Spatial Variability of Soil Chemical Properties Using Statistical Analysis and Geostatistical Interpolation Method

Bhavana R[1], Joseph krupakar[2], Anusha A[3], Harish C M[4], Karthik N[5], Prakruthi B[6], Prathiksha S Choudari[7]
[1,2,3,4,5,6,7] *Department of Civil Engineering, Jawaharlal Nehru New College of Engineering, Shivamogga, Karnataka, India*

***Abstract*—Soil properties vary spatially and temporally because of soil formation processes, land use pattern, fertilization etc. Geostatistics, remote sensing and GIS offer some of the best tools and techniques to capture the spatial variability of soil properties. Soil nutrients have a significant impact on both agriculture and the environment, particularly with regards to soil fertility, soil quality. The research was conducted across several villages, including Navule, Mathode, Javali, Hoisanahalli, Dasar kallahali, Hunsodu, Basavangangur, Pillangiri, Abblegere, Hollebenvalli. A total of 50 soil samples were collected from top 0-20cm of soil surface and were air dried. Measurement of topsoil chemical properties such as moisture content, Ph, electrical conductivity, calcium carbonate were carried out as per Indian Standard codes. Descriptive statistics were computed, correlation between the soil properties was explored and also soil properties were interpolated and mapped using IDW interpolation method. Soil properties have very large variability. The large amount of variation in soil properties is due to agricultural practices. Correlation among soil properties is not consistent. There is no significant influence of soil type on soil properties range. Regional distribution maps of soil chemical properties were produced using IDW method.**

I. INTRODUCTION

Topsoil is a thin layer on the surface of the Earth that covers the deeper rock layers beneath. It is the uppermost layer of soil, usually found in the top 5.1cm to 20cm of the ground. It contains the highest concentration of organic matter and microorganisms, and is where most of the soil's biological activity takes place. The health of plants depends on the topsoil, which provides oxygen, moisture, and nutrients needed for strong root growth. Topsoil is very important for food production, soil management, and preventing soil degradation. Good topsoil is loose and allows easy root penetration. However, it is hard to classify topsoil because it varies across time and space. One of the main problems in managing agricultural systems is the lack of data on soil properties. Storing data is expensive due to the cost of laboratory soil analysis, which is where remote sensing becomes useful. Remote sensing provides information about various earth resources in a broad overview. The availability of remotely sensed data with different spatial, temporal, radiometric, and spectral resolutions can help in extracting soil properties. GIS can be used to analyze this dataSpatial Interpolation Method:

Interpolation is a technique used to predict unknown data points based on a set of known values. Various Interpolation Techniques Are Often Used in The Atmospheric Sciences. There Are Different Methods of Spatial Interpolation They Are, Nearest Neighbour (NN), Inverse Distance Weighting (IDW), Modified Shepard, Kriging. In This Project We Are Used Inverse Distance Weighting (IDW).

Inverse Distance Weighting (IDW):
IDW serves as a deterministic approach to multivariate interpolation, utilizing a fixed collection of sample points to estimate data for unmapped locations. This technique determines values for these unknown sites by calculating a weighted average derived from the surrounding established data points.

$$V_i = \frac{\sum_j^n = 1 \frac{1}{d_{ijp}} V_i}{\sum_j^n = 1 \frac{1}{d_{ijp}}}$$

Where, V_i is i^{th} unknown value, n is the number of points taken to obtained the unknown value, V_j is the j^{th} known value, d_{ij} is distance between the i^{th} unknown value and the j^{th} known value and p is the power.

Importance of chemical properties in soil

Moisture content
The soil moisture content of soil is the quantity of water it contains. Water content is used in a wide range of scientific and technical areas and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation.
• For nutrients soil water plays a main role.
• Soil water regulates soil temperature
• Water is a fundamental requirement for the development of soils and the natural breakdown of minerals.
• Microorganisms require water for their metabolic activities.
• Soil water helps in chemical and biological activities of soil.

pH
The significance of soil pH lies in its control over nutrient accessibility for plant roots. Vital elements such as nitrogen, phosphorus, and potassium can only be absorbed by the plant if they are successfully dissolved within the soil's water content. Nutrients will not dissolve when soil pH is too acidic or alkaline. Micro-organisms activities get affected by soil pH. The population of bacteria that decompose organic matter declines and their activity is hindered in highly acidic soil, which results in accumulation of organic matter and the bound nutrients, particularly nitrogen.

Electrical conductivity:
Soil EC measures the electrical conductivity of a solution over a unit distance. It represents the amount of soluble salts in the soil, commonly known as salinity or ion concentration. Soil conductivity is a measure of water-soluble salts and essential mineral nutrients in topsoil. These levels are important for plant growth, as extreme EC values, whether too high or too low, can negatively affect crop yields. If the soluble salt content (EC value) in the soil is too high, it can cause reverse osmosis pressure, which removes water from the roots and makes the root tips turn brown or dry

Calcium carbonate
A crucial nutrient, calcium supports the cellular walls of plants and is essential for the formation of new cells. The calcium carbonate works during the winter and won't harm new growth.

Benefits of Calcium Carbonate
1. Increased availability of phosphorus.
2. Increased nitrification and mineralization
3. Enhances root architecture, leading to more effective nutrient uptake and optimized water consumption.
4. Soil pH adjustment.
5. Minimises soil levels of heavy metals.

II. PROBLEM STATEMENT

Soil chemical properties show significant spatial variability, which impacts crop growth, nutrient management, and environmental quality. This study aims to investigate the spatial distribution of soil chemical properties (e.g., moisture content, pH, electrical conductivity, and calcium carbonate) within a defined agricultural area using statistical and geostatistical interpolation methods

III. OBJECTIVES

To understand the spatial distribution and variability of soil chemical properties within a defined area.
To develop predictive maps of soil chemical properties using geostatistical interpolation methods.

IV. METHODOLOGY

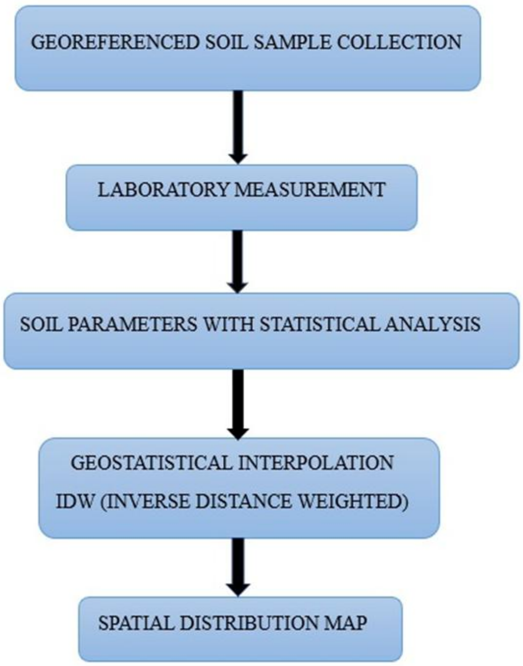

Figure 1: Flow chart of project

V. STUDY AREA

Study Area details

The study area is situated in the central part of Karnataka, Shivamogga is located on the bank of Tunga River. The city experiences a tropical savanna climate with distinct wet and dry seasons. India longitude between 74º46'30" to 74º85'51"E and latitude between 13º03'00" to 13º09'00"N. The study area consists of agricultural land, built up land, and vegetation. April is the hottest (34.3ºc) month of the year. The greatest month of precipitation occurs in July, with an average of 245mm. the average temperature in Shivamogga is 24.2ºc. The month with the highest relative humidity is July.

The soil samples were collected during a month of June which is having average temperature of 23.5ºc. The precipitation of this month is 197mm and humidity is about 85%

Reconnaissance survey was conducted to identify sampling sites with following criteria:

1. Availability of harvested agricultural fields
2. Field should be dry
3. Fields devoid of only shrubs

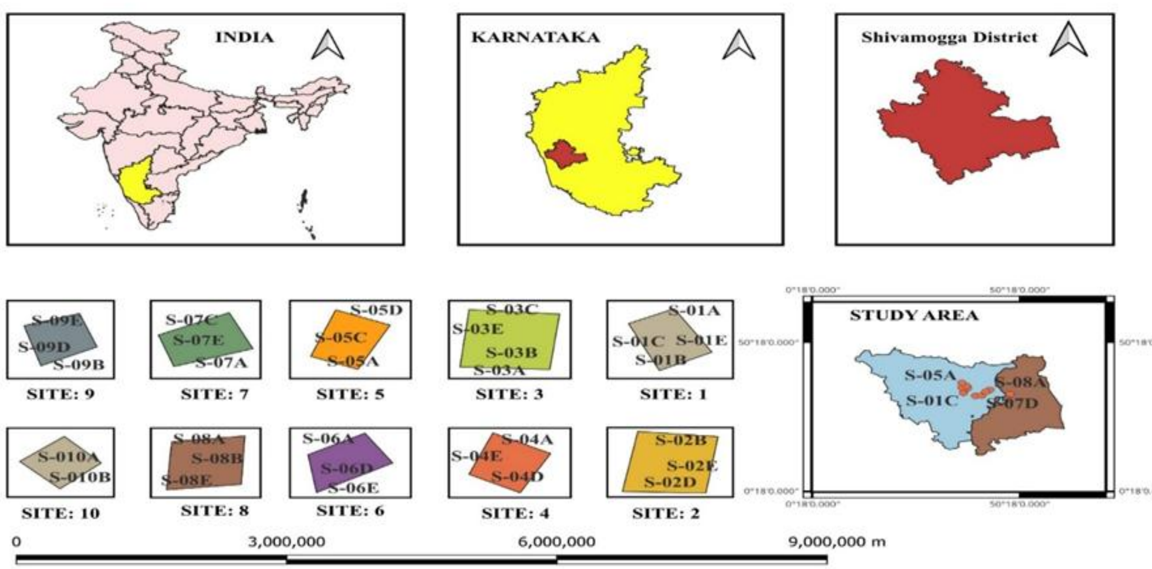

Figure 2: Study area

Soil sample collection and preparation

50 topsoil samples were collected (0-10cm) depth from harvested dry field in the 3rd week of June that is in the date of 18/06/2024 and 21/06/2024 from 10 different villages, Navule, Mathode, Javalli, Hoisanhalli, Dasr Kallahali, Hunsodu, Basavangangur, Pillangiri, Abblegere, Hollebenvalli. All the soil sample's locations considered are recorded with their respective latitude and longitude values. About 1Kg of soil samples were collected and placed

in plastic bag for transportation. Moisture content of soil samples is tested at the same day of sample collection. All the properties of soil are tested according to IS code.

Figure 3: Soil sample collection and storage of soil samples

Laboratory measurement of moisture content

Oven – drying, method is adopted for the determination of soil moisture content. Empty weight of dry container is recorded (w1). Then 25g of soil specimen in the container crumbled and placed loosely, and weighed with lid (w2). Then kept it in a oven with lid removed for a period of 24hours. After 24hours the container is taken out and kept for cooling and then its weight is recorded (w3).

By using the below formula, moisture content of soil is determined.

$$\text{water conteny} = \frac{W_2 - W_1}{W_3 - W_1} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq (1)}$$

Figure 4: Moisture content of soil

Laboratory measurement of PH

30g of the soil from the sample is taken into 100ml beaker. 75ml of distilled water is added to it. The soil is kept for suspension of about 30min. The suspension shall be stirred for a few seconds. Using a blotter sheet the supernatant liquid is obtained and it is transferred into measuring jar. The pH meter is immersed in a soil suspension and readings were recorded. The electrodes shall be removed from the suspension immediately and washed with distilled water.

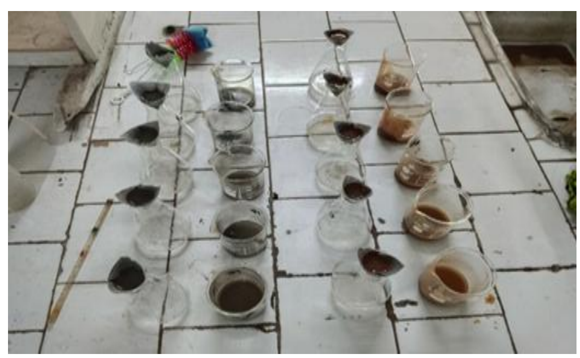

Figure 5: Testing of soil pH

Laboratory measurement of Electrical Conductivity

20g of soil samples are taken and weighed in a container, then it is transferred into a 100ml beaker, 40 ml of water is added to 100ml of beaker and stirred for 30min and then supernatant liquid of soil sample is taken by filtering the soil sample in blotter sheet. The electrode of electrical conductivity meter is immersed in a liquid and then electrical conductivity EC of soil samples is noted down.

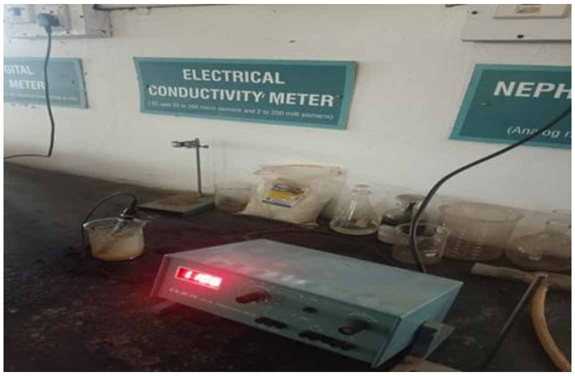

Figure 6: Electrical Conductivity

Laboratory measurement of calcium carbonate

Weigh 5g of soil accurately and transfer to a 150ml beaker and add 100ml of hydrochloric acid solution prepared (175 ml of concentrated hydrochloric acid is dissolved in 2 litres of a distilled water). Cover with a watch glass and stir vigorously several times for 1 hour. After setting, pipette off 20ml of supernatant liquid and taken into a conical flask, add 6-8 drops of bromothymol blue indicator and titrate with sodium hydroxide solution prepared until it reaches its end point blue colour (about 40g of sodium hydroxide is dissolved in a 1litres of distilled water).

$$\int \text{ calcium carbonate present in soil} = \frac{(\text{volume of 1N hydrochloric acid used for 5g of soil}) * 0.05 * 100}{5}$$

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Figure 7: Calcium carbonate test

Figure 8: soil samples stored in plastic bag

VI. RESULTS AND DISCUSSIONS

This chapter begins with a brief summary of laboratory results of soil properties such as moisture content, pH, electrical conductivity, calcium carbonate and finally ending with the statistical results explained through graphs.

Soil chemical Analysis results

50 soil samples were collected from different places so it includes different types of soil such as black soil, red soil, clay soil, etc hence different soil shows different chemical properties due to their spatial variabilities.

6.1 Analysis of moisture content

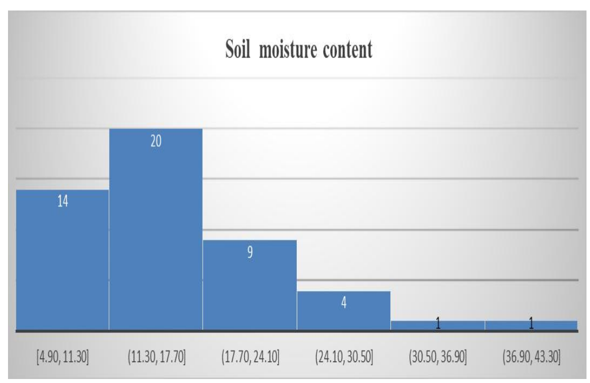

Figure 9: Histogram chart of moisture content

The moisture content of tested soil samples varies from 20% to 40% which indicates that the soils are humid and dry. This variation of water content is due to the topographic region of the site areas.

Soil Moisture Content	Condition
> 30%	Very Wet
25 - 30%	Wet
20 - 25%	Moderate
15 - 20%	Dry
<15%	Very Dry

Table 1: Standard range of moisture content in soil, (source: Hamdan Bin Omar, 2010)

6.2 Analysis of soil pH

The pH values of collected soil samples ranges from 5.5 to 6.5. The below table gives the standard range of soil pH which indicates that the soil samples are moderately acidic in nature.

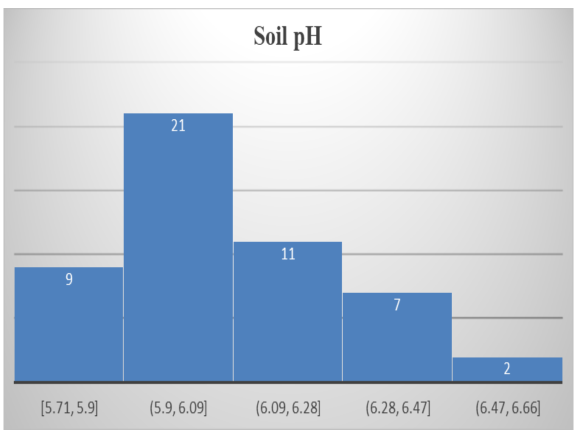

Figure 10: Histogram chart of Soil pH

Denomination	pH range
Ultra acidic	< 3.5
Extremely acidic	3.5–4.4
Very strongly acidic	4.5–5.0
Strongly acidic	5.1–5.5
Moderately acidic	5.6–6.0
Slightly acidic	6.1–6.5
Neutral	6.6–7.3
Slightly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0
Very strongly alkaline	> 9.0

Table 2: standard range of pH

0 to 6=acidic,7=neutral and 8 and above alkalinity (source: wikipedia)

6.3 Analysis of Electrical Conductivity

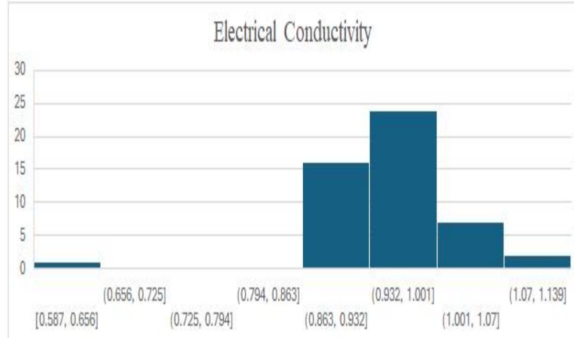

Figure 11: Histogram chart of Electrical conductivity

EC (dS/m)	Salinity Class
0 < 2	Non-saline
2 < 4	Very slightly saline
4 < 8	Slightly saline
8 < 16	Moderately saline
≥ 16	Strongly saline

Table 3: Standard range of Electrical conductivity of soil (Source: South Dakota soil health coalition)

The EC of collected soil samples ranges from 0 to 1 which indicates that the soil are non-saline. Excessive EC value also increases the probability of root rot caused by cotton rot fungus. If the EC value is too low, it indicates that the effective nutrients are insufficient. The salt concentration in water extracted from a saturated soil (called saturation extract) defines the salinity of this soil. If the salt content of this water is <3 g/l, the soil is said to be non-saline. If the salt concentration of the saturation extract is >12 g/l, the soil is said to be highly saline.

6.4 Analysis of Calcium carbonate

The average calcium carbonate equivalent ranges from less than 1 to 10 percent. Texture is usually a loam or clay loam averaging 18 to 35 percent clay, 20 to 55 percent silt, and 20 to 55 percent silt with more than 15 but less than 35 percent fine or coarser sand. (source: GARSID Series (2003).

The calcium carbonate of collected soil samples ranges from 3 to 10 percent.

A crucial nutrient, calcium supports the cellular walls of plants and is essential for the formation of new cells. Frequent fruit illnesses like blossom-end rot, which is common in tomatoes and peppers, can result from a calcium deficit.

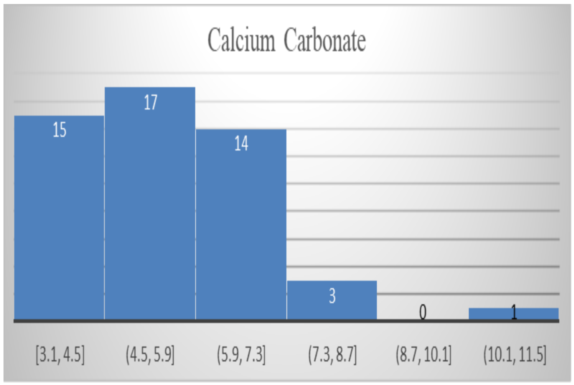

Figure 12: Histogram chart of Calcium carbonate

Table 4 : Descriptive StatisticsCorrelation between topsoil chemical properties

	Descriptive Statistics								
Properties	Minimum	Maximum	Mean(μ)	Median	SD	Variance	CV(%)	Skewness	Kurtosis
pH	5.71	6.6	6.08	6.065	0.20	0.04	3.28	0.52	-0.33
EC	0.587	1.1	0.95	0.96	0.07	0.01	7.60	-2.27	12.87
WC (%)	4.90	39.31	15.93	14.13	6.62	43.81	41.54	1.42	2.52
Ca (%)	3.1	10.8	5.38	5.05	1.44	2.07	26.75	1.11	2.73

Characterizing soil properties through laboratory experiments are laborious task. If there exists interrelationship between soil properties, the properties can be derived from each other. So that it can reduced lot of experiments, labour and time. Hence, correlation matrix was computed to examine whether, there is any relationship between soil properties.

	WC	PH	EC	CC
WC	1			
PH	-0.37445	1		
EC	-0.13831	0.109165	1	
CC	-0.31608	0.936158	-0.24728	1

Figure 13 :correlation matrix

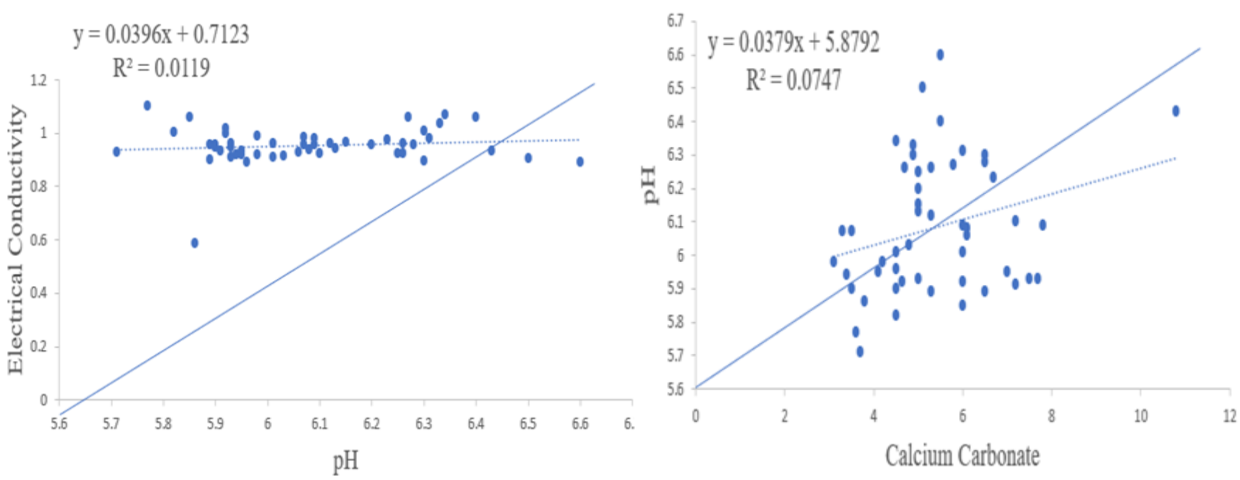

Figure 14: Regression analysis for selected soil properties

As shown in figure 14, Regression analysis of soil properties at 10 cm and 30 cm. RMS-errors were calculated for each data point using a Inverse distance weighted interpolation methods. The Solid line represents regression line (as given by the equations within the upper left of each plot) and dotted lines represents 1:1-line.

Spatial Distribution of soil properties:

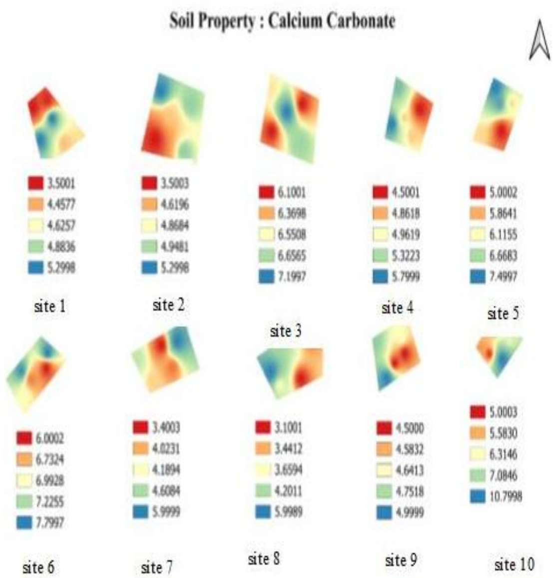

Figure 15: Thematic map of Calcium Carbonate

As shown in figure 15 the spatial distribution of soil calcium carbonate property of site 1&2 varies from 3.5-5.3 similarly site 7 & 8 varies from 3-6, site 3& 6 varies from 6-7.8 , site 4 & 9 varies from 4.5 -6 , site 5& 10 varies from 5-10.8. Minimum spatial distribution of Ca is 3.5 and the maximum value is 10.8

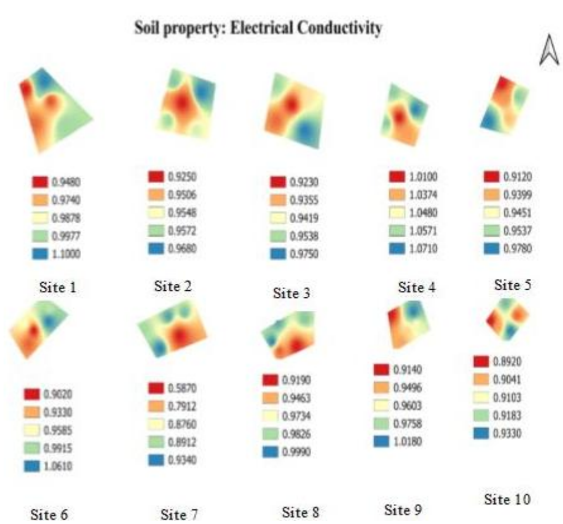

Figure 16: Thematic map of Electrical Conductivity

As shown in figure 16 the spatial distribution of soil electrical conductivity of site 1,6,9 varies from 0.9-1.1 and site 2,3,5,8 varies from 0.9 -0.99, site 7 0.5-0.93, site 10 varies from 0.8-0.93, site 4 varies from 1.0-1.07. The minimum value is 0.5 and the maximum value is 1.1.

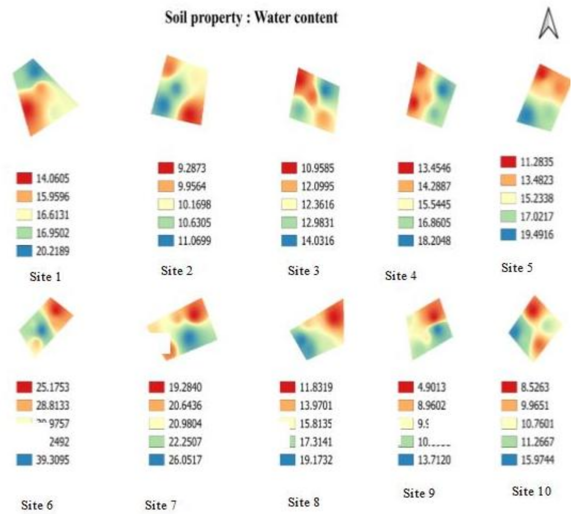

Figure 17: Thematic map of Water Content

As shown in figure 17 the spatial distribution of soil moisture content varies of site 1 varies from 14-20.2, site 2 varies from 9.2-11.06, site 3 varies from 10.95-14, site 4 varies from 13.45 -18.20, site 5 varies from 11.28-19.49, site 6 varies from 25-39, site 7 varies from 19.28-26, site 8 varies from 11.8-19.1, site 9 varies from 4.9-13.7, site 10 varies from 8.5-15.9. The minimum value is 4.9 and the maximum value is 39.30.

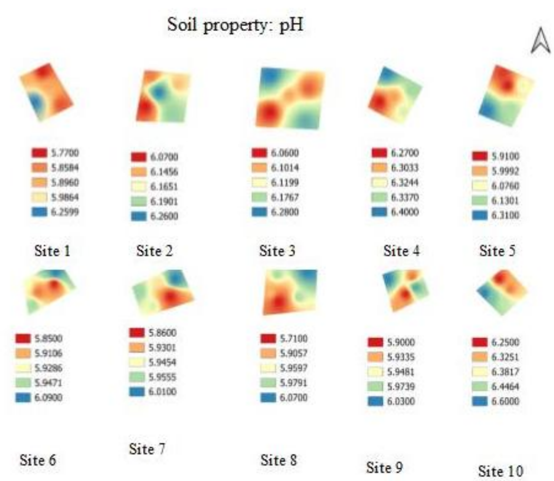

Figure 18: Thematic map of Ph

As shown in figure 18 the spatial distribution of soil pH varies of site 1,8,6,7 varies from 5.77-6.2 and site 9,5 varies from 5.9-6.3, site 2,3 varies from 6-6.29, site

4,10 varies from 6.25-6.6. The minimum value is 5.77 and the maximum value is 6.6

VII. CONCLUSIONS

In developing countries because of the lack of technical knowhow to small scale farmers agricultural production has been decreasing. Added to this topsoil is losing its fertility status because of several reasons. Hence it is crucial to know the status of topsoil properties. Spatial interpolation is the procedure of predicting the values of attributes at unsampled sites from measurements made at point locations within the same area or region. It is used to convert data from point observations to continuous fields so that spatial patterns sampled by these measurements can be compared with spatial patterns of other spatial entities. There is no significant influence of soil type on soil properties range. Restoration of small scale farmers is important in food security point of view.

One of the first important aspects for ensuring soil sustainably in agriculture is improving the knowledge about soil properties by selecting the fit production operation of soil mapping. The soil properties were described using classical statistics after the normalization of data, while their spatial variability was illustrated by using interpolation techniques in a GIS environment.

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