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Comprehensive Evaluation of Agricultural Soil Quality Through Advanced Geographic Information Systems (GIS)

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Abstract:- In 2023, a comprehensive assessment of the soil fertility state was conducted in various places within Davanagere and Haveri districts. The study found crop production restrictions related to soil conditions that must be addressed for the optimal use of agricultural land. Geo-referenced (GPS-based) composite surface soil samples ranging from 0 to 15 cm were gathered from a total of thirteen villages. The Geographic Information System (GIS) was used to map the sample points after they were acquired using a differential global position method. A soil's pH, electrical conductivity, available potassium, available nitrogen, available phosphorus, and available organic carbon were all measured. Most of the soils had a neutral composition. Organic matter in soil can range from 1.1% to 8.78%. It was discovered that the mean levels of potassium, accessible phosphorus, and total nitrogen were, respectively, 135.5 mg/kg, 41.4 mg/kg, and 154.27 mg/kg. QGIS 3.12 software was utilised to create thematic maps for each soil parameter, and Inverse Distance Weighting (IDW) interpolation was employed to forecast values for unsampled sites. The soil fertility map was prepared using the weighted overlay method. In order to effectively cultivate and develop crops, fertility provides a ready-made source of information regarding the status of soil fertility. Fertility also acts as a decision-making tool.

Keywords*:* Geographic Information System, Soil fertility, IDW, Weighted overlay, Nitrogen, phosphorus, Potassium.

1. Introduction

Soil represents the uppermost stratum of the Earth's surface, characterized by its intricate blend of minerals, organic material, water, air, and a multitude of organisms that play a vital role in supporting terrestrial ecosystems. It serves as the essential medium in which plants thrive, providing them with essential nutrients and moisture. Furthermore, soil occupies a pivotal role in the Earth's hydrological cycle by absorbing, retaining, discharging, and filtering a substantial portion of the planet's terrestrial water resources. *(Arshi I, T Khan, 2018)* Soil is also an essential part of the carbon cycle, storing and releasing carbon dioxide, a key greenhouse gas. Soil composition and characteristics may greatly vary, reflecting local climate, weathering processes, living organisms, and the land's geological history *(Arshi I, T Khan, 2018)* One method for evaluating soil quality within the realm of agriculture begins with a conventional land assessment that relies on physicochemical criteria to gauge the inherent facets of soil quality. These inherent criteria might encompass attributes like soil texture, mineral composition, and pH levels *(Arshi I, T Khan, 2018)*. oil properties are essential elements in understanding the functionality and capability of soils in different contexts such as agriculture, forestry, construction, and environmental conservation. For a thorough understanding of soil properties, it would involve detailed study and research across multiple disciplines, from soil science, agronomy, and environmental science, to microbiology and chemistry *(Sumithra S et., al, 2013)*. Soil quality can be viewed in two different ways: as an inherent attribute of soils that can be inferred from soil characteristics or indirect observations; or as a capacity to perform certain productivity, environmental, and health functions. Crop yield and quality are contingent on the presence of fertilizers and micronutrients. Soil quality is of paramount importance as it serves as a universal medium for plant growth, providing essential nutrients to plants *(Narkhede et al., 2011)*. However, the excessive use of fertilizers has led to a distortion in the physicochemical state of the soil *(Kamble et al., 2013)*. The increasing application of chemical fertilizers to the soil poses challenges in controlling the by-products of these chemicals, which can affect soil, plants, animals, and human health *(Narkhede et al., 2011)*. Soil management practices interact with and influence soil properties. The physicochemical characteristics of different soils exhibit spatial and temporal variations due to factors such as topography, climate, physical weathering processes, vegetation cover, microbial activities, and various other biotic and abiotic variables *(Paudel and Sah, 2003)*. Changes in the physicochemical properties of the soil can lead to soil infertility or barrenness, inhibiting normal vegetation growth for extended periods *(Jha and Singh, 1991)*.

1.1 Soil quality assessment

Soil properties encompass the physical, chemical, and biological characteristics that collectively define the composition and nature of the soil. A comprehensive understanding of these properties is vital for effective soil management and utilization. Physical properties cover a range of attributes, including texture, structure, color, temperature, density, porosity, and moisture content. Soil texture signifies the proportions of sand, silt, and clay particles, while soil structure pertains to their arrangement and aggregation.

Chemical properties are concerned with the mineral composition, nutrient content, pH level (acidic or alkaline nature), cation exchange capacity (the ability to retain and exchange cations), and the quantity of organic matter present in the soil. Biological properties are associated with the living organisms residing in the soil, encompassing bacteria, fungi, insects, earthworms, and more. These organisms play a pivotal role in processes like nutrient cycling, organic matter decomposition, and the overall health of the soil. Each of these properties exerts a significant influence on how soil functions and its suitability for various purposes, whether it's for agriculture, construction foundations, or the preservation of natural ecosystems*(Jithin Jyothi et., al, 2022)*.

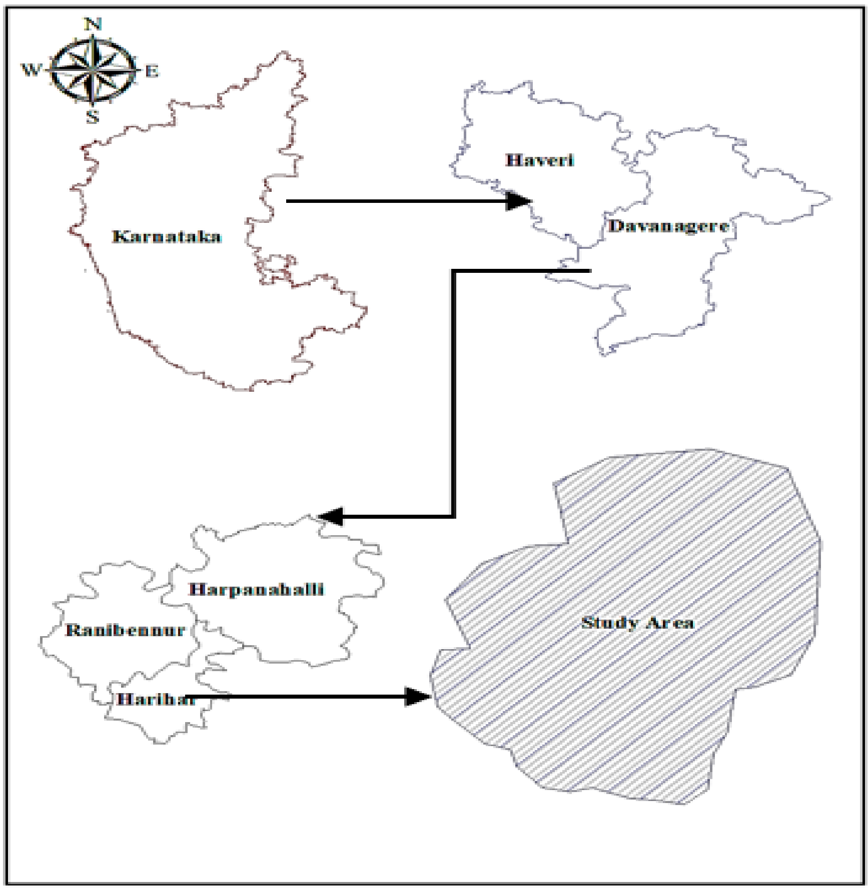
2. Materials and Methods

2.1 Study area

Ranebennur is situated in the central part of the Karnataka state, India The region's physiography is characterized by undulating plains with scattered hills. It lies at an average elevation of around 594 meters above sea level. The area is known for its rich red soil, ideal for cultivation. Agriculture is the primary occupation, with crops like cotton, millets, sugarcane, and groundnuts being grown. Harihar is situated in the Davanagere district of Karnataka, India. it lies on the banks of the Tungabhadra River and is characterized by fertile alluvial plains. The terrain is relatively flat, with gentle slopes towards the river. Harappanahalli is located in the Davanagere district of Karnataka, India, in the central part of the Deccan Plateau. Physiographically, it is characterized by undulating plains with occasional rocky outcrops and small hills. The region's elevation ranges from around 600 to 700 meters above sea level. The region has a semi-arid climate, with hot summers and moderate winters. Major crops grown include jowar, maize, sunflower, pulses, and groundnuts Table 1 shows the soil sample locations and Figure 1 Shows the Study area.

Table 1 Soil Sample Locations

Location Code	Location	Latitude	Longitude
S1	Karlahalli	14.588038	75.836667
S2	Kodihalli	14.524806	75.847960
S3	Khanderayanahalli	14.571078	75.770847
S4	Airani	14.604996	75.801948
S5	Kenchanahalli	14.587056	75.863538
S6	Shantinagar	14.647474	75.841559
S7	Dheetur	14.575317	75.826625
S8	Pamenahalli	14.594236	75.817315
S9	Telagi	14.654419	75.889768
S10	Tumbigeri	14.608025	75.873708
S11	Kurubarahalli	14.598313	75.843749
S12	Guttur	14.539417	75.812741
S13	Sarathi	14.604709	75.813302



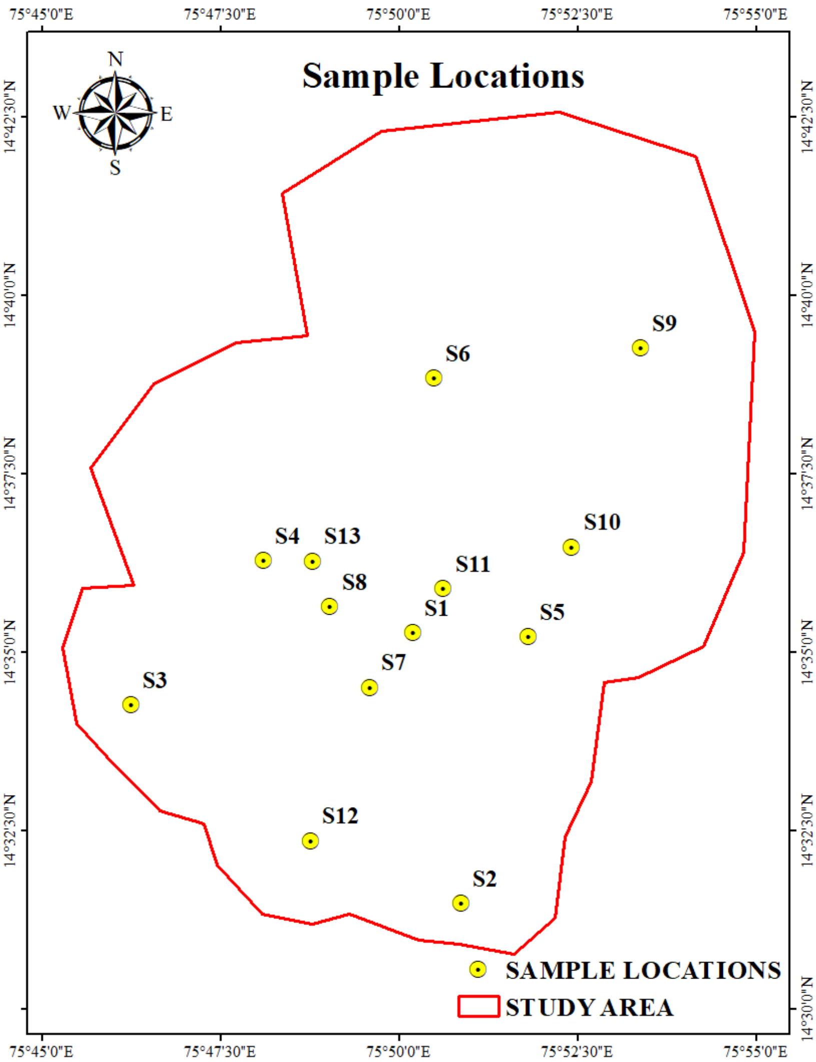


Figure 1 Study area and Sampling locations

2.2 Methods of soil analysis

When the soil samples arrived at the lab, they were first allowed to air-dry in the shade. After that, they were crushed with a pestle in a wooden mortar and sieved through a 2 mm sieve to remove any large shards (>2 mm). The fine earth was used for analysis after being kept in several containers.

2.3 Physical characteristics

For bulk size analysis, *Piper (1966)* described the use of the international pipette method. The ratio of the coarse fragments' dry weight to their volume, which was discovered using the water displacement method, was used to compute the particle density of the coarse fragments.

2.4 Chemical characteristics

A pH metre placed in a suspension of soil and water is used to measure the pH of the soil *(Sparks, D.L. (Ed.). 1996)*. Using an Elico conductivity bridge (Model CM 82T), the electrical conductivity (EC) of the saturated soil water extract was determined *(Jackson, 1973)*. The Walkley and Black wet-oxidation method *(Jackson, 1958)* was used to estimate the amount of organic carbon. The alkaline potassium permanganate method *(Subbaiah and Asija, 1956)* was used to determine the soil's available nitrogen level. All of the soils in the available phosphorus determination are calcareous, with the exception of pedon 11, which is noncalcareous and was extracted using Bray and Kurtz No. 1 extractant. Olsen's extractant (0.5 N sodium bicarbonate; pH 8.5) was used for this purpose.

By utilising ammonium molybdate and ascorbic acid as a reductant to create a blue hue, the amount of phosphorus in the extract was calculated. A spectrophotometer was used to measure the intensity of colour at 660 nm *(Jackson, 1973)*. Neutral normal ammonium acetate was used for the extraction process in the available potassium determination, and an atomic absorption spectrophotometer was used for the subsequent estimation *(Jackson, 1973)*.

2.5 Soil Fertility Mapping

Latitude, longitude and the data resulted from the soil analysis were entered into attributed table in MS-Excel and processed in QGIS 3.12 software thematic soil fertility maps and Geospatial tool i.e. Inverse Distance Weighting (IDW) interpolation was preferred for predicting values for not sampled locations.

2.6 Inverse Distance Weighting (IDW)

Inverse Distance Weighting (IDW) is a widely utilized spatial interpolation technique in geographic information systems (GIS) and spatial analysis. It estimates values at unmeasured locations based on the values at neighbouring sampled locations. IDW postulates that the influence of a known point on an unknown location diminishes with distance. This method is favoured for its simplicity and efficacy across various domains such as environmental monitoring, terrain modelling, and resource management *(Li, X., & Heap, A. D. (2014))*. At the core of IDW lies the principle that proximity matters the closer a known point is to the target location, the more it influences the estimation. This influence is quantified by assigning weights to the known values based on their distances from the target location. Thus, IDW effectively conducts a weighted averaging of the known values to predict the value at the target location *(Shekhar, S., & Chawla, S. (2003)*. Utilizing the computed weights, IDW performs interpolation by computing a weighted average of the known values. Nearby points exert a greater impact on the estimated value at the target location compared to distant ones. This process effectively smoothest the surface and generates a continuous representation of the variable of interest across the study area *(Carr, M. H., & Stamps, D. S. (2005))*. The interpolation formula of IDW involves summing the products of the known values and their corresponding weights, divided by the sum of the weights. This weighted average calculation encapsulates the essence of IDW, enabling the estimation of values at unsampled locations based on the influence of nearby known points *(Hengl, T., Heuvelink, G. B., & Rossiter, D. G. (2007))*.

The formula for this interpolation is typically

$$\boldsymbol{Z}\,(\boldsymbol{u}) = \frac{\sum_{i=1}^{n} \frac{z_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1_i}{d_i^p}}$$

Where:

Z(u) is the estimated value at location u.

Z_i is the known value at location i.

$d_i$is the distance between the target location and the known location i.

p is a parameter that controls the influence of distance on the weights. Commonly, p is set to 2 for Euclidean distance.

2.7 Weighted overlay

The weighted overlay method involves analysing spatial data layers, including environmental, social, economic, and infrastructural factors, for decision-making purposes in urban planning *Malczewski, J. (2006)*. After collecting the spatial data layers, it's essential to standardize the values within each layer to ensure they are on a comparable scale. This step typically involves transforming the data to a common range, such as rescaling values to fall between 0 and 1 or normalizing them using statistical methods like z-score normalization. Standardization allows for the direct comparison of different criteria layers, regardless of their original measurement units or scales *(Eastman, J. R et., al 1993)*. The weighted overlay method assigns weights to each criterion layer, determining its importance in decision-making. These weights, determined through stakeholder consultation, expert judgment, or quantitative methods, influence the contribution of each layer to the final map *(Saaty, T. L. (1980)*. In the overlay analysis stage, each criterion layer is multiplied by its corresponding weight to emphasize layers with higher importance. The weighted layers are then summed together to create a composite map representing the overall suitability or desirability of each location. This process combines the spatial information from multiple criteria layers into a single, integrated output, facilitating informed decision-making *(Li, J., Heap et., al 2011)*. A common formula for weighted overlay analysis is *(Malczewski, J. (1999)).*

$$W=(W1\times R1)+(W2\times R2)+\ldots+(Wn\times Rn)$$

Where:

Wi is the weight assigned to the i th raster layer,

Ri is the normalized value of the ith raster layer,

n is the total number of raster layers.

3. Results and Discussions

Soils were analyzed for mechanical composition, pH, organic matter, total nitrogen, available phosphorus, potassium and electrical conductivity results obtained from laboratory analysis report are presented in Table 2.

Table 2 Results of Chemical parameters of soil samples

Location code	Location	pH	Electrical Conductivity	Available Phosphorous as P,mg/Kg	Available Potassium as K,mg/Kg	Available Nitrogen as N,mg/Kg	Available Organic Carbon,%
S1	Karlahalli	8.45	745.3	40.3	186.3	131.6	0.7
S2	Kodihalli	7.42	756.6	50.2	523	163.1	1.1
S3	Khanderayanahalli	7.65	420.6	45.2	12.3	28.6	0.2
S4	Airani	7.38	456.3	45.3	49.2	175.3	0.5
S5	Kenchanahalli	7.88	931.1	69.3	216.1	159	0.8
S6	Shantinagar	7.31	546.4	45.3	102	82.6	0.7
S7	Dheetur	8.12	823.6	45.1	249.7	150.1	3.9
S8	Pamenahalli	7.74	463.2	41.4	120.9	40.5	0.3
S9	Telagi	8.67	441	12.39	220.5	395.31	5.13
S10	Tumbigeri	8.73	173.7	13.57	86.85	182.08	8.78
S11	Kurubarahalli	8.29	271	8.16	135.5	222.2	5.18
S12	Guttur	7.93	302	6.44	151	154.27	7.89
S13	Sarathi	7.34	207	10.67	103.5	92.63	6.31

3.1 pH

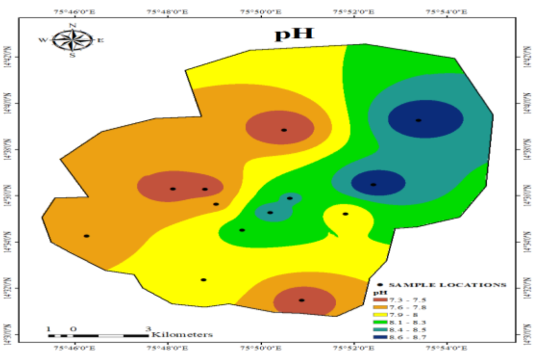


Figure 2 pH of soil at different locations

The pH is an indicator of the acidity or alkality of soil which controls the mobility and hence the availability of soil nutrients *(Amacher et al., 2007)*. The sample in the study area pH value in the range of 7.31 (Shantinagar) to 8.73 (Tumbigeri) as shown in Figure 2. All the soils samples were found to be Neutral. Soil pH influences the solubility and availability of plant nutrients. Low pH causes deficiency and unavailability of plant nutrients like P, Ca, K, Mg and Mo *(Wang et al., 2006)*. In general, soils with near neutral reaction (pH 6.0-7.0) are the most fertile *(LRMP, 1986)*.

3.2 Electrical Conductivity

The electrical conductivity of soil is indicative of its ability to conduct electrical current, primarily influenced by the presence of dissolved ions. The EC range in the study area is about 173.7 mS/m (Tumbigeri) to 931.1 mS/m (Kenchanahalli).

High EC values suggest an elevated concentration of soluble salts in the soil solution, which can adversely affect plant growth and crop yield. According to *(Singh et al. (2018)*. low EC values are associated with soils having minimal soluble salt content, often indicative of good drainage and low salinity levels.

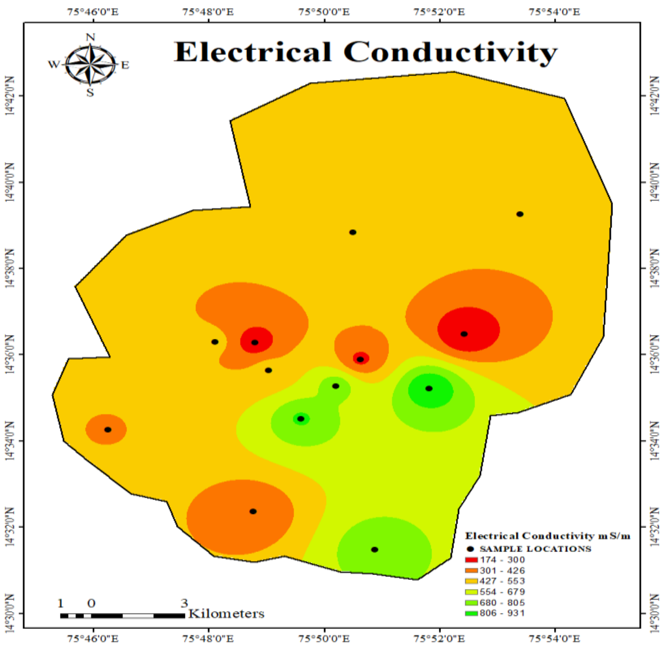


Figure 3 Conductivity of soil at different locations

Such soils are conducive to optimal root growth, nutrient uptake, and overall plant health. However, caution must be exercised as extremely low EC readings may imply nutrient deficiencies, particularly in micronutrients essential for plant growth. *(Das et al. (2019)* emphasize the importance of soil nutrient management strategies tailored to address specific deficiencies identified through comprehensive soil analysis, including EC measurements.

3.3 Phosphorus

Phosphorus is one of the important primary elements essential for plant growth and development. It is particularly helpful in the production of legumes, as it increase the activity of nodule bacteria, which fix nitrogen in the soil. The available phosphorus content in the study area varies from 6.44 (Guttur) to 69.3 mg/Kg (Kenchanahalli) with the mean value of 41.4 mg/Kg (Pamenahalli) (Table 2). Phosphorus content of most of the areas was medium in range, some of the areas Telagi, Tumbigeri, Kurubarahallihad lower phosphorus content whereas some areas of Kodihalli, Khanderayanahalli, Airani, Kenchanahalli, Shantinagar, Dheetur had higher amount of phosphorus (Fig. 4).

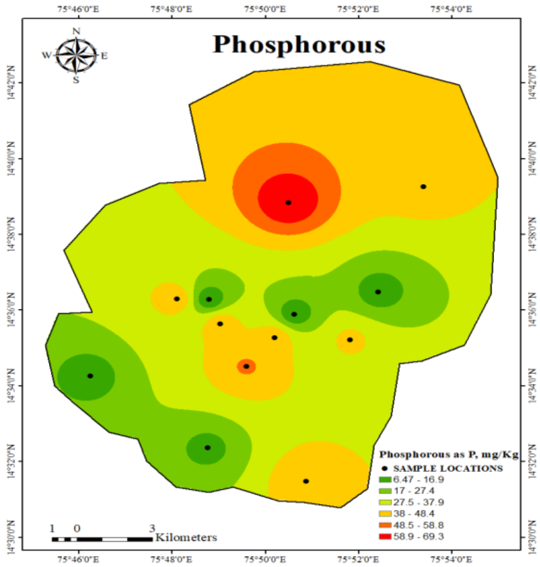


Figure 4 Available Phosphorous in soil at different locations

Generally, phosphorus deficiency causes the plant in dark-green but the lower leaves may turn yellow and dry up. Soils of the study site containing medium level of phosphorus may be possibly due to application of phosphotic fertilizer to crops by farmers.

3.4 Potassium

Potassium is the element which is involved in physiological processes of plants with the activation of large number of enzymes. It plays a vital role in the formation or synthesis of amino acids and proteins from ammonium ions which are absorbed from the soil. The available potassium ranged from 12.3 mg/Kg (Khanderayanahalli) to 523 mg/Kg (Kodihalli) with mean value of 135.5 mg/Kg (Kurubarahalli) (Table 2). Potassium is the element which is involved in physiological processes of plants with the activation of large number of enzymes. It plays a vital role in the formation or synthesis of amino acids and proteins from ammonium ions which are absorbed from the soil. The available potassium ranged from 12.3 mg/Kg (Khanderayanahalli) to 523 mg/Kg (Kodihalli) with mean value of 135.5 mg/Kg (Kurubarahalli) (table 3). In about 70% of the study area, potassium content was medium whereas in other areas potassium was low indicating that the amount of potassium is decreasing in Terai soils, which justify that recommended dose of potassium should be reviewed for increasing production of crops (Figure 5).

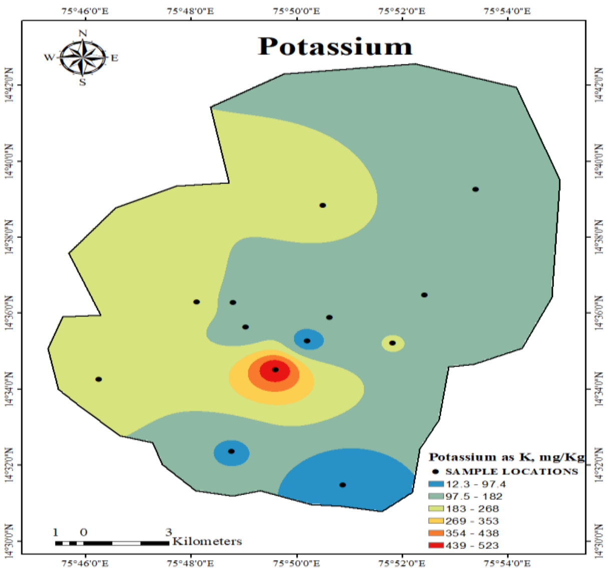


Figure 5 Available Potassium in soil at different locations

Deficiency of potassium causes the margins of leaves turn brownish and dry up. The stem remains slender. Low available potassium signifies higher leaching as evidenced by low base saturation in these soils which may be due to high rainfall in those areas *(Patil and Dasog, 1999)*.

3.5 Nitrogen

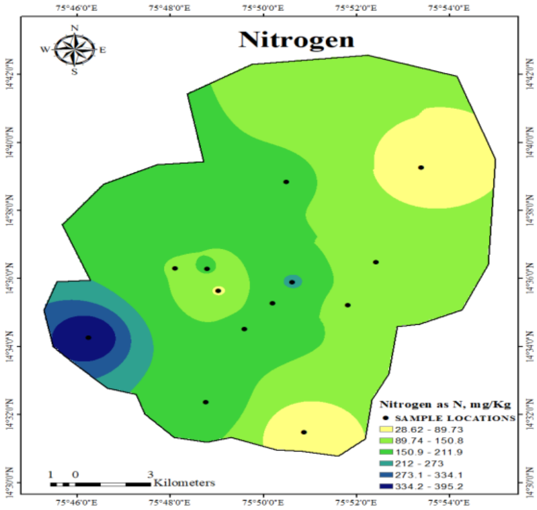


Figure 6 Available Nitrogen in soil at different locations

Nitrogen is the basic nutrient that helps in seed formation and increases the food and feed value of crops. It usually has greater effect on crop growth, crop quality and yield. The total nitrogen content varies from 28.6 mg/Kg (Khanderayanahalli) to 395.31 mg/Kg (Telagi) with the mean value of 154.27 mg/Kg (Guttur). Overall results showed that the nitrogen content was low to medium in range. Nitrogen content of Khanderayanahalli was low whereas remaining sample locations had medium nitrogen content which is recommended dose of nitrogen is required to apply in the field for increasing production of crops (Fig. 3). The low nitrogen content in the study area may be possibly due to low organic matter content in soils, crop removal and due to high temperature which facilitate faster degradation and removable of organic matter leading nitrogen deficiency. As SOM increases, available N, P K as well as some micronutrients also increase *(Oates, 1998)*.

3.6 Organic Carbon

The range of organic matter ranges from 0.2 % (Khanderayanahalli) to 8.78% (Tumbigeri) with mean value of 1.1% (Kodihalli) (Table 2) which varies from very low to medium.

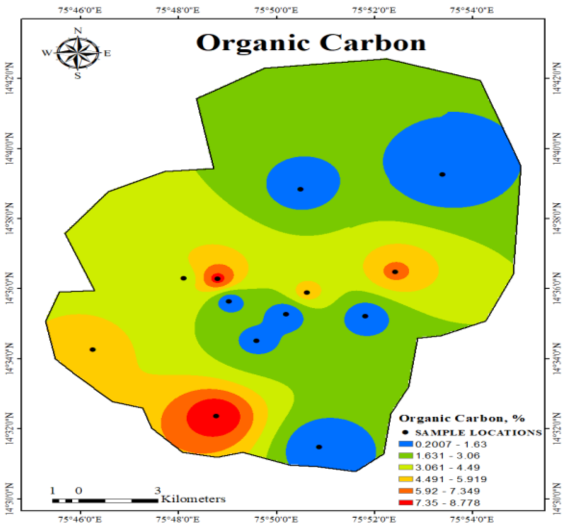


Figure 7 Available Organic Carbon in soil at different locations

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The range of organic matter ranges from 0.2 % (Khanderayanahalli) to 8.78% (Tumbigeri) with mean value of 1.1% (Kodihalli) (table 3) which varies from very low to medium. Organic matter can be considered a pivotal component of the soil because of its role in physical, chemical and biological processes. Comparatively lower organic carbon is may be due to high decomposition of organic matter in study area as the temperature in the summer season rises up to 40 °C and less application of organic residues. The amount of organic matter in a soil is highly dependent on a range of ecological factors (climate, soil type, vegetative growth, topography) in which it occurs as well as land use and management and tillage of the soil, intensive cropping. Organic matter is the main source of N, P and S for plant growth in now fertilizer smallholder agriculture *(Acquaye, 1990, Maurice et al. (1998)* used OM as an indicator of soil fertility, aggregate stability and erosion. In addition, OM contributes to enhanced soil water storage and maintenance of pH. Farmers should therefore be encouraged to return as much as residue as possible to soil in addition to application of manure and compost.

3.7 Agriculture suitability

Land capability (Fig. 8) was estimated based on the natural limitations and properties of soils, mainly for agriculture use. The capability classes found for crops cultivation (Figure 8; Table 3) are II, III, and IV comprised 11.14, 79.26, and 9.6% of the total area, respectively.

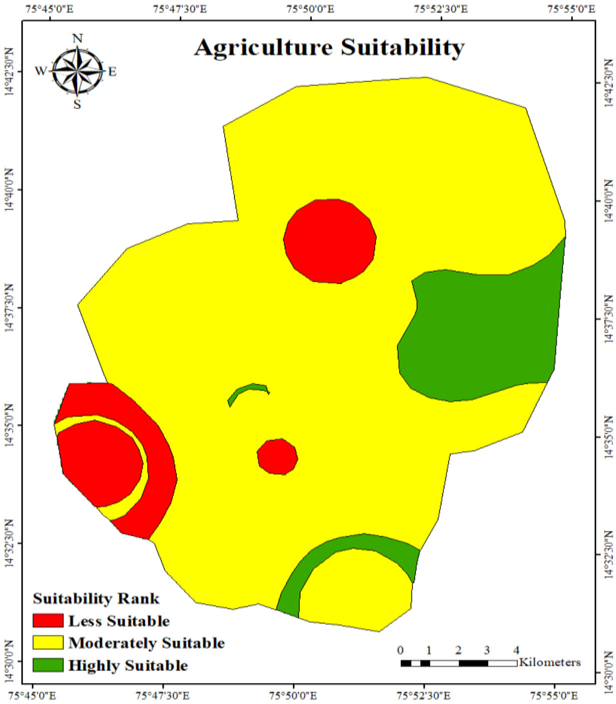

Figure 8 Soil Agriculture Suitability

Table 3 Agriculture Suitability classes

Classes	Suitability Rank	Area in Acres	% covered
II	Highly suitable	294050	11.13575625
III	Moderately suitable	2093081	79.26556648
IV	Less Suitable	253462	9.598677267
	Total	**2640593**	**100**

The selection of crops is suitable in soils of the selected area: feld crops; cotton, maize, chickpea, sunflower, corn, rice etc. while for vegetable crops; tomato, eggplant, and melon etc. All these characteristics necessitate a special care in soil management as follows: (1) protecting the land from wind blowing or depositing sand with windbreaks building a fence of trees around the farm; (2) adding organic matter to the land to increase fertility, wind dredging, and reduce water loss as much as possible while flipping the remainder of the previous crop in the land; (3) continuous increase in fertility with genes or replacement fertilizers; (4) choose the appropriate crop; and (5) fertilizer selection by permanent analysis.

4. Conclusion

According to soil tests, the majority of the study areas are suitable for growing vegetables and cereals with the suitable irrigation setup, land and soil management techniques. The study area of land is 79.27% is moderately suitable for agriculture, according to the report, 11.14% more fertile and 9.6% less fertile. It is advised to use balanced fertilisation techniques, organic materials, crop rotation, conservation tillage, and frequent soil testing to increase soil fertility. Long-term productivity and soil health are preserved by these methods. The structure and ability of the soil to hold water are enhanced by organic inputs such as agricultural leftovers, manure, compost, and cover crops. Based on nutrients available classifies as low, moderate and highly suitable classes present study area the crop suitability for each class. The use of conservation tillage techniques reduces soil erosion and disturbance. For efficient management, regular soil analyses are also essential.

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