

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

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, 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.

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). Land use and soil management strategies have an impact on soil fertility, which varies spatially from field to field (Sun *et al.*, 2003; Kumar *et al.*, 2023). Maintaining soil's fertility status is necessary for sustainable crop production through efficient nutrient management (Sinha *et al.*, 2024; Kumar *et al.*, 2024). Fertility management based on soil tests has been shown to be a successful method for boosting the productivity of agricultural soils with substantial geographical variability brought on by a combination of physical, chemical and biological processes. Soil test based fertility management is an effective tool for agricultural soils that have high degree of spatial variability (Meena *et al.*, 2024). The basic indicators of soil fertility are the physical characteristics of the soil (texture, structure, and colour), pH, organic matter, primary nutrients, secondary nutrients, and micronutrients (B, Fe, Zn, Cu, and Mn), among others (Brady and Weil, 2002). Understanding the state of the

soil's fertility is essential for creating effective soil management plans that support crop cultivation design (Schroder *et al.*, 2018; Upadhyay *et al.*, 2020). Remote sensing tool like Global Positioning System (GPS) and Geographic Information Systems (GIS) is an emerging tool for assessing the spatial variability of the soil. GIS are used to gather, store, retrieve, transform, and display spatial data (Das, 2004). 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 (Hemalatha *et al.*, 2020). 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 (Habibie *et al.*, 2021). 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.

MATERIALS AND METHODS

1. Location of the Study Area

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

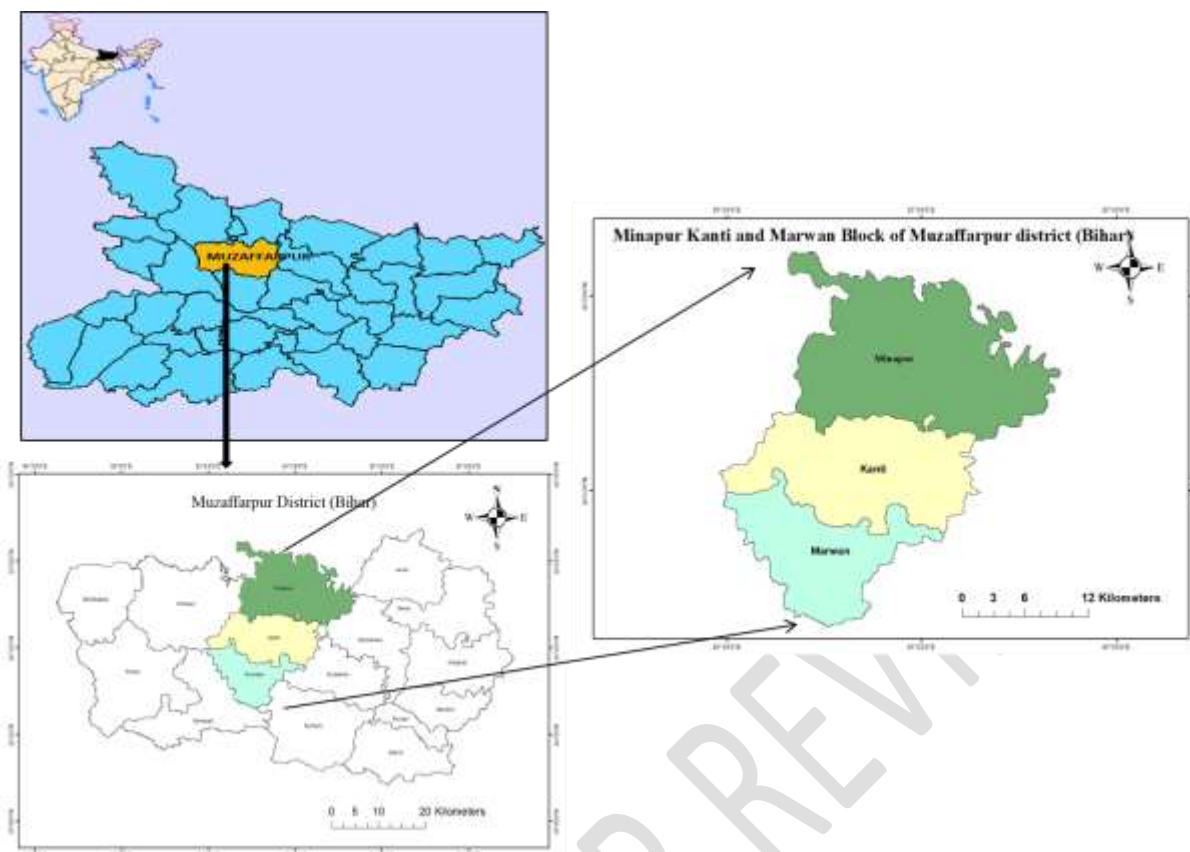


Fig.1: Location map of the study area (Minapur, Kanti and Marwan) in Muzaffarpur district.

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.

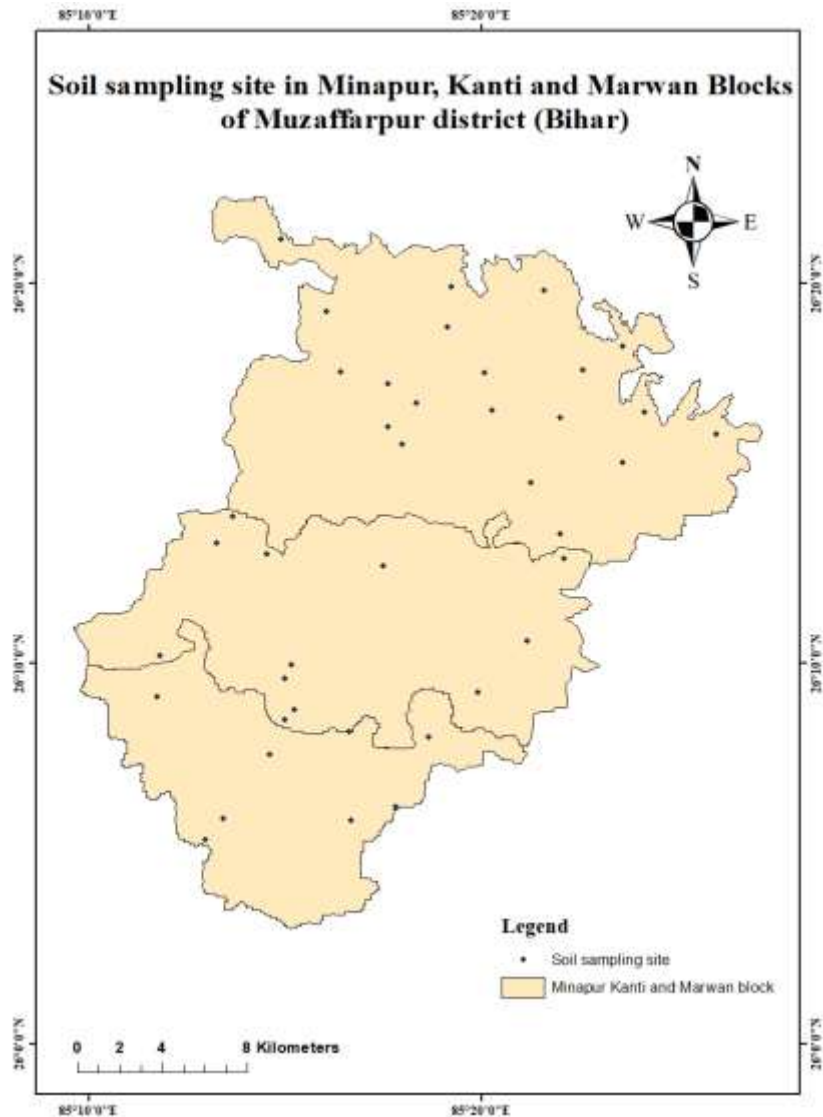


Fig. 2: Location of soil sampling points in Minapur, Kanti and Marwan block of Muzaffarpur

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.

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 Nitrogen (kg ha^{-1})	Alkaline KMnO_4 method	(Subbiah and Asija, 1956)

Available Phosphorus(kg ha ⁻¹)	Olsen's method	(Olsen, 1954)
Exchangeable Potassium (kg ha ⁻¹)	Ammonium Acetatemethod	(Hanway and Heidel, 1952)
Available Sulphur(kg ha ⁻¹)	Calcium chloridemethod	(Chesnin and Yien, 1951)

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.

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 Table 1 and 2.

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%

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 (Neina, 2019). In the present study the soil pH value across the study area was found to be in the alkaline range. Most of the soils were alkaline with a minimum pH value of 7.54 and maximum 8.96 (Table 2). Earlier similar results were also reported by Singh *et al.*,

2012. The high pH showed in the area value may be due to natural systems like mineralogy, climate, weathering, excess use of basic-forming fertilizers, etc. The generating soil fertility thematic map showing the distribution of soil pH in the study area is depicted in Fig 3. The soil map clearly indicates the distribution of pH value greater than 8.0 in northern part of the study area while the remaining area falls under soil pH value 7.5 – 8.0 (Fig. 3.). The similar results were also reported by Tagung *et al.*, (2022) which is alkaline in nature having pH value more than 7.5.

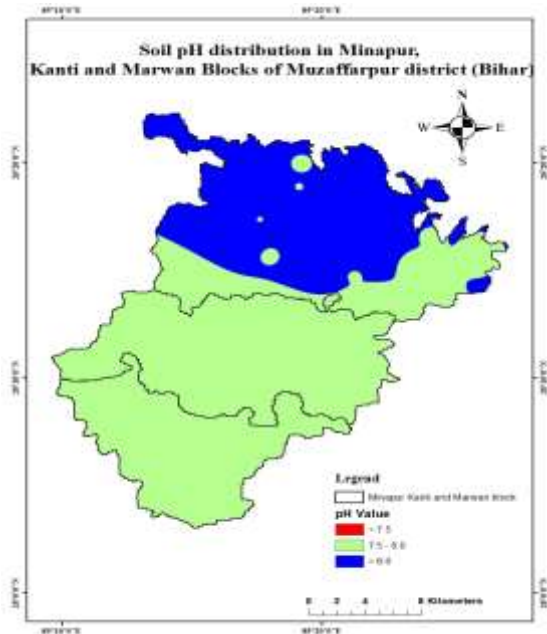


Fig. 3 Soil pH distribution in Minapur, Kanti and Marwan Block of Muzaffarpur district

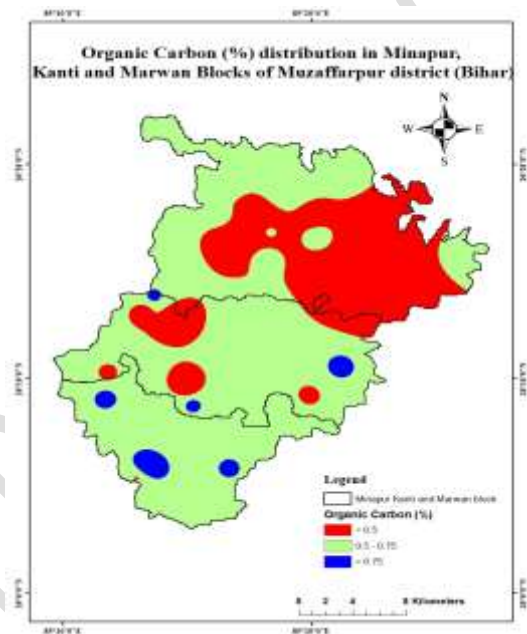


Fig. 4 Organic matter distribution in Minapur, Kanti and Marwan Block of Muzaffarpur district

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.

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).

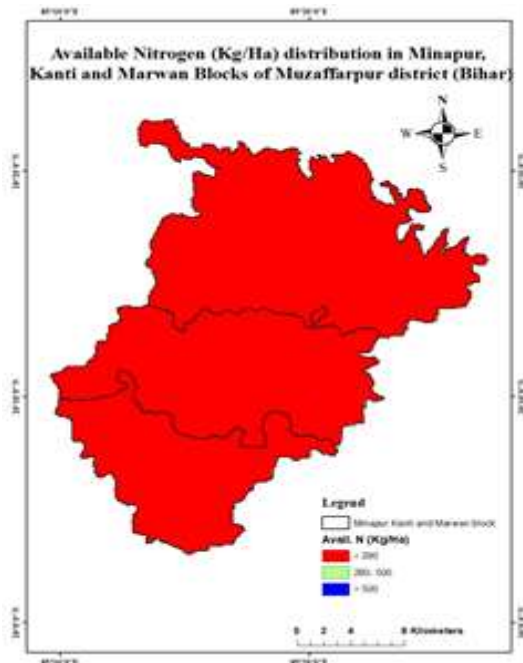


Fig. 5 Distribution of available Nitrogen (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

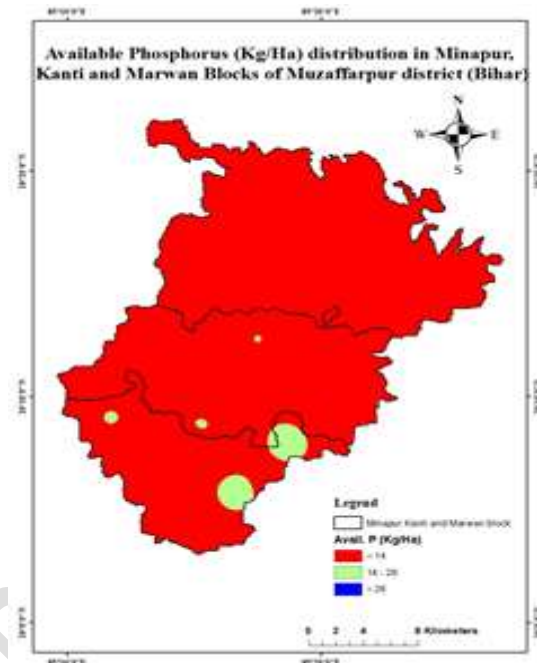


Fig. 6 Distribution of available Phosphorus (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

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.*, (2019) 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. 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.*, 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.

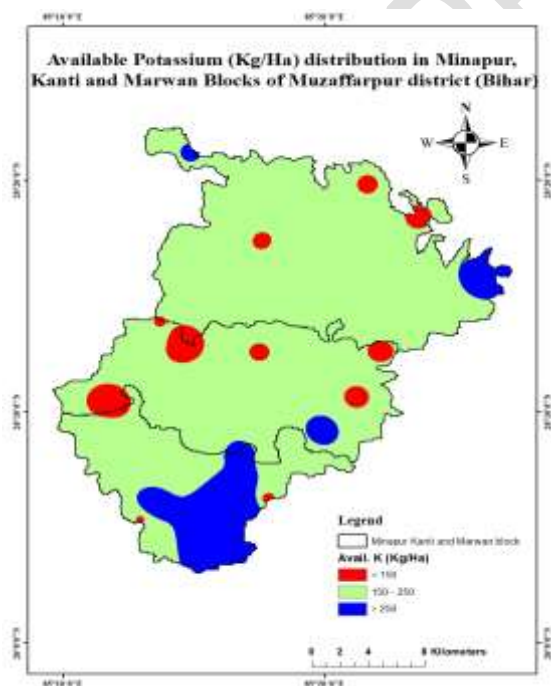


Fig. 7 Distribution of available Potassium (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

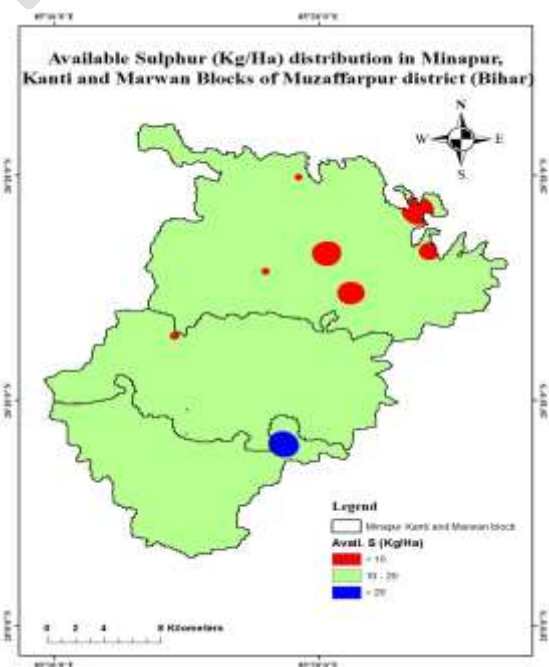


Fig. 8 Distribution of available Sulphur (kg/ha) in Minapur, Kanti and Marwan Block of Muzaffarpur district

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 (kg ha⁻¹) with a mean value of 12.54 kg ha⁻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., 2022. Half of the study area falls under medium sulphur content. Tagung *et al.*, (2022) also reported the status of available sulphur content ranged from 6.20 to 22.1 (kg ha⁻¹) with a mean value of 12.2 kg ha⁻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.

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.

REFERENCES

- Brady, N. C., and Weil, R. R. (2002). Soil and the hydrologic cycle. *The Nature and Properties of Soils*, 2.
- Chesnin, L., and Yien, C. H. (1951). Turbidimetric determination of available sulfates. *Soil Science Society of America Journal*, 15(C): 149-151.
- Das, B., Bordoloi, R., Thungon, L. T., Paul, A., Pandey, P. K., Mishra, M., and Tripathi, O. P. (2020). An integrated approach of GIS, RUSLE and AHP to model soil erosion in West Kameng watershed, Arunachal Pradesh. *Journal of Earth System Science*, 129(1): 1-18.
- Das, D. K. (2004). Role of geoinformatics in sustainable agriculture: Research, extension and service to the farmers. Chairman's address. In *Proceedings of the symposium Geoinformatics Applications for Sustainable Development* (pp. 1-11).
- Habibie, M. I., Noguchi, R., Shusuke, M., and Ahamed, T. (2021). Land suitability analysis for maize production in Indonesia using satellite remote sensing and GIS-based multicriteria decision support system. *GeoJournal*, 86(2): 777-807.
- Hanway, J. J., and Heidel, H. (1952). Soil analysis methods as used in Iowa state college soil testing laboratory. *Iowa agriculture*, 57: 1-31.
- Hemalatha, S., Sharuk Khan, M., Kalimuthu, D., Meiyandhan, M., Shrena Balasuramian, P. and Masilamani, P. (2020). Characterization and Delineation of

- soil properties of AnbilDharmalingam agricultural college and research institute farm, Tiruchinapalli. *International Journal of Theoretical and Applied Sciences*, 12(1): 30-36.
- Jackson, M. L. (1973). Soil Chemical Analysis Prentice Hall of Indian Private Limited. *New Delhi*.
- Kumar, Ajeet., Chattopadhyay, S. and Meena, S.K. (2023) Soil Fertility Assessment of Sugarcane Growing Villages in Samastipur District of Bihar. *Environment and Ecology*. 41 (2): 759-764, April-June 2023. ISSN 0970-0420. Paper link: <https://doc.article-environmentandecology.com/external/file/15vy05a767e7a4e17435695f722fc209e2248>
- Kumar, B., Sinha, S. K., Kumar, Ajeet., and Kumari, A. (2024). Exploring the Impact of Organic-Inorganic Coupling on Nutrient Use Efficiency and Cane Yield in Calcareous Soils of the Indo-Gangetic Plains of India. *Journal of Advances in Biology & Biotechnology*, 27(6), 644-656. <https://doi.org/10.9734/jabb/2024/v27i6924>; <https://hal.science/hal-04588263>.
- Meena, S.K., Kumar, Ajeet., Meena, K.R., Sinha, S.K., Rana, L., Singh, A. K., Parewa, H. P. and Meena, V. S (2024). Advanced and Emerging Techniques in Soil Health Management. Pages: 343-362; In: Bhatia, R.K., Walia, A. (eds) *Advancements in Microbial Biotechnology for Soil Health. Microorganisms for Sustainability*, vol 50. Springer, Singapore. https://doi.org/10.1007/978-981-99-9482-3_15.
- Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. *Applied and Environmental Soil Science*, 2019.
- Olsen, S. R. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (No. 939). US Department of Agriculture.
- Parmar, S. H., Panwar, G., Patel, G. R., and Pampaniya, N. K. (2022). Use of Remote Sensing and GIS Technologies in Soil and Water Conservation. *Advanced Innovative Technologies in Agricultural Engineering for Sustainable Agriculture*, 105.
- Schroder, P., Beckers, B., Daniels, S., Gnädinger, F., Maestri, E., Marmioli, N., Mench, M., Millan, R., Obermeier, M. M., Oustrière, N., and Persson, T. (2018). Intensify production, transform biomass to energy and novel goods and protect soils in Europe- A vision how to mobilize marginal lands. *Science of the Total Environment*, 616: 1101-23.
- Singh, K. K., Adarsh, A., and Kumari, A. (2019). Evaluation of Soil fertility status in Kanti block of Muzaffarpur district of North Bihar. *International Journal of Chemical Studies*, 7(1): 1375-1379.
- Singh, K. K., Kumar, R., Kumari, S., and Singh, Y. (2012). Soil fertility status in Kurani block of Muzaffarpur district of Bihar. *Research on Crops*, 13(1): 398-400.
- Sinha, S.K., Kumar, A., Kumari, A and Singh, A.K. (2024) The Integrated Effect of Organic Manure, Biofertilizer and Inorganic Fertilizer on Soil Properties, Yield and Quality in Sugarcane Plant-ratoon System under Calcareous Soil of Indo Gangetic Plains of India. *Journal of Scientific Research and Reports (JSRR)*. 30(5): 193-206. <https://doi.org/10.9734/jsrr/2024/v30i51934>; <https://hal.science/hal-04507744>.
- Subbiah, B. V., and Asija, G. L. (1956). A Rapid Procedure for the Estimation of Available Nitrogen in Soils. *Current Science*, 25(8): 259-260.
- Sun, B., Zhou, S., and Zhao, Q. (2003). Evaluation of spatial and temporal changes of soil quality based on geostatistical analysis in the hill region of subtropical China. *Geoderma*, 115(1-2): 85-99.

- Tagung, T., Singh, S. K., Singh, P., Prasad, S.S., Kashiwar, S. R. and Singh, S. K. (2022). Assessment of the spatial distribution of soil nutrients and mapping using GPS and GIS in blocks of Muzaffarpur District, Bihar. *The Pharma Innovation Journal*, 11(9): 683-692.
- Upadhyay, K. K., Sharma, K., Singh, M. K., and Pandey, A. C. (2020). Physic-chemical study of soil in Dholur city. *International Journal of Theoretical and Applied Sciences*, 12(1): 10-03.
- Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, 37(1): 29-38.

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