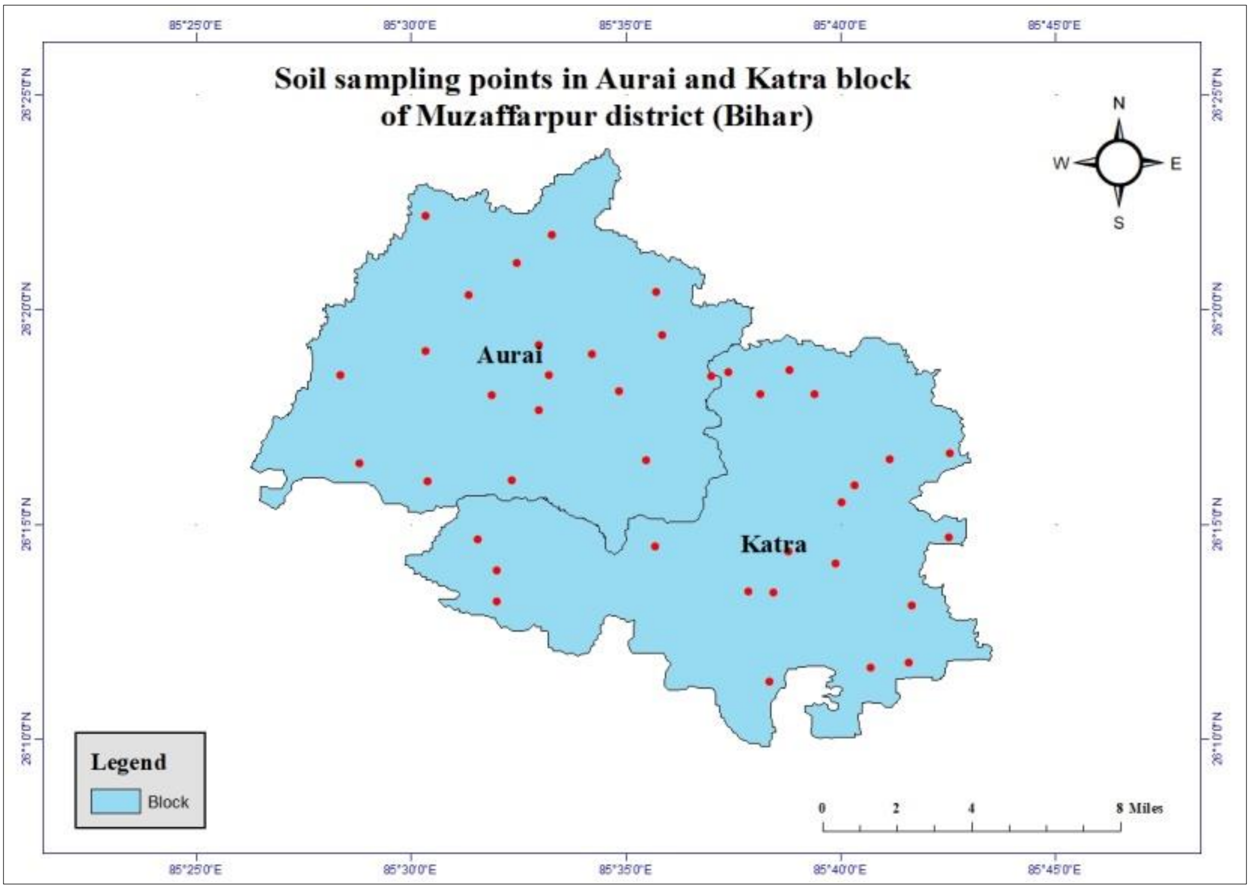

Fig 2: Location of soil sampling points in Aurai and Katra block of Muzaffarpur district (Bihar)

2.3 Laboratory Soil Analysis
Soil samples collected from the field were air dried in shade and crushed and sieved for laboratory analysis of soil parameters that include soil pH, organic matter, available nitrogen, phosphorus, potassium, sulfur, and micronutrients *viz*. zinc, copper, manganese, and iron. The parameters tested and methods used are summarised in Table 1.

Table 1: Soil test parameters and methods used for analysis

Soil test parameters	Methods	Reference
pH	Glass electrode pH meter	(Jackson, 1973) [7]
EC (dSm^{-1})	Electrical conductivity meter	(Jackson, 1973) [7]
Organic carbon (%)	Wet oxidation method	(Walkley and Black, 1934) [17]
Available Nitrogen ($kg\ ha^{-1}$)	Alkaline KMnO4 method	(Subbiah and Asija, 1956) [16]
Available Phosphorus ($kg\ ha^{-1}$)	Olsen's method	(Olsen, 1954) [12]
Exchangeable Potassium ($kg\ ha^{-1}$)	Ammonium Acetate method	(Hanway & Heidel, 1952) [6]
Available Sulphur (kg ha-1)	Calcium chloride method	(Chesnin and Yien, 1951) [1]
Available micronutrients Zn, Fe, Cu and Mn ($mg\ kg^{-1}$)	DTPA extractant	(Lindsay and Norvell, 1978) [9]

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. 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. MS Excel and SPSS packages were employed for descriptive statistics of soil parameters.

3. Results and Discussions
Soils were analyzed for pH, electrical conductivity, organic matter, available nitrogen, available phosphorus, available potassium, available sulfur, and micronutrients like Copper, Zinc, Iron, and manganese. The status of soil fertility (Table 1) and percent distribution (Table 2) obtained from laboratory analysis are summarised below.

Table 2: Soil fertility status of Aurai and Katra Block in Muzaffarpur district of Bihar

Sl. No.	Soil parameters	Unit	Minimum	Maximum	Mean	Standard Deviation
1	pH	pH scale	7.42	7.93	7.57	0.05
2	Soil Organic Carbon (SOC)	%	0.16	0.82	0.45	0.09
3	Available Nitrogen (N)	Kg/ha	152.2	262.7	207.2	11.2
4	Available Phosphorus (P)	Kg/ha	0.49	42.1	15.1	5.1
5	Available Potassium (K)	Kg/ha	94.4	656.2	247.6	76.8
6	Available Sulphur (S)	Kg/ha	6.20	22.1	12.2	1.8
7	DTPA-Zinc (Zn)	Mg/kg	0.13	0.67	0.45	0.08
8	DTPA-Copper (Cu)	Mg/kg	0.25	0.74	0.49	0.07
9	DTPA-Iron (Fe)	Mg/kg	3.12	8.90	5.67	0.86
10	DTPA-Manganese (Mn)	Mg/kg	1.88	6.12	3.67	0.59

Table 3: Distribution of soil fertility in Aurai and Katra Block of Muzaffarpur district (Bihar)

Soil parameters	Class	Limit	No. of sample	% Samples
pH	Acidic	<6.5	0	0%
	Neutral	6.5-7.5	11	27.5%
	Alkaline	>7.5	29	72.5%
Soil Organic Carbon (%)	Low	<0.5	23	57.5%
	Medium	0.5-0.75	16	40.00%
	High	>0.75	1	2.5%
Available Nitrogen (kg/ha)	Low	<280	40	100.0%
	Medium	280-560	0	0.0%
	High	>560	0	0.00%
Available Phosphorus (kg/ha)	Low	<14	23	57.5%
	Medium	14-28	15	37.5%
	High	>28	2	5.0%
Available Potassium (kg/ha)	Low	<150	10	25.0%
	Medium	150-250	18	45.0%
	High	>250	12	30.0%
Available Sulphur (kg/ha)	Low	<10	15	37.5%
	Medium	10-20.0	24	60.0%
	High	>20	1	2.5%
DTPA-Zinc (mg/kg)	Low	<0.6	36	90.0%
	Medium	0.6-1.8	4	10.0%
	High	>1.8	0	0.00%
DTPA-Iron (mg/kg)	Low	<4.5	14	35.0%
	Medium	4.5-9	26	65.0%
	High	> 9	0	0.0%
DTPA-Copper (mg/kg)	Low	<0.2	0	0.0%
	Medium	0.2-0.8	40	100.0%
	High	>0.8	0	0.0%
DTPA-Manganese (mg/kg)	Low	<3.5	17	42.5%
	Medium	3.5 - 5.0	17	42.5%
	High	>4	6	15.0%

3.1 Soil Reaction (pH)

The soil pH is a measure of the soil's acidity or alkalinity and regulates the availability of its nutrients (Neina, 2019) [11]. The soil pH of the study area was found to be in the range from neutral to moderately alkaline. Most of the soils were moderately alkaline and only a few were neutral (27.5%) and slightly alkaline in nature (Table 2). The pH value was found to be in the range of 7.42 to 7.93 (Table 1). Most of the soils were found to be saline in nature (72.5%) which may be due to natural systems like mineralogy, climate, weathering, excess use of basic-forming fertilizers, etc. Soil pH influences the solubility and availability of plant nutrients. In general, soils with near neutral reactions (pH 6.0-7.0) are considered to be the most fertile. The soil fertility map showing the distribution of soil pH in the study area is depicted in Fig 3.

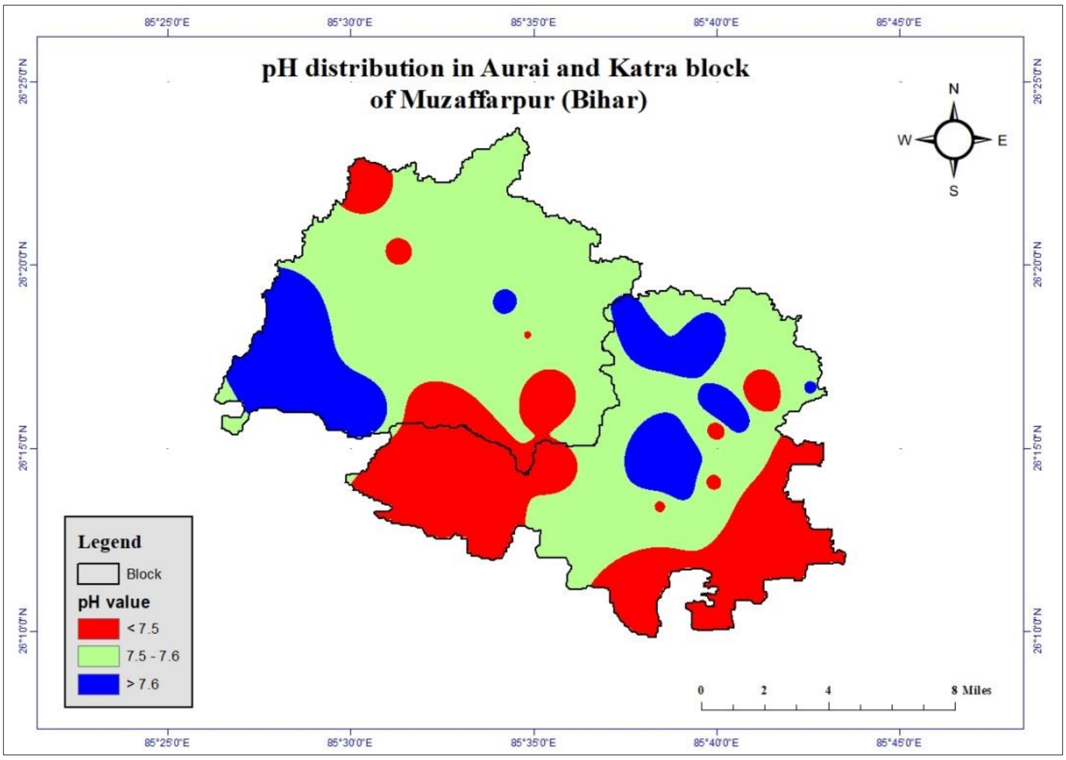

Fig 3: Soil pH distribution in Aurai and Katra Block of Muzaffarpur district, Bihar

3.2 Organic Matter

In the present study, the soil organic matter ranges from 0.16 to 0.82% with a mean value of 0.45% to 3.6% with a mean value of 1.5% (table 1). The soil fertility map showing the distribution of soil organic carbon in the study area is depicted in Fig 4. The study also reveals that around 57.5%, 40%, and 2.59% of the study area falls under low, medium, and high organic carbon content respectively (Table 2). Lower organic carbon content in the area may be due to the high decomposition of organic matter as the temperature in the summer season rises to 40 °C and less application 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.

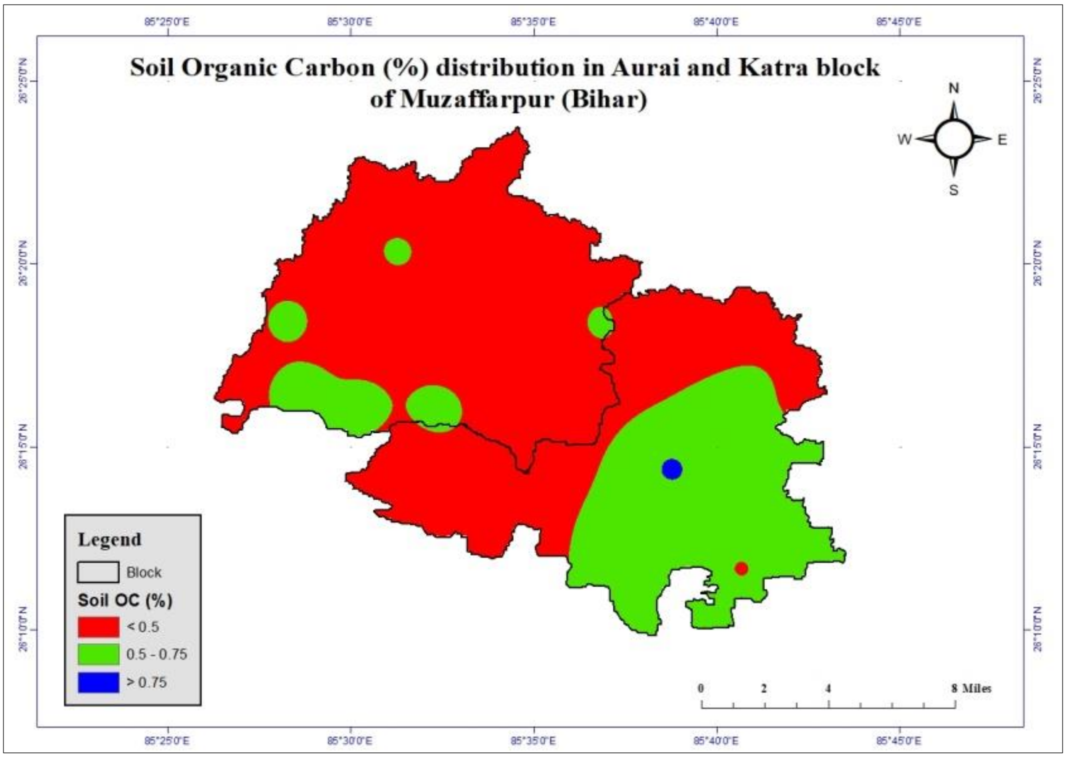

Fig 4: Soil organic carbon (%) distribution in Aurai and Katra Block of Muzaffarpur district, Bihar

3.3 Available Nitrogen

The available nitrogen content of the study area varied from 152.2 to 262.7 kg/ha with a mean value of 207.2 kg/ha (Table 1). The generated soil fertility map showing the distribution of soil available nitrogen in the study area is depicted in Fig 5. Overall the finding reveals that the nitrogen content was low in the study area (Table 2). The low nitrogen content in the study area may be possibly due to low organic matter content in soils, crop removal, and high temperatures which facilitate faster degradation and removable of organic matter leading to nitrogen deficiency.

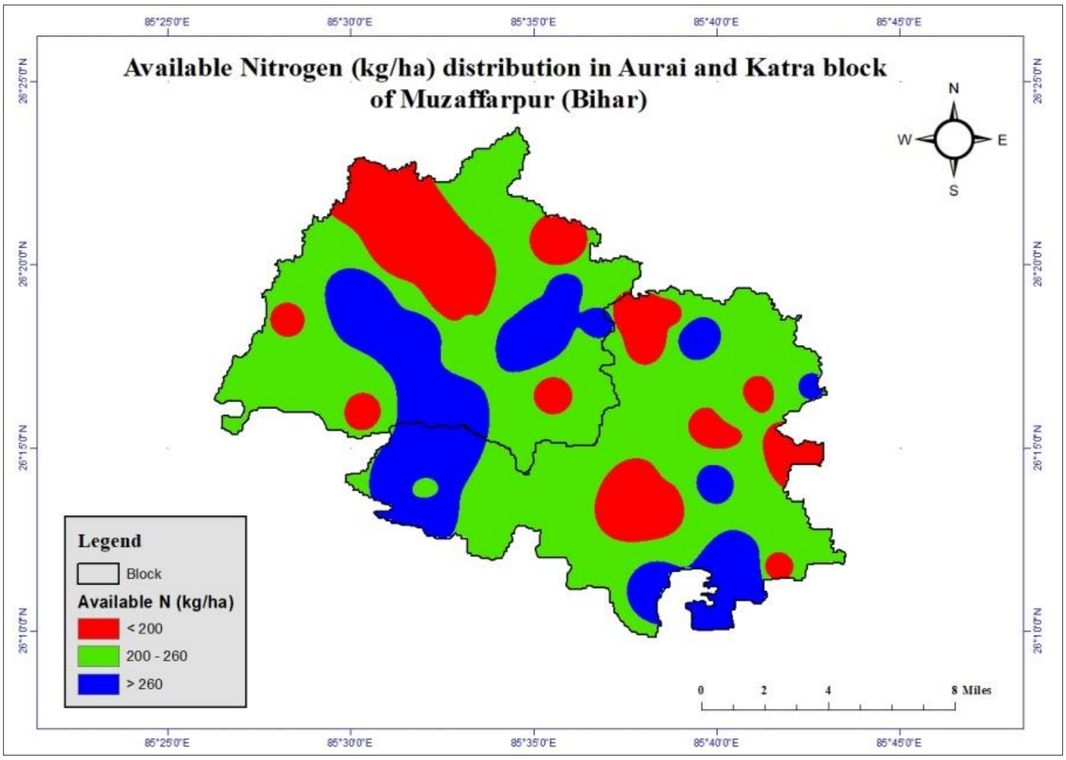

Fig 5: Distribution of available Nitrogen (kg/ha) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.4 Available Phosphorous

The available phosphorus content in the study area ranged from 0.49 to 49.1 (kg/ha) with a mean value of 15.1 kg/ha (Table 1). The study also reveals that around 57.5%, 37.5%, and 5% of the study area falls under low, medium, and high phosphorus content respectively (Table 2). Overall the finding reveals that more than half of the study area falls under low phosphorus content. The generated soil fertility map showing the distribution of soil available phosphorus in the study area is depicted in Fig 6.

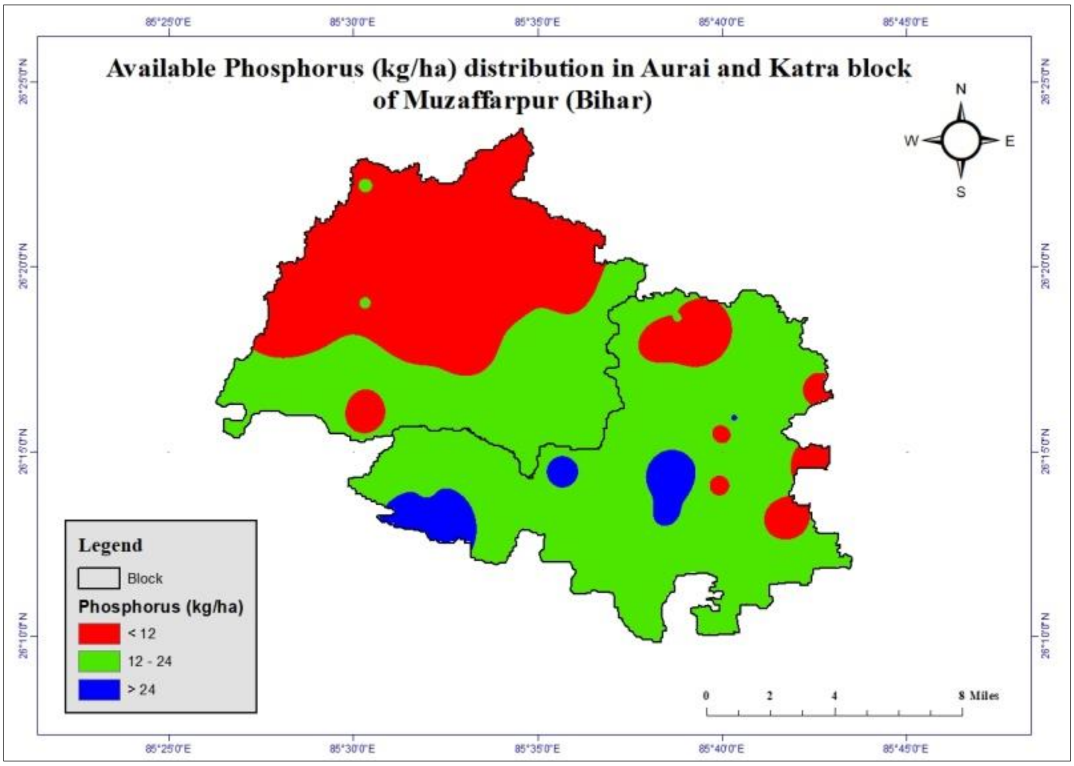

Fig 6: Distribution of available Phosphorus (kg/ha) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.5 Available Potassium
The physiological processes of plants are involved in the activation of several enzymes. The available potassium content in the study area ranged from 94.4 to 656.2 (kg/ha) with a mean value of 247.6 kg/ha (Table 1). The study also reveals that around 25%, 45%, and 30% of the study area falls under low, medium, and high potassium content respectively (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 generated soil fertility map showing the distribution of soil available potassium in the study area is depicted in Fig 7.

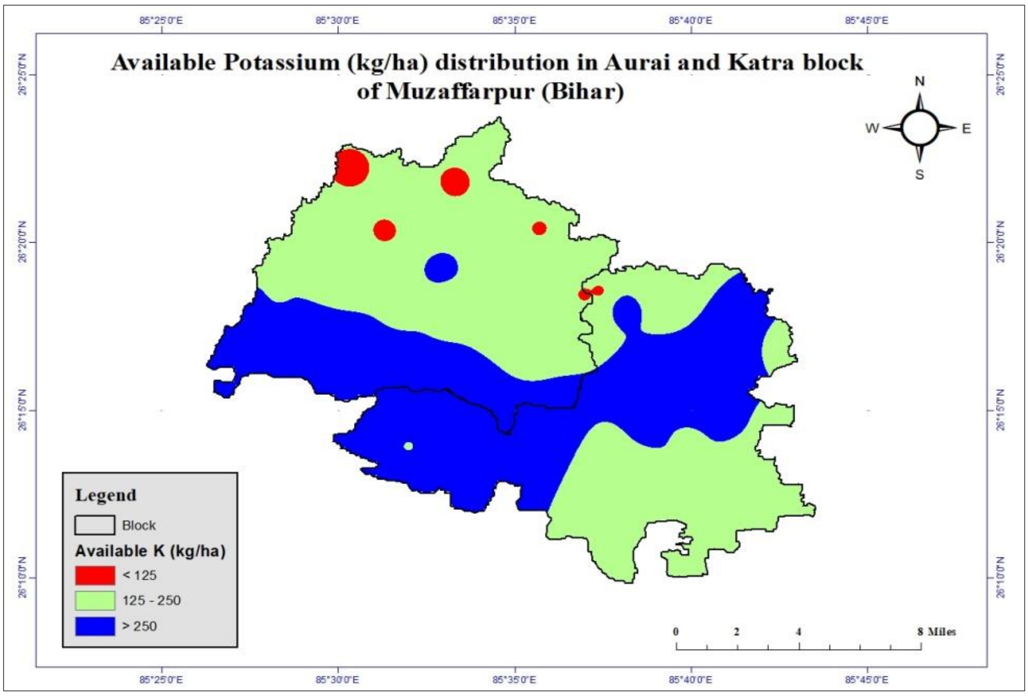

Fig 7: Distribution of available Potassium (kg/ha) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.6 Available Sulphur
The status of available sulfur content is presented in Table 1. The data revealed that available sulfur content in the study area ranged from 6.20 to 22.1 (kg/ha) with a mean value of 12.2 kg/ha (Table 1). The finding of the study reveals that around 37.5%, 60.0%, and 2.5% of the study area falls under low, medium, and high sulfur content respectively (Table 2). Overall the finding reveals that more than half of the study area falls under medium sulfur content. The generated soil fertility map showing the distribution of soil available sulfur content in the study area is depicted in Fig 8.

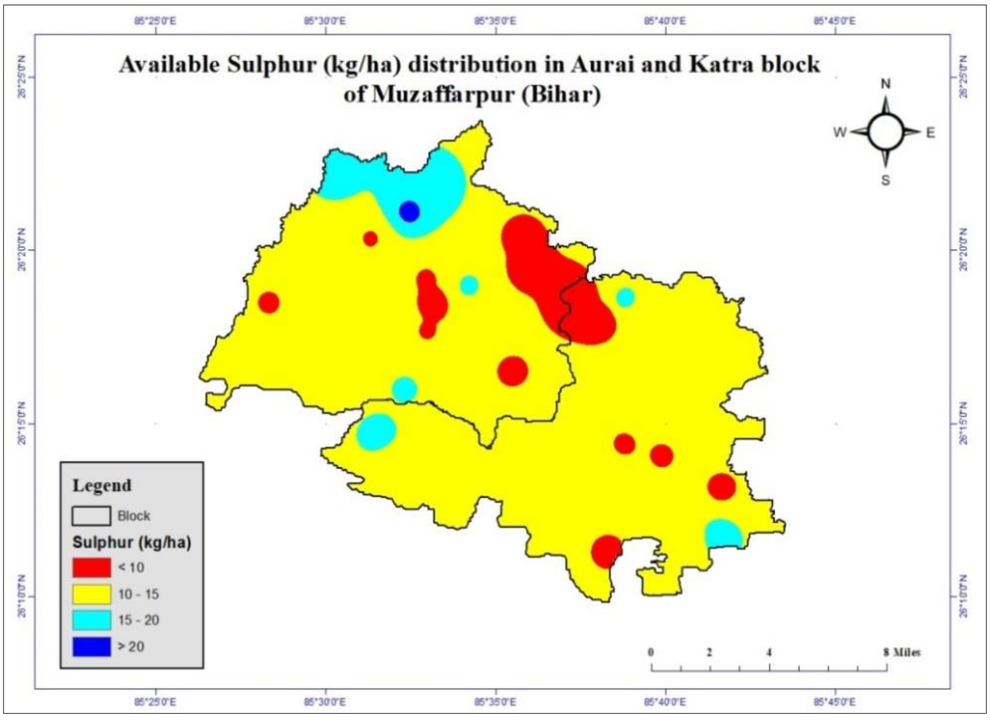

Fig 8: Distribution of available Sulphur (kg/ha) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.7 Available Micronutrients

3.7.1 DTPA-Zinc: Zinc is an important micronutrient that plays a crucial role in the plant required in trace quantity for plant growth. For plants to grow normally and healthily, zinc (Zn) is a necessary trace element. The growth of chlorophyll in leaves is connected to it. The available zinc content ranged from 0.13 to 0.67 mg/kg with the mean value of 0.45 mg/kg (Table 1). The finding of the study reveals that around 90% of the study area falls under low Zinc content (Table 2). The reason for low fertility may be the intensive cropping system and imbalanced use of fertilizer. Lower zinc content in the region may also be attributed to lower organic carbon content. The soil fertility map of Zinc showing its distribution in the study area is depicted in Fig. 9.

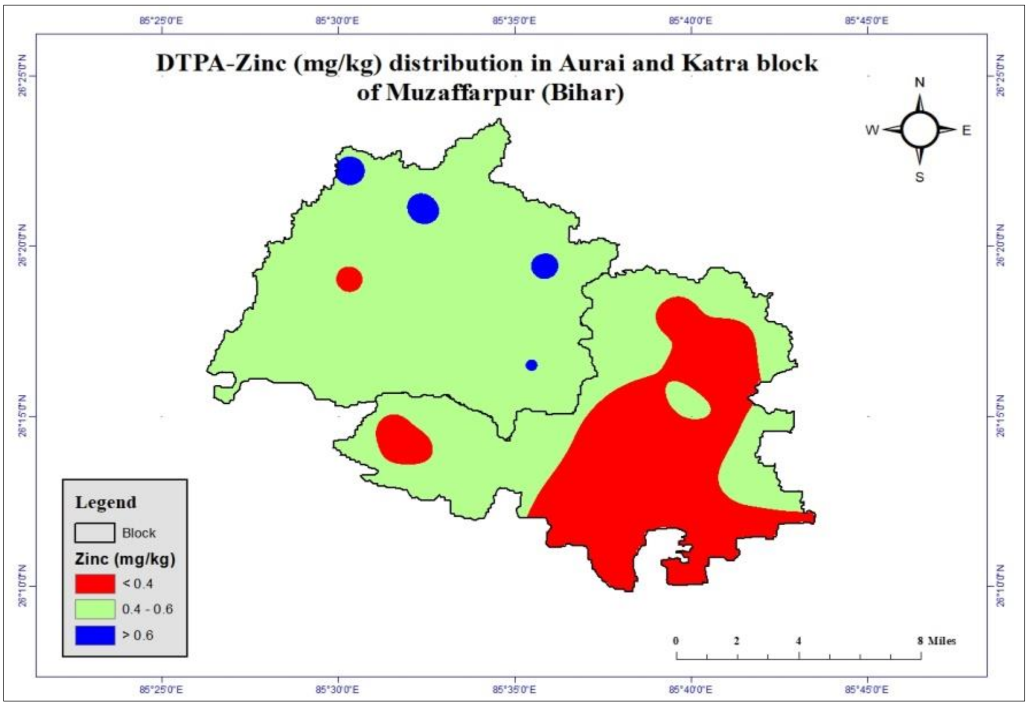

Fig 9: Distribution of DTPA-Zinc (mg/kg) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.7.2 DTPA-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 Iron content in the study area varied from 3.12 to 8.90 mg/kg with a mean value of 5.67 mg/kg (Table 1). The finding of the study reveals that around 35% and 65% of the study area falls under low and medium Fe content respectively (Table 2). The generated soil fertility map showing the distribution of DTPA-Fe content in the study area is depicted in Fig 10. In leaf cells, the oxidation process is significantly influenced by iron concentration. Severe deficiency results in loss of leaf and restricts plant growth to a larger extent. A severe shortage of Fe causes leaf loss and significantly limits plant growth.

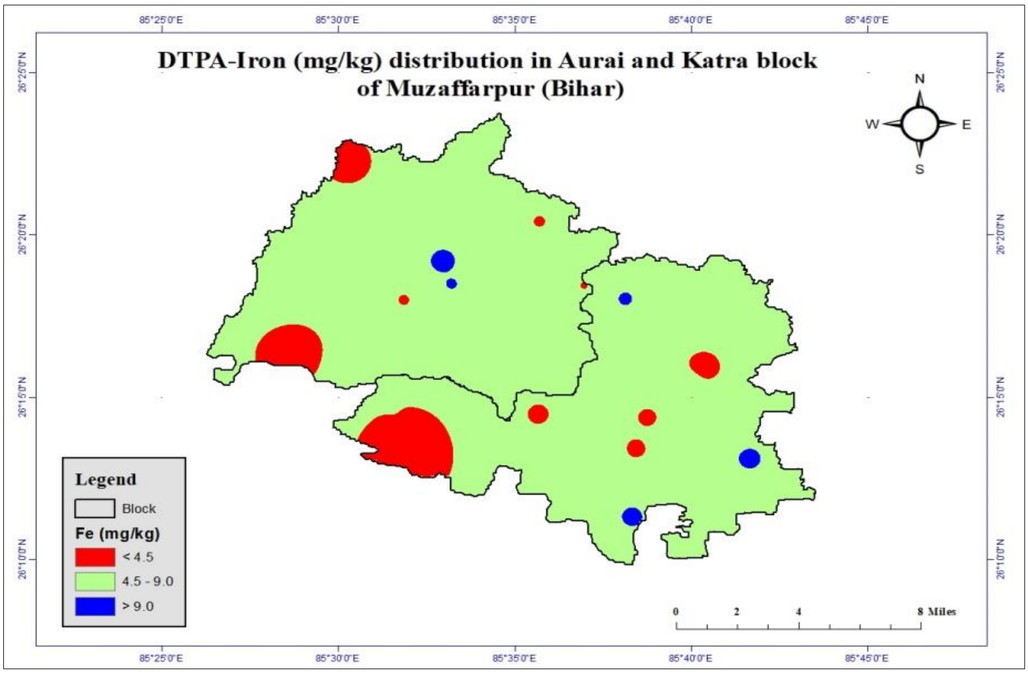

Fig 10: Distribution of DTPA-Fe (mg/kg) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.7.3 DTPA-Mn
The status of manganese (Mn) content is presented in Table 1. The data revealed that DTPA-Mn content in the study area ranged from 1.88 to 6.12 (mg/kg) with a mean value of 3.67 mg/kg. The finding of the study also reveals that around 42.5%, 42.5%, and 15.0% of the study area falls under low, medium, and high manganese content respectively (Table 2). The generated soil fertility map showing the distribution of DTPA-Mn content in the study area is depicted in Fig 11.

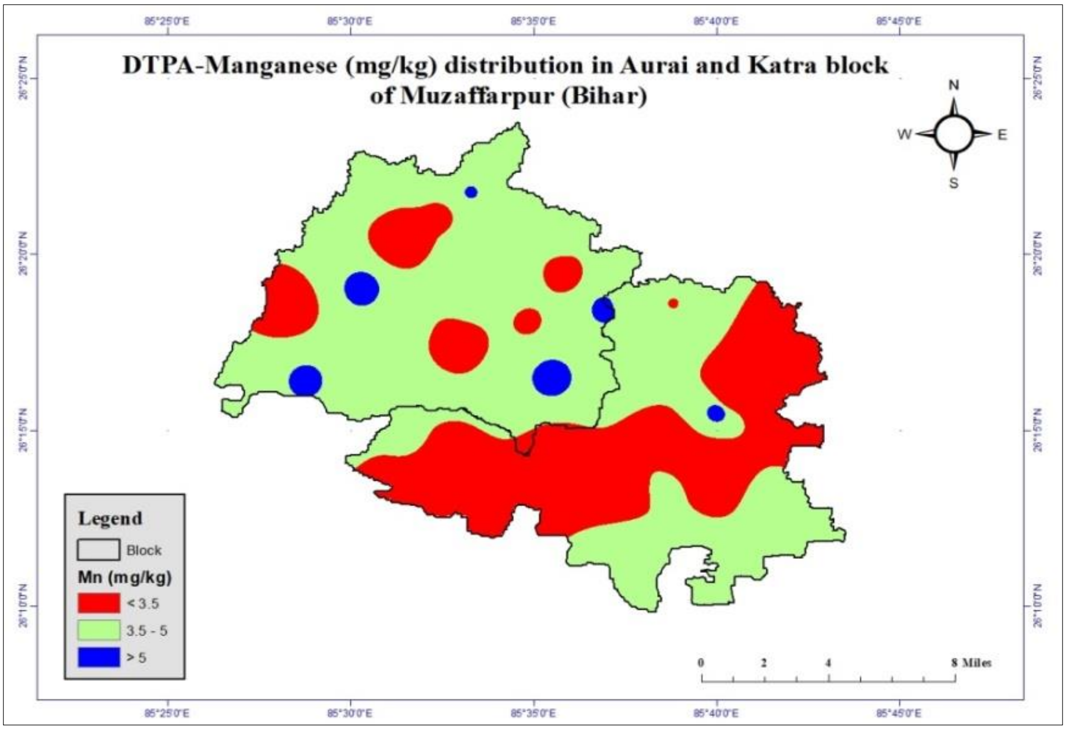

Fig 11: Distribution of DTPA-Mn (mg/kg) in Aurai and Katra Block of Muzaffarpur district, Bihar

3.7.4 DTPA-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. Copper (Cu) content in the study area varied from 0.25 to 0.74 mg/kg with the mean value of 0.49 mg/kg (Table 1). The finding of the study reveals that the majority of the study area falls under medium copper content (Table 2). Figure 12 depicts the soil fertility map showing the distribution of DTPA-Cu content in the study area.

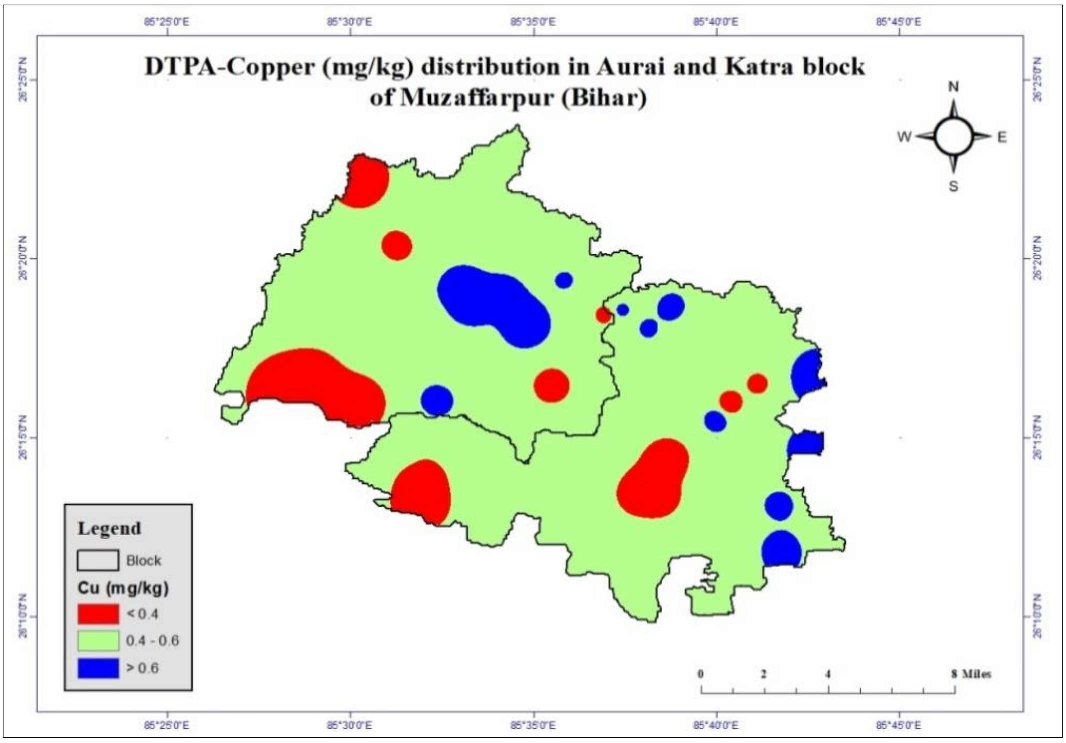

Fig 12: Distribution of DTPA-Cu (mg/kg) in Aurai and Katra Block of Muzaffarpur district, Bihar

4. Conclusion

Agricultural production, which affects food security and livelihood, is influenced by soil fertility and nutrient management. The findings show that the research area's general intrinsic fertility status was poor. The main cause of soil depletion is nutrient mining, which involves taking out more nutrients than are put back. To better manage the soil for sustainability and productivity, farmers and planners will benefit from the spatial distribution and fertility maps that have been created. These maps will help them understand the current soil conditions and make informed decisions.

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