*Biological Forum – An International Journal* **14(3): 1663-1671(2022)**

**ISSN No. (Print): 0975-1130**
**ISSN No. (Online): 2249-3239**

# GPS and GIS based Soil Fertility Assessment and Mapping in Blocks of Muzaffarpur District of Bihar

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*(Received 03 August 2022, Accepted 06 September, 2022)*
*(Published by Research Trend, Website: www.researchtrend.net)*

**ABSTRACT: The soil fertility maps generated through Global Positioning System (GPS) and Geographic Information Systems (GIS) for effective decisions making of nutrient management. A soil fertility inventory research was carried out in the Kurhani and Sakra block of Muzaffarpur, Bihar. Assessment of fertility status, altogether 40 (forty) geo-referenced composite soil samples were collected from the various locations of the studied area using a GPS device. The processed soil samples used for soil attributes determination using prescribed standard methods. Soil nutrient status and fertility maps were created by using ArcGIS software employing IDW interpolation techniques. The results clearly indicated that the soils reaction was alkaline in nature having pH value more than 7.5. Soil organic matter and potassium content was found to be low to medium whereas, available nitrogen, phosphorus, and sulphur were recorded low in the blocks. However, copper (Cu) and Iron (Fe) the value of micronutrients showed below critical limits.**

**Keywords:** GIS, GPS, Muzaffarpur, Soil Fertility Maps.

## INTRODUCTION

As the wellspring of all life, soil is the most important and valuable natural resource (Das *et al.*, 2020). For effective nutrient management measures to be implemented, a thorough understanding of the soil's fertility status is necessary for sustainable crop production. Land use and soil management strategies have an impact on soil fertility, which varies spatially from field to larger region scale (Sun *et al*., 2003). 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. 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 (Schröder *et al.*, 2018; Upadhyay *et al*., 2020). Geographic Information Systems (GIS) and GPS are also crucial instruments for assessing the spatial variability of the soil. A potent suite of tools called GIS may be used to gather, store, retrieve, transform, and display spatial data (Das, 2004). Agriculture-related thematic maps generated through a GPS tool helps in showing soil fertility, land usage, land cover and also aids in developing site-specific nutrient management strategies for the area. Soil fertility maps for nutrient management for precisions agriculture (Hemalatha *et al.*, 2020) based on Geographic Information Systems (GIS) are also helpful in developing solutions to resource management problems like land management, soil erosion, soil degradation, water quality, and urban planning (Parmar *et al.*, 2022; Prasad *et al*., 2022). It also serves as a decision support tool for nutrient management (Habibie *et al.*, 2021). The present study was undertaken to assess the soil fertility status and to generate soil fertility maps using remote sensing and GIS for Kurhani and Sakra blocks of Muzaffarpur district of Bihar.

## MATERIALS AND METHODS

**Location of the Study Area.** The study area Kurhani and Sakra is situated in the South of Muzaffarpur district of Bihar consisting of a geographical area of 437.85 km$^2$. The study area lies between 25.9025° to 26.1081° North Latitude and 85.2609° to 85.7013° 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 1640.2 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.

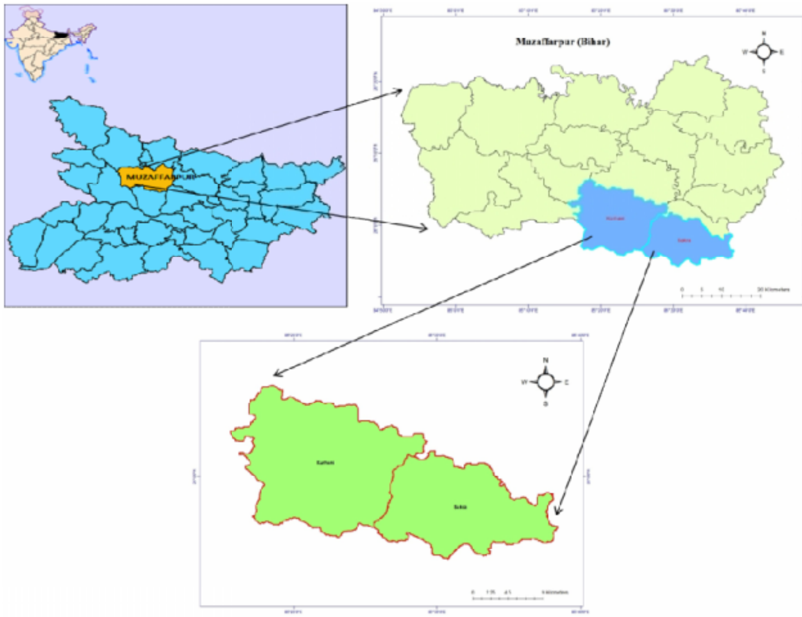


**Fig. 1.** Location map of the study area (Aurai and Katra block) in Muzaffarpur district of Bihar.

**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 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 (Kurhani and Sakra 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.

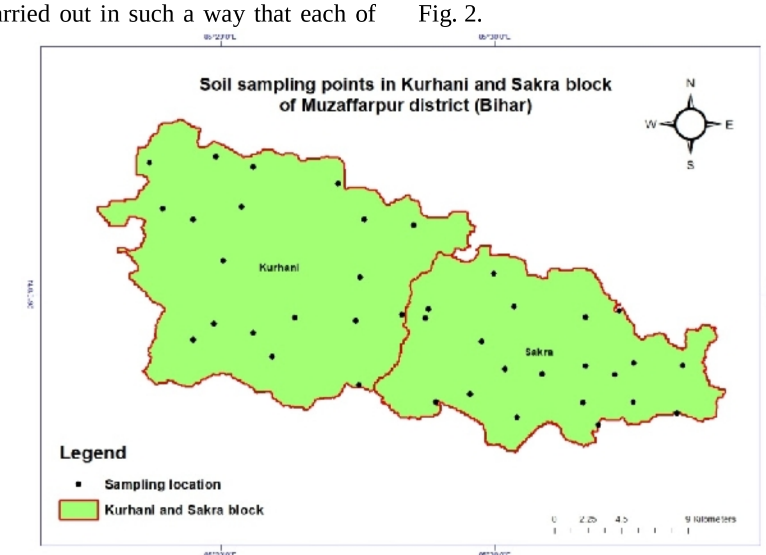


**Fig. 2.** Location of soil sampling points in Kurhani and Sakra block of Muzaffarpur district (Bihar).

**Laboratory Soil Analysis.** Soil samples collected from the field were air dried in shade and thereafter crushed and sieved for laboratory analysis of soil parameters that include soil pH, organic matter, available nitrogen, phosphorus, potassium, sulphur, and micronutrients *viz*., manganese, copper, iron, and zinc. The soil 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) |
| EC ($dSm^{-1}$) | Electrical conductivity meter | (Jackson, 1973) |
| Organic carbon (%) | Wet oxidation method | (Walkley and Black 1934) |
| Available Nitrogen (kg $ha^{-1}$) | Alkaline $KMnO_4$ method | (Subbiah and Asija 1956) |
| Available Phosphorus (kg $ha^{-1}$) | Olsen's method | (Olsen's, 1954) |
| Exchangeable Potassium (kg $ha^{-1}$) | Ammonium Acetate method | (Hanway and Heidel 1952) |
| Available Sulphur (kg $ha^{-1}$) | Calcium chloride method | (Chesnin and Yien 1951) |
| Available micronutrients Zn, Fe, Cu and Mn (mg $kg^{-1}$) | DTPA extractant | (Lindsay and Norvell 1978) |

**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.

## RESULTS AND DISCUSSION

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

**Soil pH.** 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 of the study area was found to be in the alkaline range. Most of the soils were moderately alkaline with a minimum pH value of 7.7 and maximum 8.41 (Table 2). Similar results were reported by Singh *et al*. (2012). The high pH value may be due to natural systems like mineralogy, climate, weathering, excess use of basic-forming fertilizers, etc. The soil fertility 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 North Western and Eastern part of the study area while the remaining area falls under soil pH value 7.5 – 8.0 (Fig. 3).

**Organic Carbon (%).** The soil organic matter ranged from 0.2 to 0.89 % with a mean value of 0.54% (Table 1). The study also revealed that around 42.5%, 40%, and 17.5 % of the study area falls under low, medium, and high organic carbon content respectively (Table 2). The soil fertility map showing the distribution of soil organic carbon in the study area is depicted in Fig. 4. The map clearly depicts that low OC is widely distributed in the eastern region while the central part of the study area covered by medium OC. 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.

**Available Nitrogen (kg $ha^{-1}$).** The available nitrogen content of the study area varied from 152.1 to 319.1 kg/ha with a mean value of 230.1 kg/ha (Table 1). Around 90% of the study area found to be deficit in nitrogen content (Table 2). The generated soil fertility map showing the distribution of soil available nitrogen in the study area is depicted in Fig. 5. The generated soil map revealed that the nitrogen deficit was distributed entirely in the study area while a small patch in the northern and eastern region of the study area falls under medium nitrogen content (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.

**Table 1: Soil fertility status of Kurhani and Sakra Block in Muzaffarpur district of Bihar.**

| Sr. No. | Soil parameters | Unit | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| 1. | pH | pH scale | 7.73 | 8.41 | 7.95 | 0.10 |
| 2. | Soil Organic Carbon (SOC) | % | 0.20 | 0.89 | 0.54 | 0.09 |
| 3. | Available Nitrogen (N) | Kg/ha | 152.1 | 319.1 | 230.1 | 22.8 |
| 4. | Available Phosphorus (P) | Kg/ha | 4.35 | 26.5 | 14.3 | 2.08 |
| 5. | Available Potassium (K) | Kg/ha | 84.9 | 667.9 | 219.9 | 58.4 |
| 6. | Available Sulphur (S) | Kg/ha | 6.15 | 25.8 | 14.1 | 2.79 |
| 7. | DTPA-Zinc (Zn) | ppm | 0.23 | 1.12 | 0.63 | 0.12 |
| 8. | DTPA-Copper (Cu) | ppm | 0.21 | 1.20 | 0.89 | 0.12 |
| 9. | DTPA-Iron (Fe) | ppm | 1.77 | 13.1 | 8.16 | 1.97 |
| 10. | DTPA-Manganese (Mn) | ppm | 1.02 | 4.65 | 2.68 | 0.75 |

**Available Phosphorous (kg ha$^{-1}$).** The available phosphorus content in the study area ranged from 4.35 to 26.5 (kg/ha) with a mean value of 14.3 kg/ha (Table 1). Around 42.5% and 57.5% of the study area falls under low and medium phosphorus content respectively (Table 2). The generated soil fertility map of phosphorus reveals that patches in eastern and western region fall under P deficit while the central the remaining area falls under medium P 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.

**Table 2: Distribution of soil fertility in Kurhani and Sakra Block 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 | 40 | 100% |
| Soil Organic Carbon (%) | Low | <0.5 | 17 | 42.5% |
| | Medium | 0.5-0.75 | 16 | 40.0% |
| | High | >0.75 | 7 | 17.5% |
| Available Nitrogen (ppm) | Low | <280 | 36 | 90.00% |
| | Medium | 280-560 | 4 | 10.00% |
| | High | >560 | 0 | 0.00% |
| Available Phosphorus (ppm) | Low | <14 | 17 | 42.5% |
| | Medium | 14-28 | 23 | 57.5% |
| | High | >28 | 0 | 0.0% |
| Available Potassium (ppm) | Low | <150 | 12 | 30.0% |
| | Medium | 150-250 | 17 | 42.5% |
| | High | >250 | 11 | 27.5% |
| Available Sulphur (ppm) | Low | <10 | 7 | 17.5% |
| | Medium | 10-20.0 | 26 | 65.0% |
| | High | >20 | 7 | 17.5% |
| DTPA-Zinc (ppm) | Low | <0.6 | 16 | 40.0% |
| | Medium | 0.6-1.8 | 20 | 50.0% |
| | High | >1.8 | 4 | 10.0% |
| DTPA-Iron (ppm) | Low | <4.5 | 8 | 20.0% |
| | Medium | 4.5-9 | 9 | 22.5% |
| | High | > 9 | 23 | 57.5% |
| DTPA-Copper (ppm) | Low | <0.2 | 0 | 0.0% |
| | Medium | 0.2-0.8 | 9 | 22.5% |
| | High | >0.8 | 31 | 77.5% |
| DTPA-Manganese (ppm) | Low | <3.5 | 34 | 85.0% |
| | Medium | 3.5 - 5.0 | 6 | 15.0% |
| | High | >4 | 0 | 0.0% |

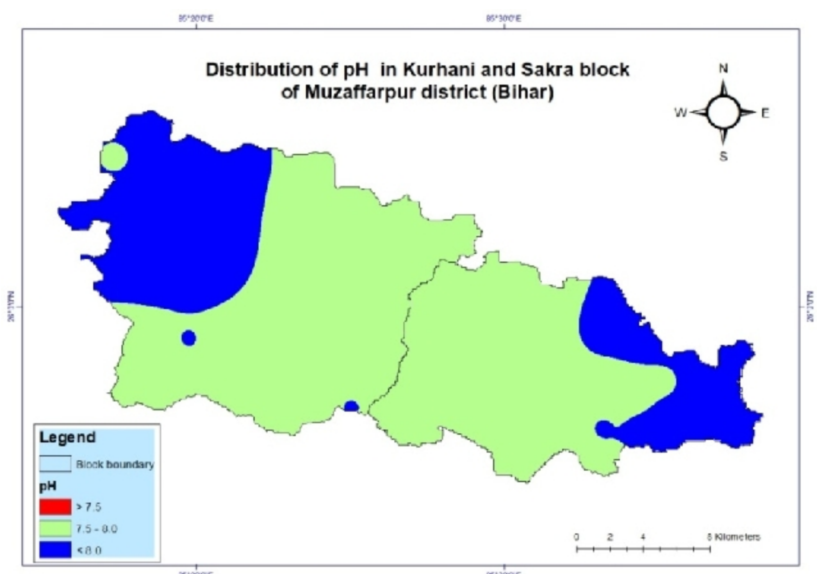


**Fig. 3.** Soil pH distribution in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

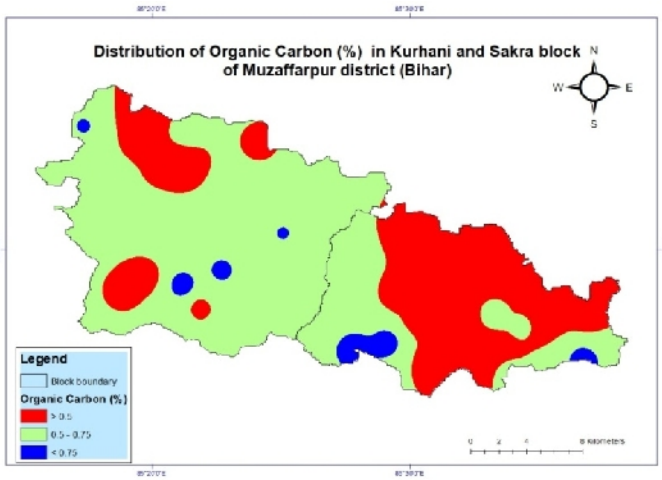


**Fig. 4.** Soil organic carbon (%) distribution in Kurhani and Sakra block of Muzaffarpur district, Bihar.

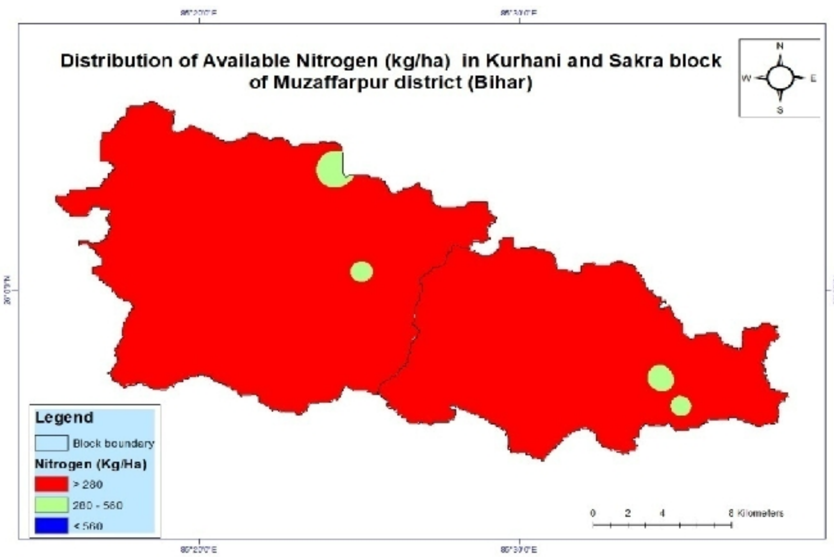


**Fig. 5.** Distribution of available Nitrogen (kg/ha) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

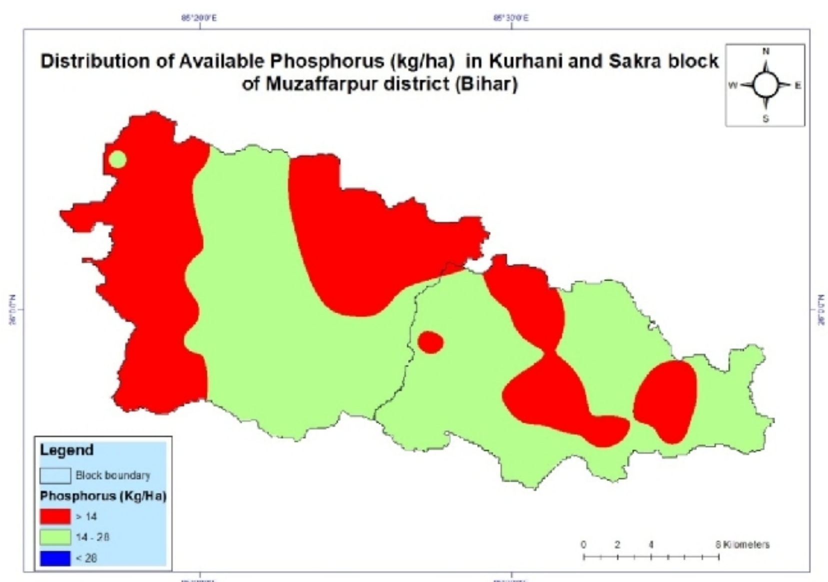


**Fig. 6.** Distribution of available Phosphorus (kg/ha) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

**Available Potassium (kg ha$^{-1}$).** The physiological processes of plants are involved in the activation of several enzymes. The available potassium content in the study area ranged from 84.9 to 667.9 (kg/ha) with a mean value of 219.9 kg/ha (Table 1). The study also reveals that around 30%, 42.5%, and 27.5 % 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. The generated fertility map reveals that the available K higher than 250 Kg/ha is distributed mostly in northern and southern part while the eastern and western region is distributed sparsely in patches with K content lower than 150 Kg/Ha. The available K content having higher than 250 Kg/Ha falls under majority of the study area and is distributed mostly in the central region. Similar results were reported by Singh *et al.,* 2019 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. Other factors that influence K content includes liming and soil pH, CEC, K absorption by plants and method and rate of K application.

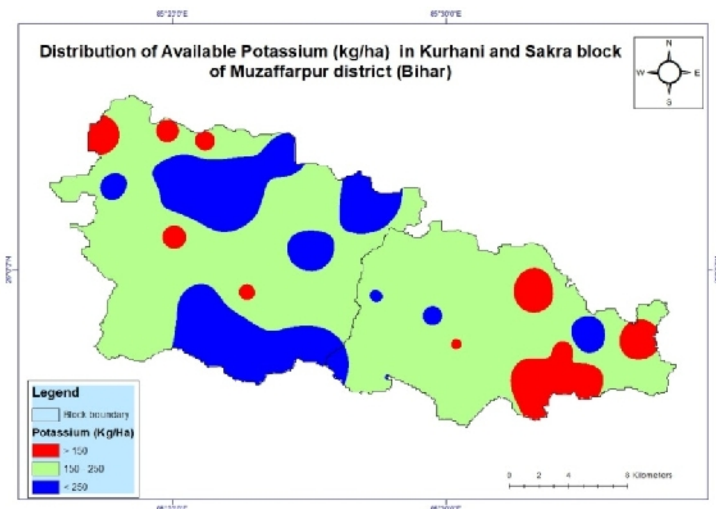


**Fig. 7.** Distribution of available Potassium (kg/ha) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

**Available Sulphur (kg ha$^{-1}$).** The status of available sulfur content is presented in Table 1. The data revealed that available sulfur content in the study area ranged from 6.15 to 25.8 (kg/ha) with a mean value of 14.1 kg/ha (Table 1). The finding of the study reveals that around 17.5%, 65.0%, and 17.5 % 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. Low status of organic matter might be the cause of lower content of available sulphur in the region. Moreover, sulfur mining also results from overlooking the fact that crops regularly absorb sulphate nutrients from the soils.

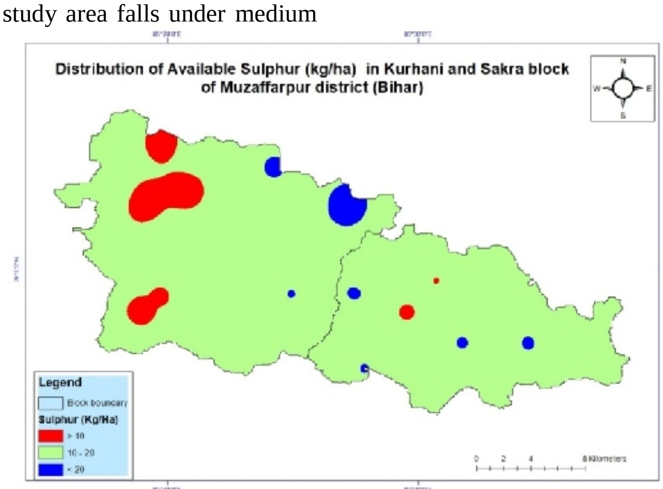


**Fig. 8.** Distribution of available Sulphur (kg/ha) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

**Available Micronutrients (ppm)**

**DTPA-Zinc.** Zinc (Zn) is an important micronutrient required in trace quantity and plays a crucial role for plant to grow normally and healthily growth. The growth of chlorophyll in leaves is connected to it. In the present study, the available zinc content ranged from 0.23 to 1.12 ppm with the mean value of 0.63 ppm (Table 1). The finding of the study reveals that around 90 % of the study area falls under low to medium Zn content (Table 2). The reason may be due to 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.

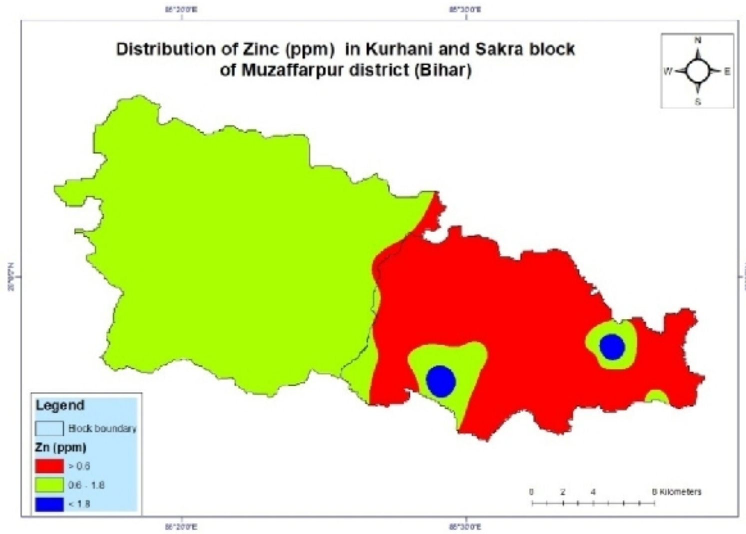


**Fig. 9.** Distribution of DTPA-Zinc (ppm) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

**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 1.77 to 8.16 ppm with a mean value of 8.16 ppm (Table 1). The generated soil fertility map showing the distribution of DTPA-Fe content in the study area is depicted in Fig. 10. The map clearly indicates that higher Fe content in the western part and low to medium content in the eastern region of the study area (Fig. 10). The high proportion of available iron may be due to the presence 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 etc. as high iron availability may end up iron toxicity symptoms in crops.

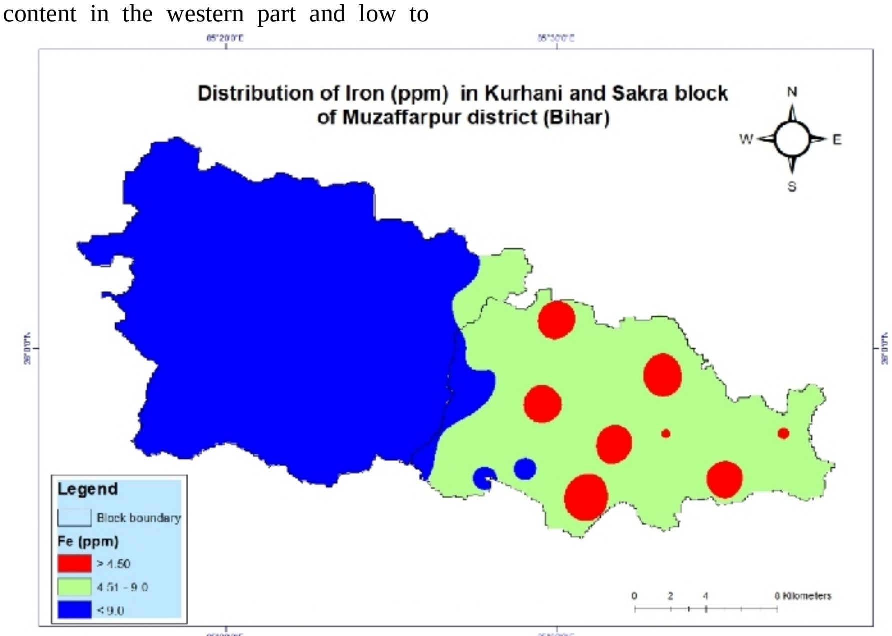


**Fig. 10.** Distribution of DTPA-Fe (ppm) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

**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 1.02 to 4.65 (ppm) with a mean value of 2.68 ppm. The finding also reveals 85% of the study area falls under low manganese content (Table 2). Medium (3.5 to 5.0 ppm) Mn content is distributed in patches in the study area (Fig. 11). The generated soil fertility map showing the distribution of DTPA-Mn content in the study area is depicted in Fig. 11. Manganese deficiencies in the region may be due to well drained neutral or calcareous soils (Table 1). It can also be attributed to heavy applications of lime and heavy fertiliser dosage in the region.

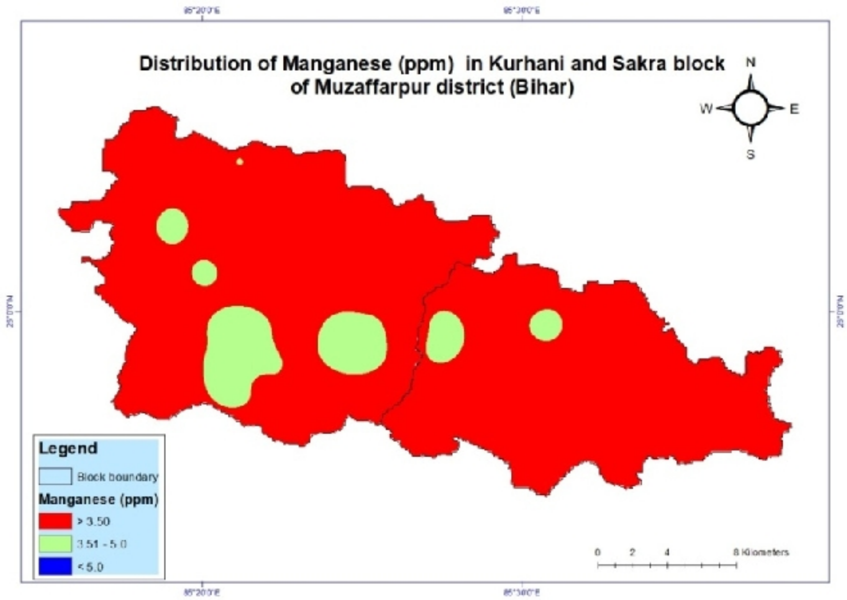


**Fig. 11**. Distribution of DTPA-Mn (ppm) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

**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 0.21 to 1.2 ppm with the mean value of 0.89 ppm (Table 1). The finding of the study reveals that the majority of the study area falls under medium to high copper content (Table 2). Fig. 12 depicts the soil fertility map showing the distribution of DTPA-Cu content in the study area. The reason for medium to high 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.

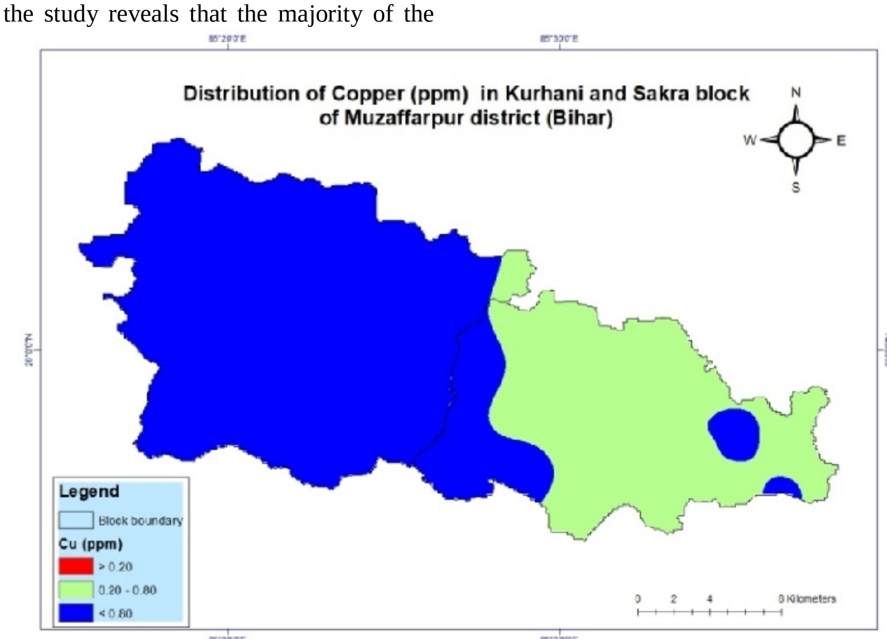


**Fig. 12.** Distribution of DTPA-Cu (mg/kg) in Kurhani and Sakra Block of Muzaffarpur district, Bihar.

## CONCLUSION

The management of nutrients and soil fertility have an impact on agricultural production, which impacts food security and livelihood. The results indicate that the intrinsic fertility status of the studied area was generally low. Nutrient mining, which entails pulling more nutrients out than are put back in, can be considered as the main reason for soil depletion along with the prevalent soil management practice and environmental conditions in the study area. The spatial distribution and fertility maps that have been produced will be useful to farmers and planners in improving soil management for sustainability and productivity. These maps are expected to aid in their comprehension of the existing soil conditions and decision-making.

**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.
**Conflicts of Interest**. None.

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**How to cite this article:** Techi Tagung, Sanjay Kumar Singh, Pankaj Singh, Sumedh R. Kashiwar and Santosh Kumar Singh (2022). GPS and GIS based Soil Fertility Assessment and Mapping in Blocks of Muzaffarpur District of Bihar. *Biological Forum – An International Journal*, *14*(3): 1663-1671.