OPEN ACCESS International Journal of Applied Biology

ISSN : 2580-2410
eISSN : 2580-2119

Use of Gis for Spatial Mapping of Soil Fertility in Dhanusha, Nepal

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Abstract

Soil fertility evaluation is an important aspect in the context 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. A total of 61 soil samples were collected based on land use, slope, and aspects with the use of Google Earth Pro (GEP) and *ArcGIS*. The soil was analyzed for its texture, soil pH, total nitrogen, available phosphorous, and potassium. The majority of the study area (36.35%) has loam soils followed by (28.17%) sandy loam soil. The soil pH was strongly acidic to nearly neutral with pH values ranging from 5.2 to 7.5. The Soil organic matter (SOM) varied from 1.14% to 1.83% with a mean value of 1.52% and was medium in most of the soil. The mean total Nitrogen, available phosphorus, and available potassium were 0.08 %, 120.96 kg/ha, and 146.13 kg/ha respectively. The total nitrogen was found to be medium in content, Phosphorus is high in content and potassium is low in content in the study area. To maintain the nutrient status of soil, use of organic manure, reduced use of chemical fertilizers, and different soil management practices should be adopted in this area. The study can conclude that GPS and GIS based soil fertility mapping helps farmers, scientists, planners, researchers, and students in providing soil test based fertilizer recommendation for sustainable soil management as well as developing future research strategies in the farm.

Article History
Received November 11, 2021
Accepted December 14, 2022

Keyword
ArcGIS;
Nypa fruticans;
Soil fertility;
Soil Organic Matter;
Spatial Variation

Introduction

Soil fertility is the most important factor for determining soil productivity. Fertile and productive soil enhances life whereas, unfertile 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

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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 *et al*., 2018a).Mapping the status and the spatial distribution of soil fertility plays an important role in the sustainable land use planning process (Khadka *et al*., 2018b). 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 the 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).

Method and Methodology

Study Area

The study was carried out in Dhanushadham municipality Dhanusha, Nepal (Figure 1). The study area is located at 26°52'N, 86°02'E. The climate in the study area is the subtropical type with hot and wet summer and cool, dry winter. Average air temperature ranges from a minimum of about 9°C in winter to a maximum of about 40°C in summer. Since rainfall is not uniform throughout the year, more than 85% of rainfall occurs during four months (June-September). However, the stability of the landscape for the development of soil is affected by the variability and intensity of rainfall. The major crops of Dhanushadham municipality are rice, wheat, mustard, maize, sugarcane, mung, lentils, vegetables, and pulses.

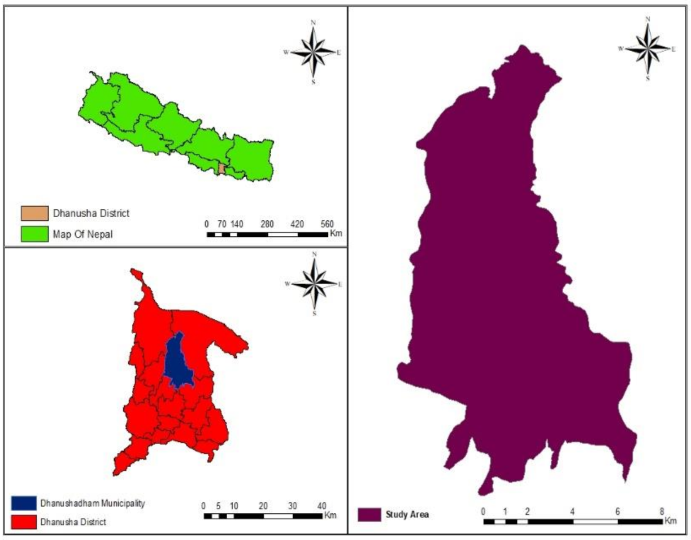

Figure 1: Location of study area

Soil Survey Methods

The total of 61 soil samples (0-20 cm depth) was collected from different location of Dhanusha district. The exact locations of the samples were recorded using a handheld GPS receiver for the preparation of thematic soil fertility maps and imported to *ArcGIS* software. The random method based on the variability of the land was used to collect soil samples. A detailed soil survey of the study area was carried out on grid map prepared using Arc GIS software. The soil sampling locations were decided based on the land system units, morphology, land use condition, and geology. The soil samples were collected for laboratory analysis of soil parameters that include particle size distribution, soil pH, total nitrogen, organic matter, available phosphorus, and available potassium.

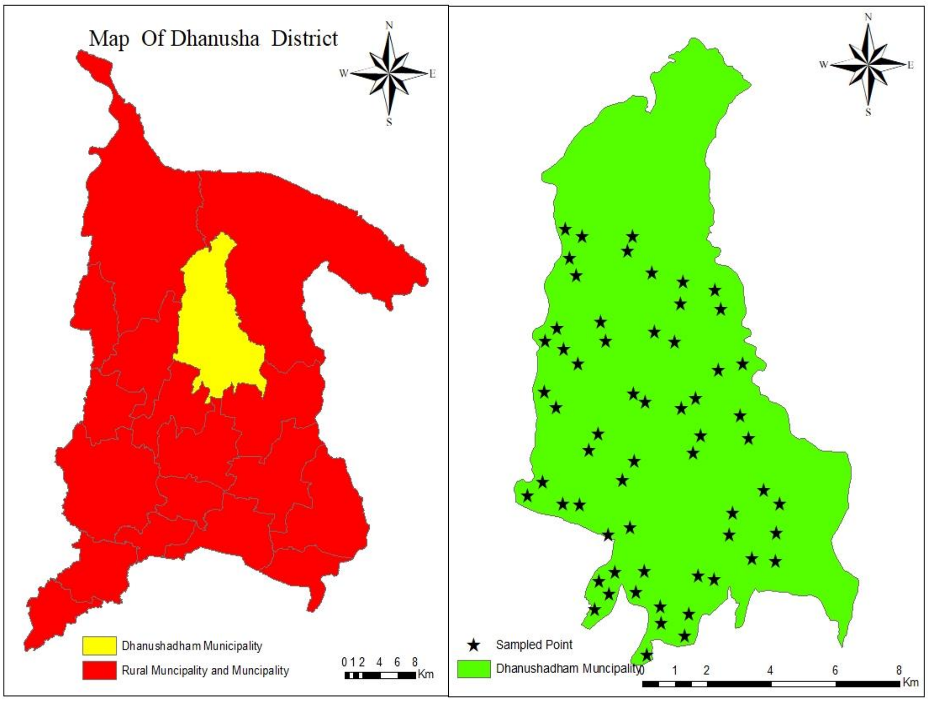

Figure 2. Dhanushadham and Soil sampling points inside the study area

Table 1. Different rating classes of soil test data adapted soil testing laboratory, Nepal

SN	Soil Parameters	Units	Very Low	Low	Medium	High	Very high
1	Organic Matter	%	<0.75	0.75-1.5	1.5-3.0	3.0-5.0	>5
2	Total Nitrogen	%	<0.03	0.03-0.07	0.07-0.15	0.15-0.25	>2.5
3	Available P_2O_5	Kg/ ha	<11	11-28	28-56	56-112	>112
4	Available K_2O	Kg/ ha	<55	55-110	110-280	280-500	>500

Table 2. Rating of soil pH adapted by soil testing laboratory, Nepal

Soil Reaction (pH)	pH Range
Extremely Acidic	<4.5
Very Strongly Acidic	4.5-5.0
Strongly Acidic	5.0-5.5
Moderately Acidic	5.5-6.0
Slightly Acidic	6.0-6.5
Nearly Neutral	6.5-7.5
Slightly Alkaline	7.5-8.0
Moderately Alkaline	8.0-8.5
Strongly Alkaline	8.5-9.5
Very Strongly Alkaline	9.5-10
Extremely Alkaline	>10

Laboratory Soil Analysis

Soil samples collected from the field were air-dried in shade, crushed, and sieved for Physic-chemical laboratory analysis. The parameters tested and methods used are given in the Table 1 and Table 3.

Table 3. Soil parameters and laboratory soil test methods

Test parameters	Methods
Particle size fraction and texture	Hydrometer (Bouyoucos, 1962) and Texture classification (USDA Texture triangle)
Soil pH	1:2.5 soil water suspension (Jackson, 1967)
Soil Organic Matter Content (%)	Walkley and Black (Walkely and Black, 1934)
Total Nitrogen content (Total N %)	Micro-Kjeldahl (Bremner and Mulvaney, 1982)
Available Phosphorus (P_2O_5 kg/ha)	Olsen (Olsen et al., 1954)
Available Potassium (K_2O kg/ha)	Ammonium acetate (Jackson, 1967)

Statistical Analysis and Soil Fertility Mapping

Latitude, longitude, and the data resulting from the soil analysis were entered into the attributed table in MS-Excel professional plus 2016 and processed in ArcGIS10.8 software. Thematic soil fertility maps and Geospatial tools i.e. ordinary Kriging (OK) and interpolation (Cressie, 1992) was preferred for predicting values for not sampled locations. Ordinary Kriging is one of the advanced geostatistical tools that create a surface by using spatial correlation from a scattered set of points by incorporating their properties

(Economic and Social Research Institute, 2001). Descriptive statistics (minimum value, maximum value, mean and standard deviation) of soil parameters were computed in the MS-Excel professional plus 2016 and *ArcGIS*10.8 package. Rating (very low, low, medium, high, and very high) of determining values of different parameters were based on Soil testing laboratory, Nepal. Arc Map10.8 with geostatistical analyst extension of *ArcGIS* software was used to prepare spatial distribution map of soil parameters, while interpolation method employed was ordinary kriging with stable semi-variogram.

Results and Discussion

Soils were analyzed for mechanical composition, pH, organic matter, total nitrogen, available phosphorus, and potassium.

Soil Texture

Soil texture is the proportion of sand, silt, and clay and is a permanent attribute of soils. Crop production, land use, and land management are greatly affected by soil texture and also it has a direct role in water infiltration, drainage, and nutrient retention (Brady & Weil, 2008). The soil texture of the first horizon (0-20cm) was determined by the laboratory test using the textural model. Seven different classes of soil texture were identified in the study area dominated by loan soil (36.65%), 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%). The highest area was occupied by loam soil (36.35%) and the lowest was occupied by clay loam (1.74%) which is presented in Table 4 and Figure 4. Sandy loam, loam, sandy clay loam site is good for the cultivation of different kinds of crops however special care should be taken for soil conservation and water management in the sloppy areas.

Table 4. Area occupying different soil textural classes in Dhanushadham Municipality, Dhanusha, Nepal

Texture 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%

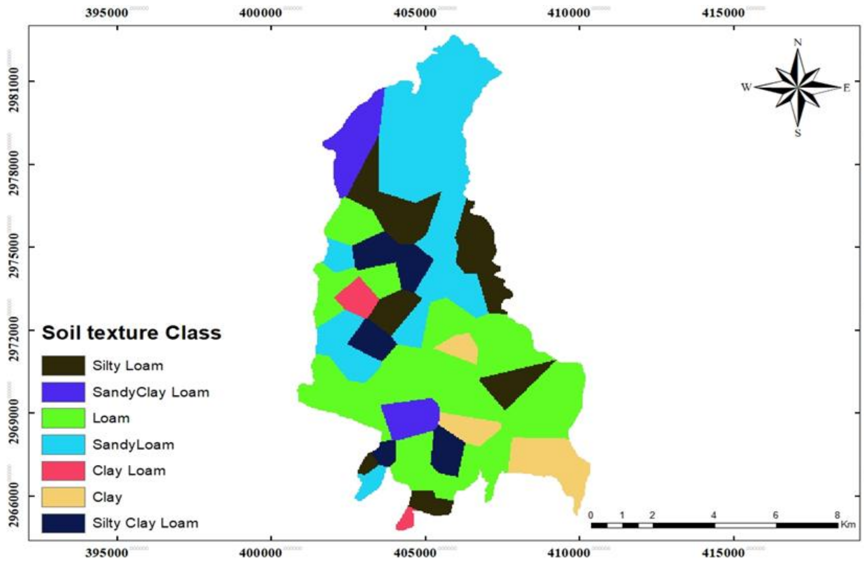

Figure 4. Spatial distribution of soil texture in Dhanushadham Municipality, Dhanusha, Nepal

Soil pH

Soil pH refers to the acidity and alkalinity of the soil influenced by the presence of different acid and base-forming cations. Soil pH is an important chemical parameter of soil that affects nutrient availability solubility, and plant growth (Brady and Weil, 2008).

Higher soil acidity causes loss of nutrients like Ca, Mg, increases phototoxic elements such as Al and Mn; reduces the activity of beneficial microbes, destroys the structure of soil leading to unfavorable soil conditions (Nduwumuremyi, 2013). Hence, soil acidity should be reduced to improve soil fertility for sustainable soil management. Therefore, agricultural lime should be applied to make soil pH adequate.

The soil pH in the study area varied from 5.2 to 7.5 with a mean value of 6.30 and a standard deviation of 0.69. The soil pH class was distributed from strongly acidic to nearly Neutral (Table 2). The majority of the study area (28.01%) is under moderately acidic soil followed by slightly acidic (28%) and strongly acidic (25.25%). About 18.24% area has nearly neutral soils as shown in Figure 5 and Table 5.

Table 5. 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%
Strongly Acidic	2312.96	25.25%
Nearly Neutral	1716.15	18.74%
Total Area	9157.99	100%

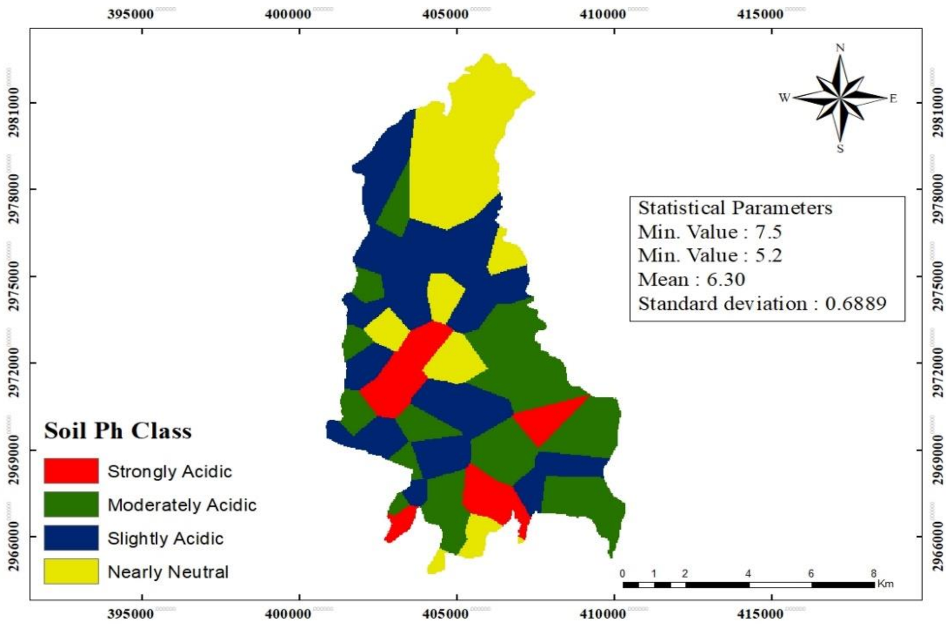

Figure 5. Spatial distribution of soil pH in Dhanushadham Municipality, Dhanusha, Nepal

Soil Organic Matter

Soil organic matter (SOM) plays a vital role in crop performance and maintaining soil health as it improves different physical, biological and chemical properties (Hoyle *et al.,* 2011). SOM has a direct influence on water holding capacity due to its ability to absorb large amounts of water.

The organic matter content varied from 1.14 to 1.83% (Table 6) with a mean value of 1.52%. The distribution of organic matter ranged from low to medium, but mostly medium was prevalent (Figure 6). About 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 as shown in Table 6 and Figure 6.

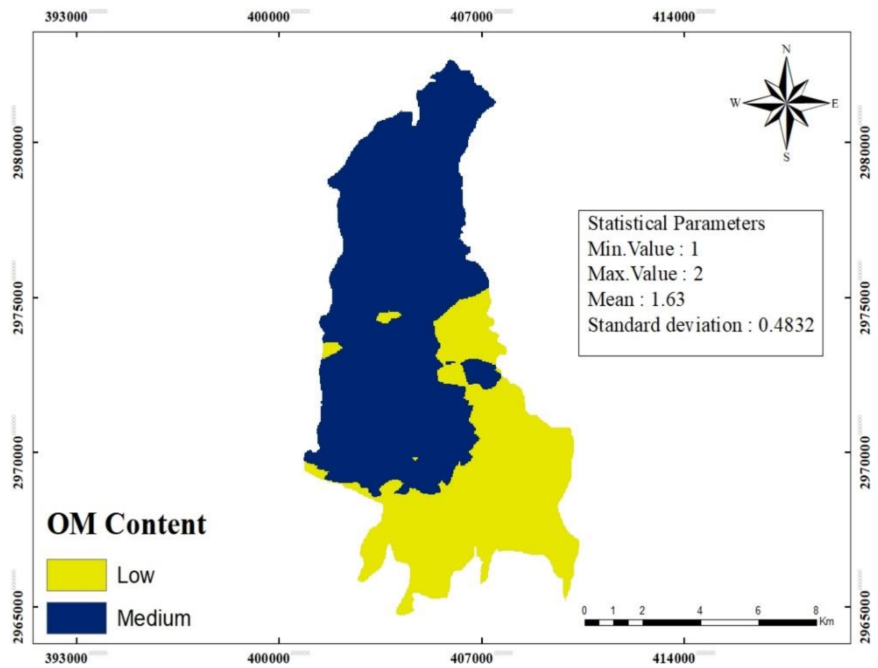

Figure 6. Spatial distribution of soil organic matter in Dhanushadham Municipality, Dhanusha, Nepal

Total Nitrogen

Nitrogen is one of the major nutrients required for the growth and development of plants. Nitrogen imparts dark green color in plants and promotes vegetative growth (Bloom, 2015). Plants get nitrogen from the soil which is added naturally to the soil from N-fixation by soil bacteria and soil legumes. Plants absorb nitrogen from the soil as nitrate (NO_3^-) and ammonium (NH_4^+). The yellowing of plant leaves, retarded growth, reduced apical dominance, and poor vegetative growth of plants are some symptoms of nitrogen deficiency (Bloom, 2015).

The total nitrogen content in the study area varied from 0.08% to 0.13% with the mean value of 0.08% as shown in Figure 7 and Table 6. Nitrogen content was in the range of low to medium. About 68.91% of the total area has a medium range of nitrogen and 31.09% has a low range of nitrogen in the study area.

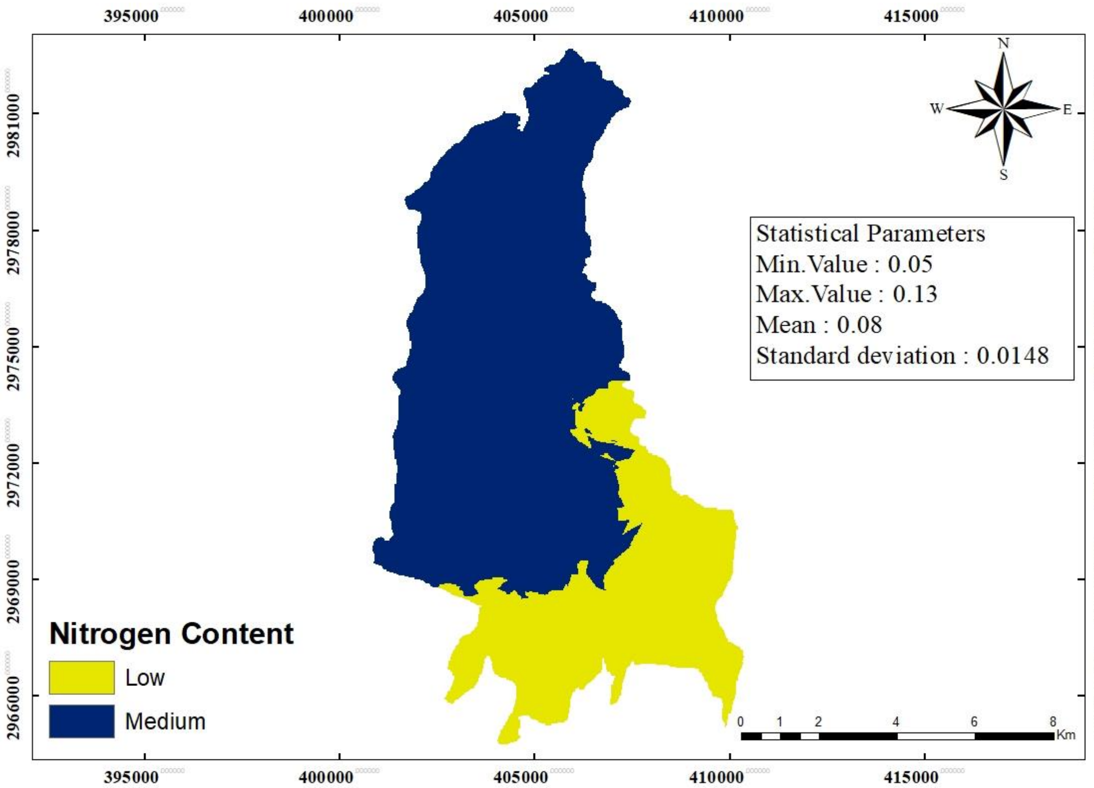

Figure 7. Spatial distribution of total nitrogen in Dhanushadham Municipality, Dhanusha, Nepal

Available Phosphorous

Phosphorous, next to Nitrogen, is often the most limiting nutrients for the growth and development of plants (Sharma *et. al*., 2017). Phosphorous provides a means of using the energy harnessed by photosynthesis to drive the metabolism in plants. Phosphorous also helps in the production of legumes, as it increases the activity of nodule bacteria, which fix nitrogen in the soil.

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 as shown in Figure 8 and Table 6. The available phosphorus content was in the range of medium to very high.

About 59.83kg/ha of the total area has a high range of phosphorus followed by 36.83 kg/ha has very high phosphorus and 3.34 kg/ha has a medium range of available phosphorus in the study area.

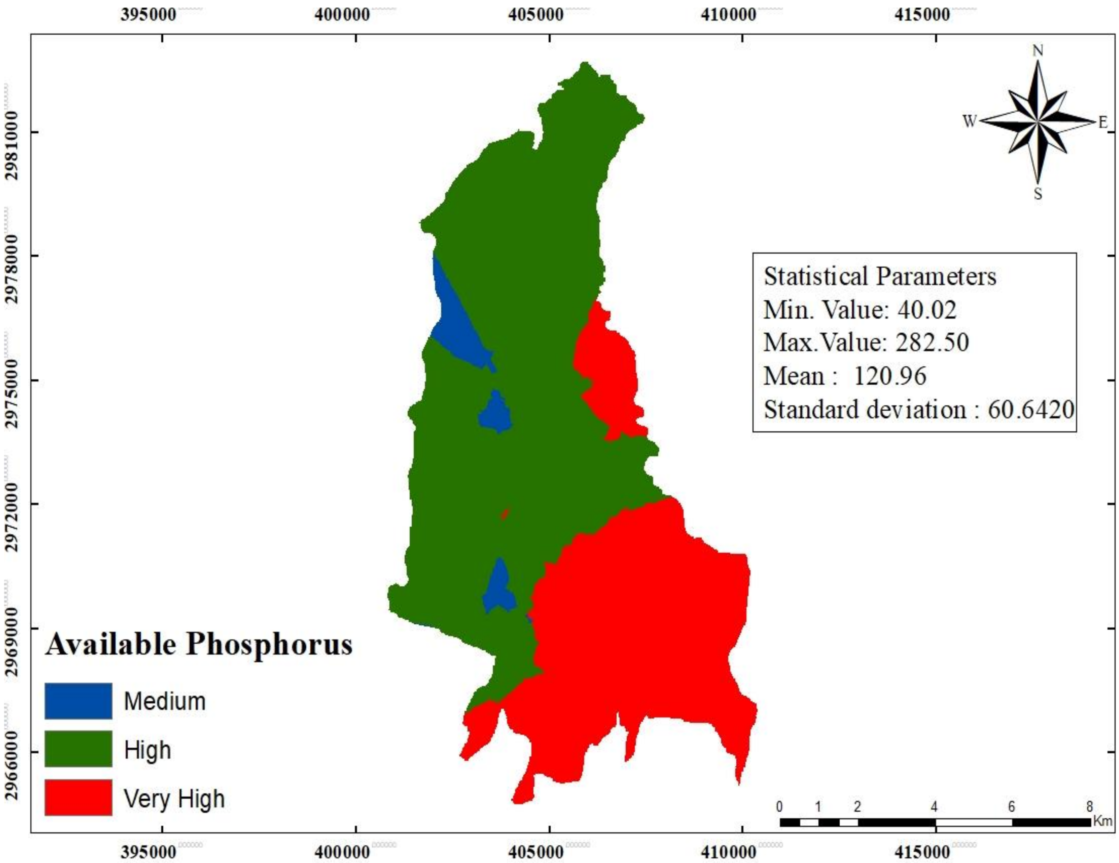

Figure 8. Spatial distribution of available phosphorous in Dhanushadham Municipality, Dhanusha, Nepal

Available Potassium

Potassium (K) is the third most important essential element next to N and P that limits plant productivity (Havlin *et al*., 2010). It plays a vital role in synthesis of amino acids and proteins from ammonium ion which is absorbed from the soil. The available potassium content in the study area 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, dominated by medium range of phosphorous.

About 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 in the study area as shown in Figure 9 and Table 6 and 7.

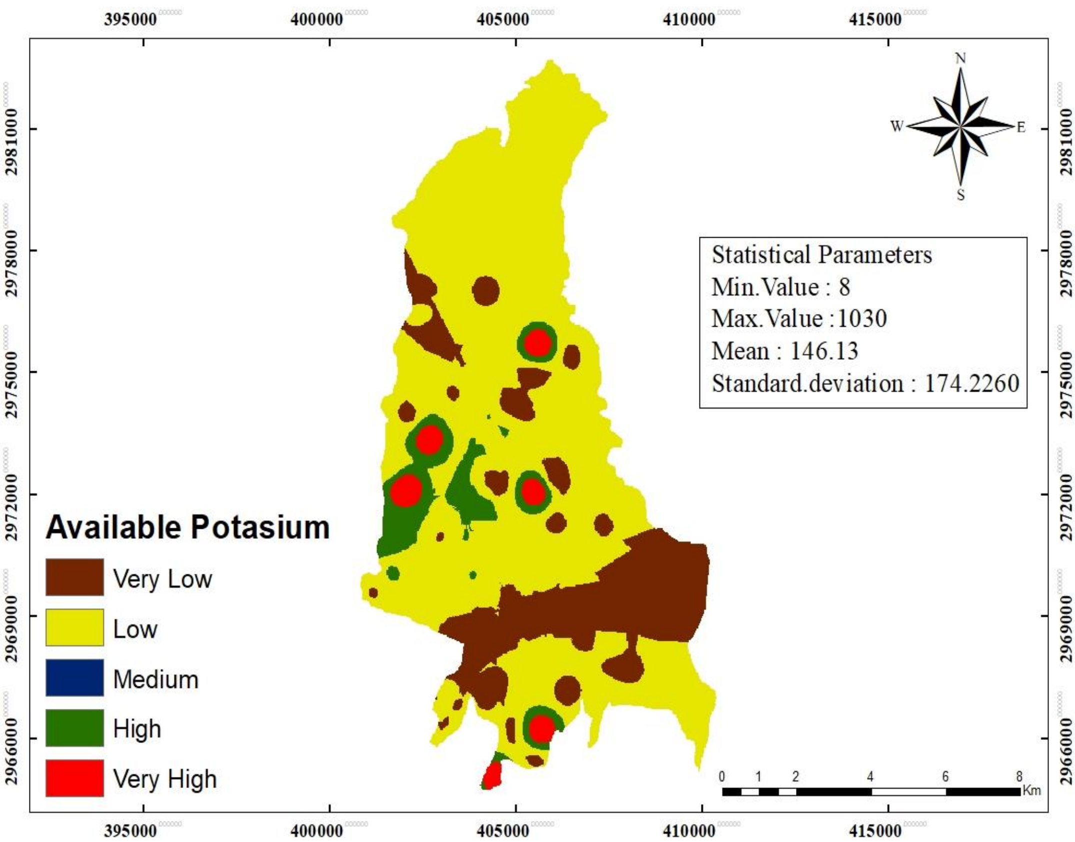

Figure 9. Spatial distribution of available potassium in Dhanushadham Municipality, Dhanusha, Nepal

Table 6. Soil fertility status of Dhanushadham Municipality, Dhanusha, Nepal

Soil Parameters	Units	Min. Value	Max. Value	Mean Value	Standard Deviation
Soil pH	pH scale	5.2	7.5	6.30	0.6889
SOM	%	1.14	1.83	1.52	0.1441
Total Nitrogen	%	0.05	0.13	0.08	0.0147
Available P_2O_5	Kg/ ha	40.02	282.50	120.96	60.6420
Available K_2O	Kg/ ha	8.44	1026.89	173.79	104.6048

Note: SOM denotes soil organic matter

Table 7. Area occupying different classes of soil parameters in Dhanushadham Municipality, Dhanusha, Nepal

Soil Parameters	SOM	Total Nitrogen	Available Phosphorus	Available Potassium
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	5476.70 (59.80%)	592.19 (6.45%)
Very High	NA	NA	3373.04 (36.83%)	230.34 (2.5%)
Total Area(Ha)	9157.99	9157.99	9157.99	9157.99

Note: % =Percentage, (NA) = Not applicable

Conclusion

The soil nutrient status of Dhanusadham was mapped using GIS which can facilitate the management of nutrients. The soil pH of the study area was mostly acidic and ranged from 5.2-7.5. SOM, an integral part of soil nutrient varied from very low to medium throughout the municipality. There was no significant difference in SOM content in different land types. The total nitrogen content over the municipality ranged from low to medium with a grand mean of 0.08% which is low. There was no significant difference in N-content over land use.

Similarly, the available phosphorous ranged from medium to very high over municipality with a mean value of 120.95 kg/ha, and available potassium varied from very low to very high throughout the municipality with a mean of 146.13 kg/ha.

Acknowledgement

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

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