Fundamental and Applied Agriculture
Vol. 7(4), pp. 308–316: 2022
doi: 10.5455/faa.93545

REMOTE SENSING | ORIGINAL ARTICLE

Use of GIS for spatial mapping of soil fertility in Dhanushadham Municipality, Dhanusha, Nepal

Karuna Kafle, Santosh Kumar Yadav*, Abichal Poudel, Rashil Gelal, Bhusan Adhikari, Biplov Oli

G.P Koirala college of Agriculture and Research Centre (GPCAR), Morang, Nepal

ARTICLE INFORMATION

Article History
Submitted: 10 Oct 2022
Accepted: 25 Dec 2022
First online: 30 Dec 2022

Academic Editor
Md Rostom Ali
rostomfpm@bau.edu.bd

**Corresponding Author*
Santosh Kumar Yadav
Sy607667@gmail.com

OPEN ACCESS

ABSTRACT

Soil fertility evaluation is an important aspect in the coxt of sustainable agricultural production of an area. This study was carried out to find the soil fertility status of the Dhanushadham Municipality, Dhanusha, Nepal located at 26°52'N, 86°02'E using GPS and GIS using Google Earth Pro (GEP) and ArcGIS, 61 soil samples were collected based on land use, slope, and aspects. The soil's texture, pH, total nitrogen, available phosphorous, and potassium levels were all measured. Most of the study area (36.35%) has loam soils, followed by sandy loam soil (28.17%). The soil pH ranged from 5.2 to 7.5, indicating that it was strongly acidic to nearly neutral. Soil organic matter (SOM) ranged from 1.14% to 1.83% with a mean value of 1.52% in most of the soil. Total nitrogen was 0.08%, available phosphorus was 120.96 kg/ha, and available potassium was 146.13 kg/ha, respectively. In the study area, total nitrogen was found to be medium, phosphorus found to be high, and potassium was found to be low. To maintain soil nutrient status, organic manure, reduced use of chemical fertilizers, and different soil management practices should be considered. The study concludes that GPS and GIS-based soil fertility mapping assists farmers, scientists, planners, researchers, and students in providing soil test-based fertilizer recommendations for sustainable soil management and developing future farm research strategies.

Keywords: ArcGIS, soil fertility, soil Organic matter, spatial variation

Cite this article: Kafle K, Yadav SK, Poudel A, Gelal R, Adhikari B, Oli B. 2022. Use of GIS for spatial mapping of soil fertility in Dhanushadham Municipality, Dhanusha, Nepal. Fundamental and Applied Agriculture 7(4): 308–316. doi: 10.5455/faa.93545

1 Introduction

Fertile and productive soil enhances life whereas, infertile and unproductive soil decreases soil productivity leading to hunger and famine. However different calamities like soil erosion, landslides, flood, and other different soil degradation factors cause a serious problem in rapid nutrient depletion and pose a great challenge in soil fertility management. Therefore, soil fertility evaluation and its spatial distribution play an important decision-making role in planning a particular land-use system (Oli et al., 2020).

The evaluation of soil fertility is the measurement of available plant nutrients and estimation of soil capacity to maintain continue the supply of plant nutrients for agricultural practices. Among the various techniques for a soil fertility evaluation, soil testing is the most widely used technique in the world (Havlin et al., 2010).The analysis of physical and chemical properties of soil and soil testing is obligatory for the sustainable management of soil (Panda, 2010).

Soil testing provides information regarding the nutrient availability in soils which forms the basis for the fertilizer recommendations for maximizing crop yields.The texture, structure, color are important physical parameters of soil while the soil pH, organic matter, macro, and micronutrients are important chemical parameters of soil. These soil parameters are determined only after analyzing them in the laboratory (Khadka, 2018). Mapping the status and the spatial distribution of soil fertility plays an important role in the sustainable land use planning process (Khadka et al., 2018). The use of new technologies like GIS and GPS makes it easy in describing the spatial variability of soil fertility for a larger area. The geographic information system (GIS) is a powerful software tool for collecting, storing, retrieving, transforming, and displaying data (Cone, 1998).

Collection of soil samples by using GPS is very important for preparing thematic soil fertility maps (Mishra et al., 2013). The Geographical Information System (GIS) is a potential tool to access, retrieve and manipulate voluminous data of natural resources which is difficult to handle manually. The GPS and GIS technologies have been adopted in agriculture for better management of land and other resources for sustainable crop production (Palaniswami et al., 2011).

2 Methodology

2.1 Study area

The research was conducted in the Dhanushadham municipality of Dhanusa, Nepal (Fig. 1). The study site is at 26°52'N, 86°02'E. The study area has a subtropical climate with hot and wet summers and cool, dry winters. The average air temperature ranges from around 9 °C in winter to around 40 °C in summer. Because rainfall is not uniform throughout the year, more than 85% of the rain falls for four months (June–September). The variability and intensity of rainfall, on the other hand, affect the stability of the landscape for soil development. Rice, wheat, mustard, maize, sugarcane, mung, lentils, vegetables, and pulses are the most important crops in Dhanushadham municipality.

2.2 Soil survey methods

A total of 61 soil samples (0-20 cm depth) were collected from various locations throughout the Dhanusa district. The precise locations of the samples were recorded using a handheld GPS receiver to create thematic soil fertility maps, which were then imported into ArcGIS software. Soil samples were collected using a random method based on the variability of the land. A detailed soil survey of the study area was conducted using an ArcGIS grid map. The land system units, morphology, land use condition, and geology were used to determine soil sampling locations. Soil samples were taken for laboratory analysis of soil parameters such as particle size distribution, pH, total nitrogen, organic matter, available phosphorus, and available potassium.

2.3 Laboratory soil sample analysis

Soil samples were collected in the field and air-dried in the shade before being crushed and sieved for physicochemical laboratory analysis. Table 1 lists the parameters tested and the methods used.

2.4 Statistical analysis and soil fertility mapping

Latitude, longitude, and soil analysis data were entered into the attributed table in MS-Excel professional plus 2016 and processed with ArcGIS10.8 software. For predicting values for non-sampled locations, thematic soil fertility maps and geospatial tools such as ordinary Kriging (OK) and interpolation (Cressie, 2015) were preferred. Ordinary Kriging is a sophisticated geostatistical tool that generates a surface from a scattering of points by incorporating their properties (Economic and Social Research Institute, 2001). Soil parameters' descriptive statistics (minimum, maximum, mean, and standard deviation) were computed using MS Excel professional plus 2016 and the ArcGIS10.8 package. Soil testing laboratory in Nepal provided ratings (very low, low, medium, high, and very high) for determining values of various parameters. To create a spatial distribution map of soil parameters, Arc Map10.8 with the geostatistical analyst extension of ArcGIS software was used, and the interpolation method used was ordinary kriging with a stable semi-variogram.

3 Results and Discussion

Mechanical composition, pH, organic matter, nitrogen, available phosphorus, and potassium were all measured in soils.

3.1 Soil texture

The proportion of sand, silt, and clay in soil texture is a permanent feature of soils. Soil texture has a direct impact on water infiltration, drainage, and nutrient retention, as well as crop production, land use, and land management (Brady et al., 2008). The textural model was used in the laboratory to determine the soil texture of the first horizon (0-20 cm). In the study area, seven different classes of soil texture were identified, with loan soil (36.65%) dominating, followed by sandy loam (28.17%), silty loam (13.6%), silty clay loam (6.97%), clay (6.83%), sandy clay loam (6.34%), and clay loam (1.74%). Table 2 and Fig. 2 show that loam soil occupied the most area (36.35%), while clay loam occupied the least (1.74%). The sandy loam, loam, sandy clay loam site is suitable for growing a variety of crops; however, special care should be taken for soil conservation and water management in sloppy areas.

3.2 Soil PH

The acidity and alkalinity of the soil are influenced by the presence of various acid and base-forming cations. Soil pH is a critical chemical parameter that influences nutrient availability, solubility, and plant

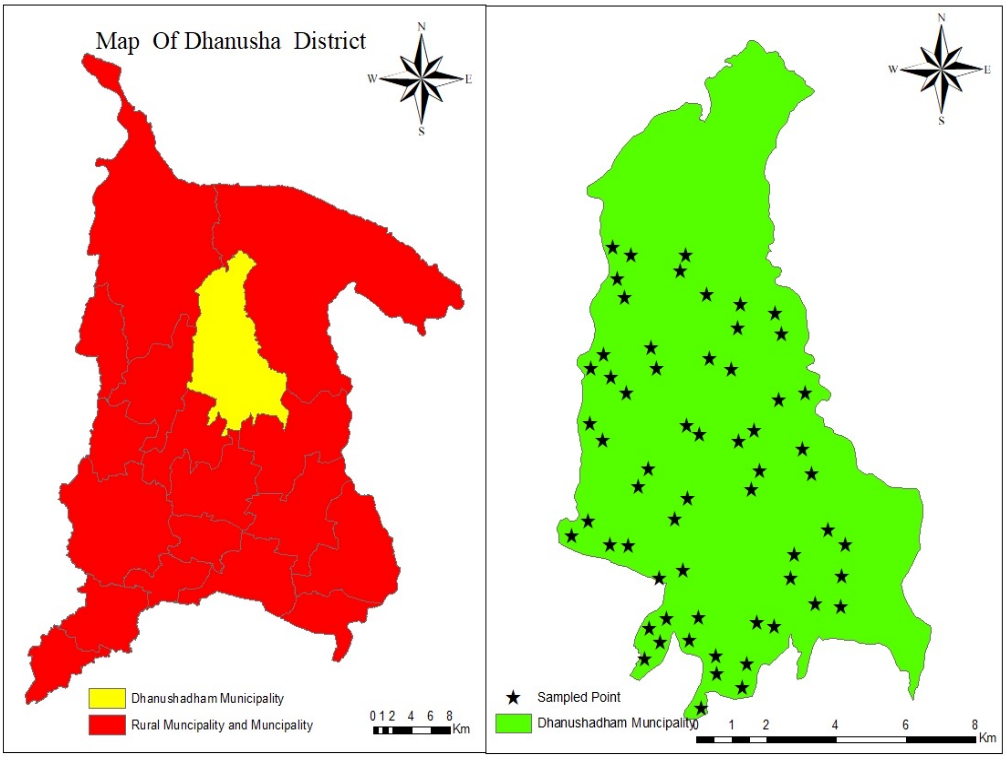

Figure 1. Location of the study site. Dhanushadham and Soil sampling points inside the study area

Table 1. Soil parameters and laboratory soil test methods

Test parameters	Methods
Particle size fraction and texture	Hydrometer (Bouyoucos, 1962) and USDA Textural triangle
Soil pH	1:2.5 soil water suspension (Jackson, 1967)
Soil organic matter content (%)	(Walkley and Black, 1934)
Total nitrogen content (%)	Micro-Kjeldahl (Bremner and Mulvaney, 2015)
Available phosphorus (P2O5 kg/ha)	(Olsen, 1954)
Available potassium (K2O kg/ha)	Ammonium acetate (Jackson, 1967)

Table 2. Area occupying different soil textural classes in Dhanushadham Municipality, Dhanusha, Nepal

Textural class	Area (ha)	(Percentage)
Loam	3328.31	36.35%
Sandy loam	2579.17	28.17%
Silty loam	1245.21	13.6%
Silty clay loam	638.28	6.97%
Clay	625.88	6.83%
Sandy clay loam	581.25	6.34%
Clay loam	159.89	1.74%
Total area	9157.99	100%

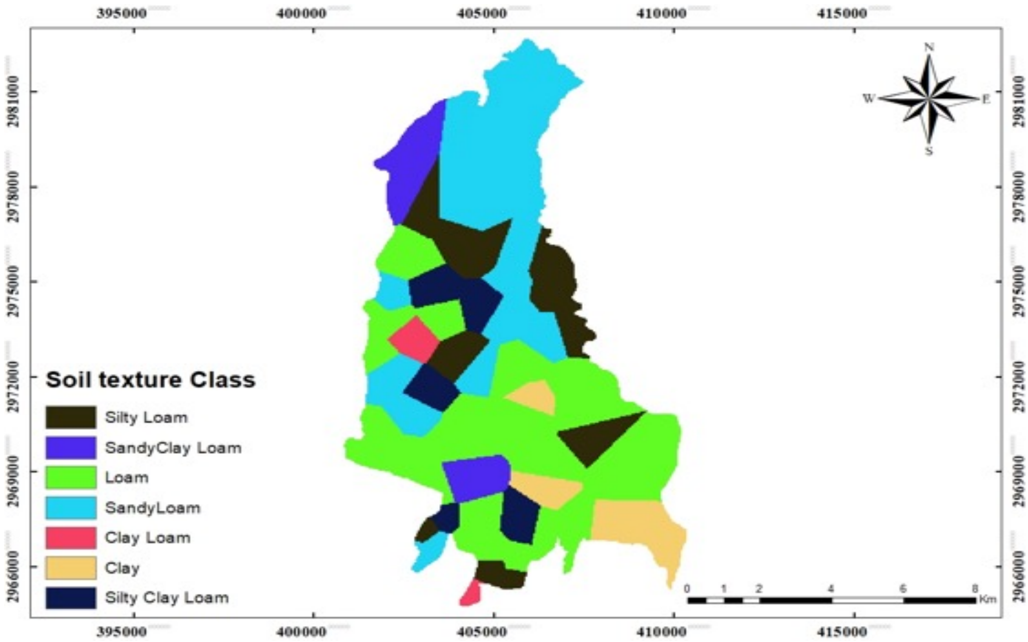

Figure 2. Spatial distribution of soil texture in Dhanushadham Municipality, Dhanusha, Nepal

growth (Brady et al., 2008). Higher soil acidity causes nutrient loss such as Ca and Mg, increases phototoxic elements such as Al and Mn, reduces the activity of beneficial microbes, and destroys soil structure, resulting in unfavorable soil conditions (Nduwumuremyi et al., 2013). As a result, soil acidity should be reduced to improve soil fertility for long-term soil management. As a result, agricultural lime should be used to raise the pH of the soil. The soil pH ranged from 5.2 to 7.5 in the study area, with a mean of 6.30 and a standard deviation of 0.69. The pH of the soil ranged from strongly acidic to nearly neutral. Most of the study area (28.01%) is covered by moderately acidic soil, with slightly acidic soil (28%) and strongly acidic soil (25.25%). Fig. 3 and Table 3 show that nearly neutral soils cover approximately 18.24% of the land area.

3.3 Soil organic matter

Soil organic matter (SOM) is essential for crop performance and soil health because it improves various physical, biological, and chemical properties (Hoyle et al., 2011). Because of its ability to absorb large amounts of water, SOM has a direct impact on water holding capacity. Table 4 shows that the organic matter content ranged from 1.14 to 1.83%, with a mean value of 1.52%. Organic matter distribution ranged from low to medium, with medium being the most common (Fig. 4). As shown in Table 5 and Fig. 5, approximately 62.85% of the total area has a medium range of SOM content and 37.15% of the total area has a low range of SOM.

3.4 Total nitrogen

Nitrogen is one of the most important nutrients for plant growth and development. Nitrogen gives plants a dark green color and promotes vegetative growth (Bloom, 2015). Plants obtain nitrogen from the soil, which is naturally added to the soil through N-fixation by soil bacteria and legumes. Nitrogen from the soil is absorbed by plants as nitrate (NO_3^-) and ammonium (NH_4^+). Yellowing of plant leaves, slowed growth, decreased apical dominance, and poor vegetative growth are all symptoms of nitrogen deficiency (Bloom, 2015). Fig. 4 and Table 5 show that the total nitrogen content in the study area ranged from 0.08% to 0.13%, with a mean value of 0.08%. Nitrogen content ranged from low to medium. In the study area, approximately 68.91% of the total area has a medium range of nitrogen and 31.09% has a low range of nitrogen.

3.5 Available phosphorous

Phosphorus, along with nitrogen, is frequently the most limiting nutrient for plant growth and development (Sharma et al., 2017). Phosphorous allows plants to use the energy captured by photosynthesis to strength their metabolism. Phosphorus also aids legume production by increasing the activity of nodule bacteria, which fixes nitrogen in the soil.

Fig. 6 and Table 5 show that the available phosphorous content in the study area ranged from 40.02 to 282.59 kg/ha, with a mean value of 120.95 kg/ha. The available phosphorus content ranged from medium to very high. In the study area, approximately 59.83 kg/ha of the total area has a high range

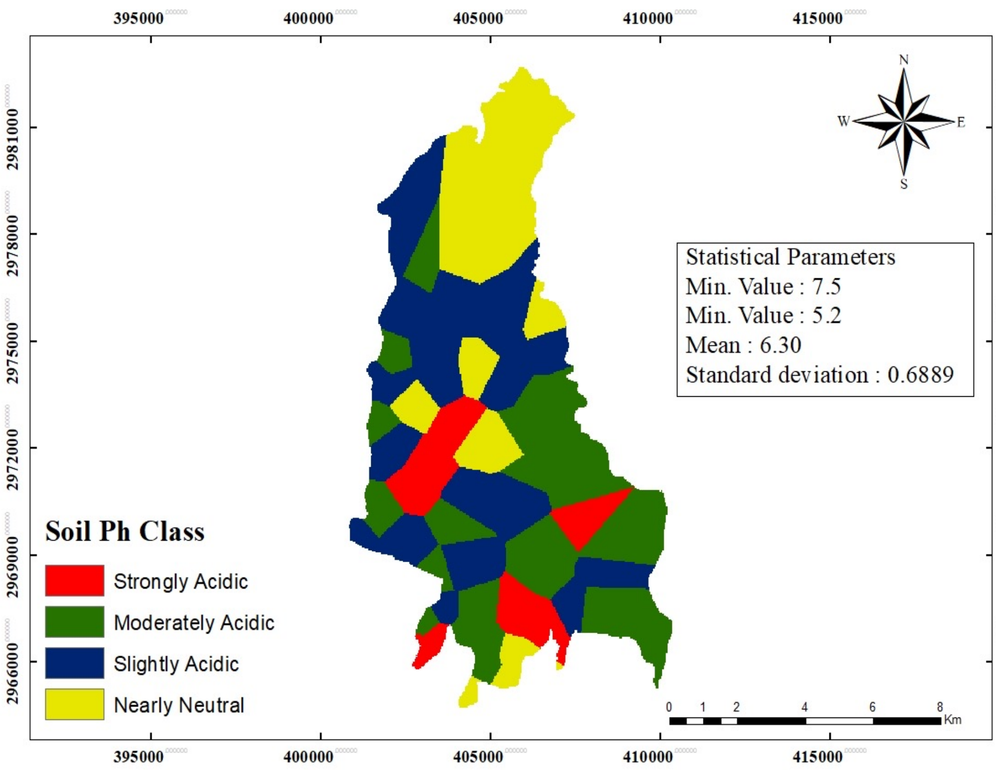

Figure 3. Spatial distribution of soil pH in Dhanushadham Municipality, Dhanusha, Nepal

Table 3. Area occupying different pH classes in Dhanushadham Municipality, Dhanusha, Nepal

Soil reaction (pH)	Area (ha)	Percentage
Moderately acidic	2564.8	28.01%
Slightly acidic	28.01	28.00%
Strongly acidic	2312.96	25.25%
Nearly neutral	1716.15	18.74%
Total area	9157.99	100%

Table 4. Soil fertility status of Dhanushadham Municipality, Dhanusha, Nepal

Soil parameters	Min. Value	Max. Value	Mean Value	Standard Deviation
Soil pH	5.2	7.5	6.3	0.6889
SOM (%)	1.14	1.83	1.52	0.1441
Total nitrogen (%)	0.05	0.13	0.08	0.0147
Available P2O5 (kg/ha)	40.02	282.5	120.96	60.642
Available K2O (kg/ha)	8.44	1026.89	173.79	104.6048

SOM: soil organic matter

Table 5. Area occupying different classes of soil parameters in Dhanushadham Municipality, Dhanusha, Nepal

Soil parameters	SOM	Total N	Available P	Available K
Very low	NA	NA	NA	69.502 −0.74%
Low	3402.21 −37.15%	2848.94 −31.09%	NA	1876.21 −20.49%
Medium	5755.78 −62.85%	6309.05 −68.91%	308.24 −3.37%	6389.75 −69.82%
High	NA	NA	5476.7 −59.80%	592.19 −6.45%
Very high	NA	NA	3373.04 −36.83%	230.34 −2.50%
Total area (ha)	9157.99	9157.99	9157.99	9157.99

SOM: soil organic matter, NA: data not available

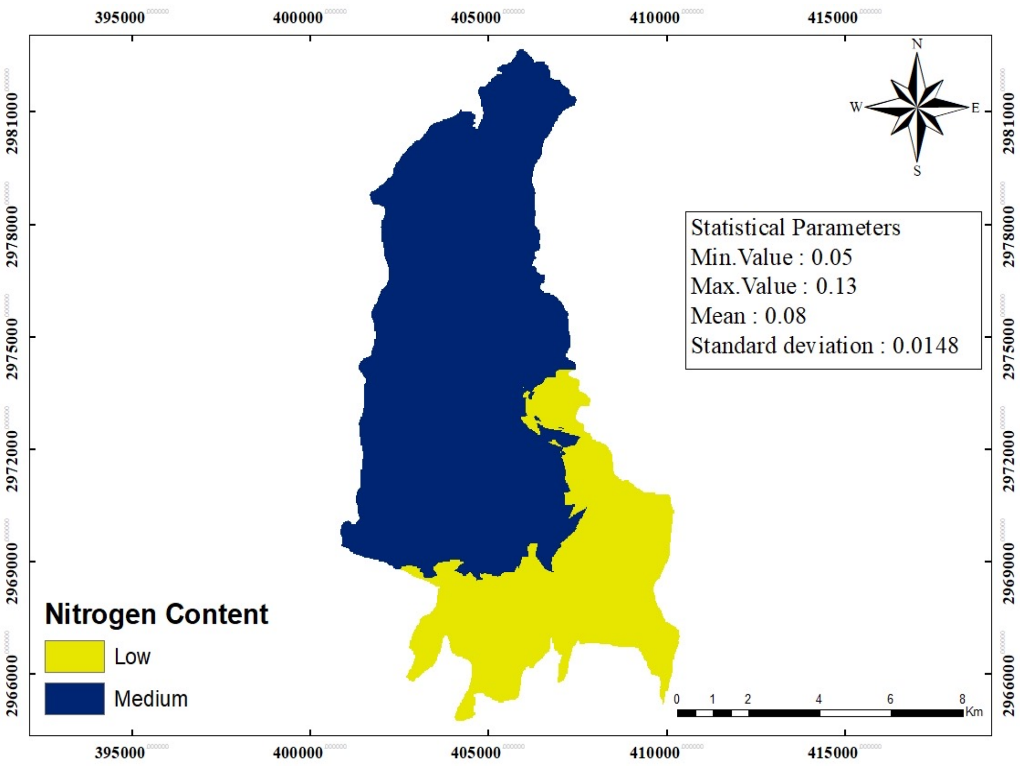

Figure 4. Spatial distribution of total nitrogen in Dhanushadham Municipality, Dhanusha, Nepal

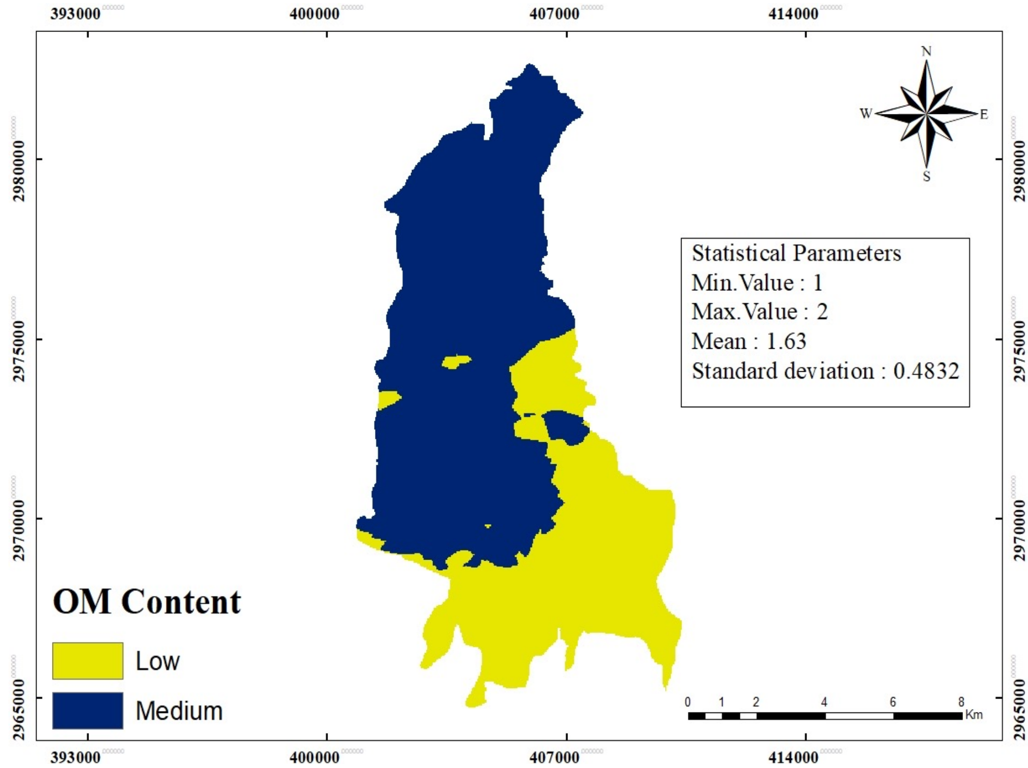

Figure 5. Spatial distribution of soil organic matter in Dhanushadham Municipality, Dhanusha, Nepal

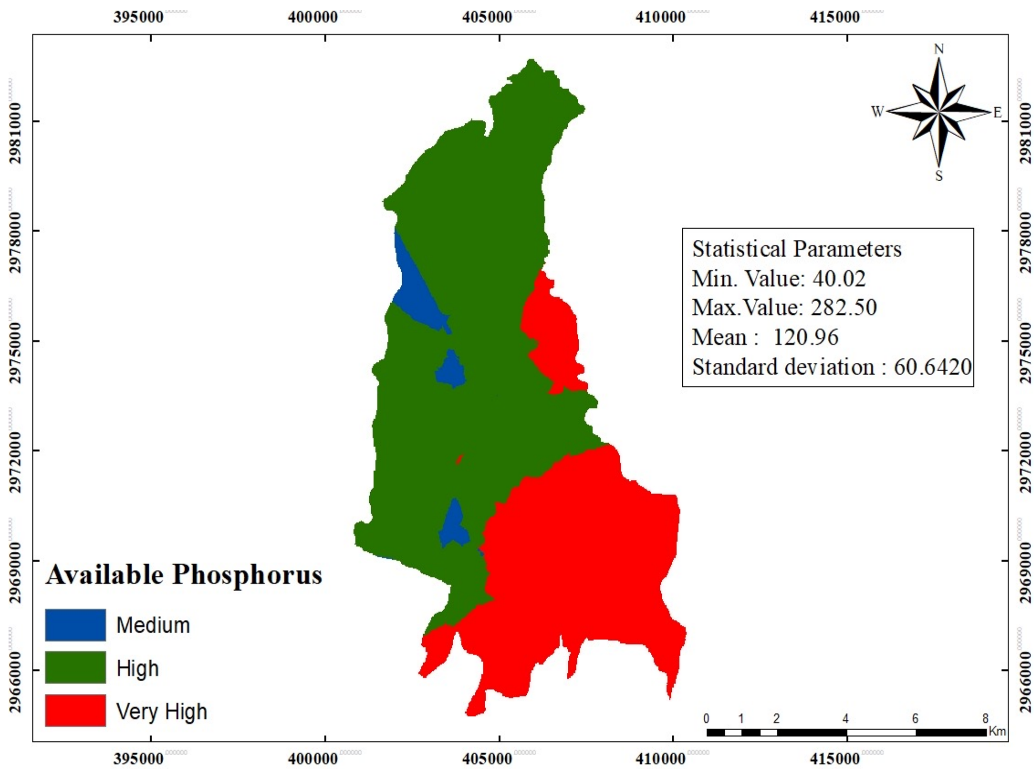

Figure 6. Spatial distribution of available phosphorus in Dhanushadham Municipality, Dhanusha, Nepal

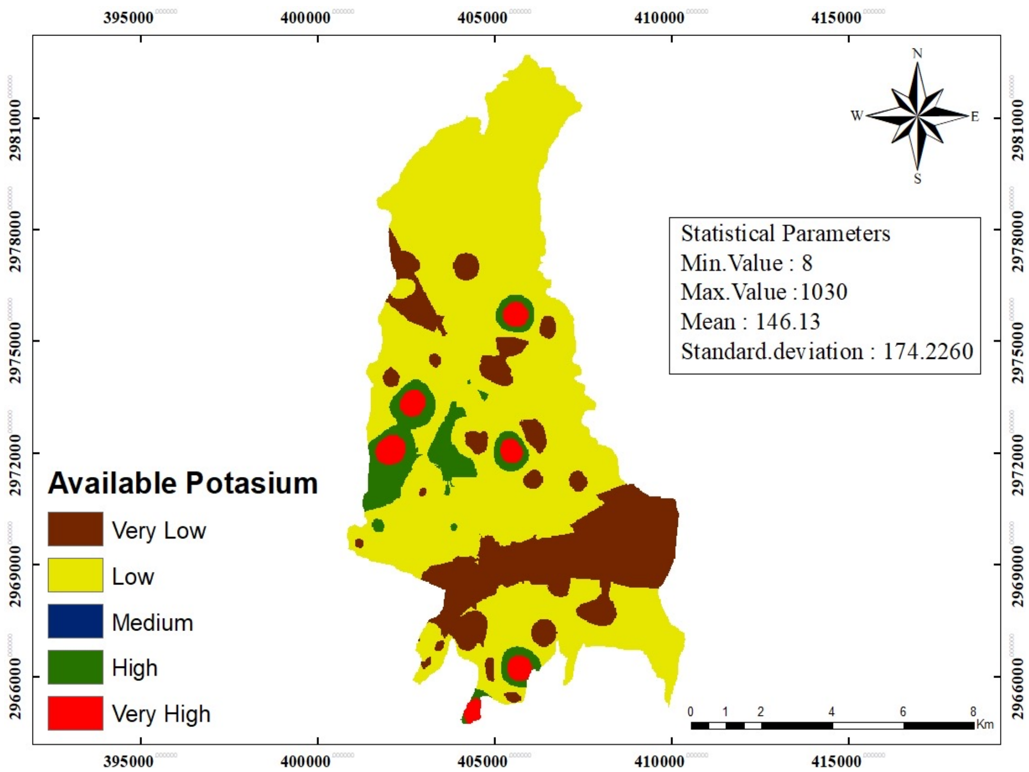

Figure 7. Spatial distribution of available potassium in Dhanushadham Municipality, Dhanusha, Nepal

of phosphorus, 36.83 kg/ha has a very high range of phosphorus, and 3.34 kg/ha has a medium range of available phosphorus.

3.6 Available potassium

Following nitrogen and phosphorus, potassium (K) is the third most important essential element that limits plant productivity (Havlin et al., 2010). It is essential in the synthesis of amino acids and proteins from ammonium ion absorbed from the soil. The study area's available potassium content ranged from 169.87 to 358.68 kg/ha, with a mean value of 146.13 kg/ha. The available potassium content ranged from very low to very high, with phosphorus dominating the medium range. According to Fig. 7 , Tables 4 and 5, approximately 69.82% of the total area has a medium range of phosphorus, followed by low (20.49%), high (6.45%), very high (2.5%), and 0.74% has a very low range of available potassium.

4 Conclusion

Dhanusadham's soil nutrient status was mapped using GIS, which can support nutrient management. The pH of the soil in the study area was mostly acidic, ranging from 5.2 to 7.5. SOM, an essential component of soil nutrients, ranged from very low to medium across the municipality. There was no discernible difference in SOM content between land types. The total nitrogen content ranged from low to medium across the municipality, with a grand mean of 0.08%, which is low. There was no significant difference in N-content based on land use. Similarly, available phosphorous ranged from medium to very high throughout the municipality, with a mean value of 120.95 kg/ha, and available potassium ranged from very low to very high, with a mean of 146.13 kg/ha.

Acknowledgments

We are grateful to PMAPMP, PIU Dhanusha for providing us Intern opportunity. Also, we would like to extend deepest gratitude towards our advisor Mr. BiplovOli for his consistent and guidance. Furthermore, we are grateful towards our college administration (PU, GPCAR).

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Bloom AJ. 2015. The increasing importance of distinguishing among plant nitrogen sources. Current Opinion in Plant Biology 25:10–16. doi: 10.1016/j.pbi.2015.03.002.

Bouyoucos GJ. 1962. Hydrometer method improved for making particle size analyses of soils 1. Agronomy Journal 464–465:11–20.

Brady NC, Weil RR, Weil RR. 2008. The nature and properties of soils. volume 13. Prentice Hall Upper Saddle River, NJ.

Bremner JM, Mulvaney CS. 2015. Nitrogen-Total. In: Agronomy Monographs. American Society of Agronomy, Soil Science Society of America. p. 595–624. doi: 10.2134/agronmonogr9.2.2ed.c31.

Cone J. 1998. Principles of geographical information systems by Peter A. New Zealand Geographer 54:56–57. doi: 10.1111/j.1745-7939.1998.tb02089.x.

Cressie N. 2015. Statistics for Spatial Data. John Wiley & Sons.

Havlin HL, Beaton JD, Tisdale SL, Nelson WL. 2010. Soil Fertility and Fertilizers- an introduction to nutrient management (7th edition). PHI Learning Private Limited, New Delhi, India.

Hoyle FC, Baldock JA, Murphy DV. 2011. Soil organic carbon – role in rainfed farming systems. In: Rainfed Farming Systems. Springer Netherlands. p. 339–361. doi: 10.1007/978-1-4020-9132-2_14.

Jackson ML. 1967. Soil chemical analysis prentice, Vol 498 (1). Hall of India Private Limited, New Delhi.

Khadka D. 2018. Soil fertility assessment and mapping of chungbang farm, Pakhribas, Dhankuta, Nepal. Advances in Plants & Agriculture Research 8:219–227. doi: 10.15406/apar.2018.08.00317.

Khadka D, Lamichhane S, Bhurer KP, Chaudhary JN, Ali MF, Lakhe L. 2018. Soil fertility assessment and mapping of Regional Agricultural Research Station, Parwanipur, Bara, Nepal. Journal of Nepal Agricultural Research Council 4:33–47. doi: 10.3126/jnarc.v4i1.19688.

Mishra A, Das D, Saren S. 2013. Preparation of gps and gis based soil fertility maps for Khurda district, Odisha. Indian Agriculturist 57:11–20.

Nduwumuremyi A, Ruganzu V, Mugwe JN, Rusanganwa AC. 2013. Effects of unburned lime on soil pH and base cations in acidic soil. ISRN Soil Science 2013:1–7. doi: 10.1155/2013/707569.

Oli B, Lamichhane S, Oli K. 2020. Use of GIS in soil fertility mapping of Rapti Municipality, Chitwan, Nepal. Journal of Agriculture and Applied Biology 1:64–73. doi: 10.11594/jaab.01.02.04.

Olsen SR. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture.

Palaniswami C, Gopalasundaram P, Bhaskaran A. 2011. Application of GPS and GIS in sugarcane agriculture. Sugar Tech 13:360–365. doi: 10.1007/s12355-011-0098-9.

Panda SC. 2010. Soil Management and Organic Farming. Bharat Printing Press, Jodhpur, India.

Sharma L, Bali S, Zaeen A. 2017. A case study of potential reasons of increased soil phosphorus levels in the Northeast United States. Agronomy 7:85. doi: 10.3390/agronomy7040085.

Walkley A, Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29–38. doi: 10.1097/00010694-193401000-00003.

© 2022 by the author(s). This work is licensed under a Creative Commons. Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

The Official Journal of the
Farm to Fork Foundation
ISSN: 2518–2021 (print)
ISSN: 2415–4474 (electronic)
http://www.f2ffoundation.org/faa