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Spatial Variability Mapping of Soil Chemical Properties Using GIS & GPS

N. Subhasree [a++*], S. Sajeena [b#], K. Prasanthi [c†] and V. M. Abdul Hakkim [b‡]

[a] *Dr. NTR CAE, ANGRAU, India.*
[b] *KCAET, Tavanur, KAU, Kerala, India.*
[c] *ICAR KVK Malappuram, Kerala, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Excessive application of fertilizers can cause wastage of fertilizer which increases input cost and environmental pollution. Implementation of Precision Agriculture through site specific nutrient management is the best suitable solution to increase nutrient application efficiency and thereby increase crop productivity. The present study was carried out in the Instructional Farm of KCAET campus, Tavanur, Malappuram, Kerala, to access the spatial variability of different soil chemical properties. The methodology follows the delineation of the study area, location of sampling points and soil samples were collected and analysed for the soil chemical properties such as pH, Electric Conductivity, Available Nitrogen, Available Phosphorous, Available Potassium, Boron and Sulphur using standard methods. Spatial variability maps of soil chemical properties were prepared by using Inverse Distance Weighing method of interpolation in ArcGIS. From this study, it could be concluded that, GIS along with GPS could be used as an effective tool for preparation of spatial

[++] *Ph. D Student;*
[#] *Associate Professor (SWE);*
[†] *Assistant Professor;*
[‡] *Professor(SWE);*
**Corresponding author: E-mail: subhacae23@gmail.com;*

variability maps for determining the spatial distribution of chemical properties of soils and thereby helps to achieve site specific nutrient recommendation which improves crop productivity, quality and reduce environmental stress. It also involves a lesser number of soil analysis and thus reduces the cost of operation compared to plot-to-plot analysis.

Keywords: Geographic Information of System (GIS); Global Positioning System (GPS); Site Specific Nutrient Management (SSNM); Inverse Distant Weighing method (IDW).

1. INTRODUCTION

The population has been augmenting everywhere in the planet which leads to the need of accelerating food production. Use of various fertilizers has a significant contribution in increasing food production in order to reduce world food insecurity. Recent studies showed that nutrient inputs are responsible for 30–50% of the crop yield. However excessive application of fertilizers can cause wastage of fertilizer which increases input cost and environmental pollution. In order to solve all these problems, implementation of Precision Agriculture through site specific nutrient management is the best suitable solution to increase nutrient application efficiency and thereby increase crop productivity. Site Specific Nutrient Management (SSNM) is the real time feeding of crops with nutrients while recognizing the spatial variability within the fields.

Many technologies such as remote sensing, variable rate technologies, nano technology etc., are used for the implementation of site-specific nutrient management but GIS found to be the most promising tool due to its vast applications. GIS techniques in Precision Agriculture are used for varieties of applications such as conservation of important plant species in land use planning, land use suitability evaluations, crop selections and rotations, irrigation and mechanisation planning. Spatial analysis is the most important component of SSNM which is determined through the Geographical Information System (GIS). Agricultural management interacts with environmental parameters and natural resources that have a clear spatial character and hence, GIS plays a critical role in agricultural productivity, notably in the application of fertilisers. In most research, GIS is used to process model inputs and to display outcomes, but they may also be used for other purposes. GIS plays a key role in unravelling more complex and specialised problems, such as fertiliser management difficulties.

2. MATERIALS AND METHODS

Fertility status of the soil is an important factor for achieving sustainable agricultural production, which is declining day by day resulting in declining yields and enhancing environmental pollution. Fertilizer management varies with zones, and it has a significant impact on agricultural output and quality [1]. The spatial variability of soil properties is needed for agricultural productivity, food safety and environmental modelling [2]. Understanding of soil nutrient distributions and the factors affecting them are crucial for fertilizer management and environmental protection in vulnerable ecological regions [3]. Preparation of fertility maps with the help of both GPS and GIS by locating sampling points, thereby collecting and analysing of samples were done by using standard methods. Recommendations were given to farmers based on the spatial distribution maps. The study was carried out in the Instructional Farm of Kelappaji College of Agricultural Engineering and Technology (KCAET) Campus which is situated in Tavanur village of Malappuram district, Kerala. The study area is located between 10° 51' 6.51" to 10° 51' 31.417" N latitude and 75° 59' 2.37" to 75° f Gridding was done in order to locate the sampling points, by using 59' 25" E longitude and 13 m above mean sea level. The area was delineated by using the cadastral map of the study area and coordinates of the corner of the study area were found with the help of hand-held GPS. Georeferencing of the map was done by using the georeferencing tool of ArcGIS 10.3. Shape file of the study area was prepared along with the features such as buildings, placemarks, road and river as shown in Fig.1.

2.1 Soil Sampling Points by Using Gridding

Gridding was done in order to locate the sampling points, by using the gridding tool in ArcGIS. A grid interval of 100 ×100 m was taken for the study. The grid map was then exported to google earth which is easier for visual identification of sampling points. It can be achieved by converting layer to kml file using the conversion tool in ArcGIS tool box. The kml file is opened in google earth and sampling points were identified. Sampling points shown in Fig. 2 consists of cultivable area and built-up area which was excluded while collecting samples. Soil samples were collected from 40 sampling points in the study area which were numbered sequentially from 1 to 40.

2.2 Collection of Soil Samples

The sampling points in the study area were identified with the help of GPS (Garmin Etrex 3X) by using coordinates of those sampling points which obtained from GIS map (Fig. 3). Soil samples were collected from each sampling point as per the procedure and at each sampling point, four subsamples were collected at a depth of 15 cm. The surface trashes and litter were removed at sampling location and a 'V' shaped cut was made with the help of spade. Samples collected were mixed thoroughly and again checked for any small stones and other foreign materials. One kg of soil sample was obtained and taken as a representative sample by using the four-quartering rule. The samples were numbered and kept for air drying for two weeks for the analysis of soil nutrients.

2.3 Analysis of Soil Samples

The sieve analysis of air-dried soil samples was carried out for soil analysis with 2 mm sieve for pH and EC and 0.5 mm sieve for other soil nutrients. The soil analysis was carried out at soil testing laboratory, KVK, Malappuram. The soil samples were analysed for the soil chemical properties such as pH, Electric Conductivity, Available Nitrogen, Available Phosphorous, Available Potassium, Boron and Sulphur by using standard methods (Table 1). Based on Table 2, soil chemical properties were classified as low medium and high in the study area.

2.4 Preparation of Fertility Maps by Using ArcGIS

Fertility Maps were prepared by using the Interpolation tool in Arc tool box supported by Geoprocessing tool in ArcGIS. The Inverse Distance Weighting method (IDW) in ArcGIS was used to interpolate the spatial distribution of soil pH, EC, N, P, K, B and S from the soil samples collected from the study area. Inverse Distance Weighting method (IDW) determines grid cell values by averaging of sample data points that are closer to the cell. The point which is close to the centre of the cell being estimated, the more influence or weight has been given in the averaging process (Anjana 2019). An Inverse Distance Weighted method of interpolation created continuous maps for each soil parameter which helps to estimate the soil properties of the entire area.

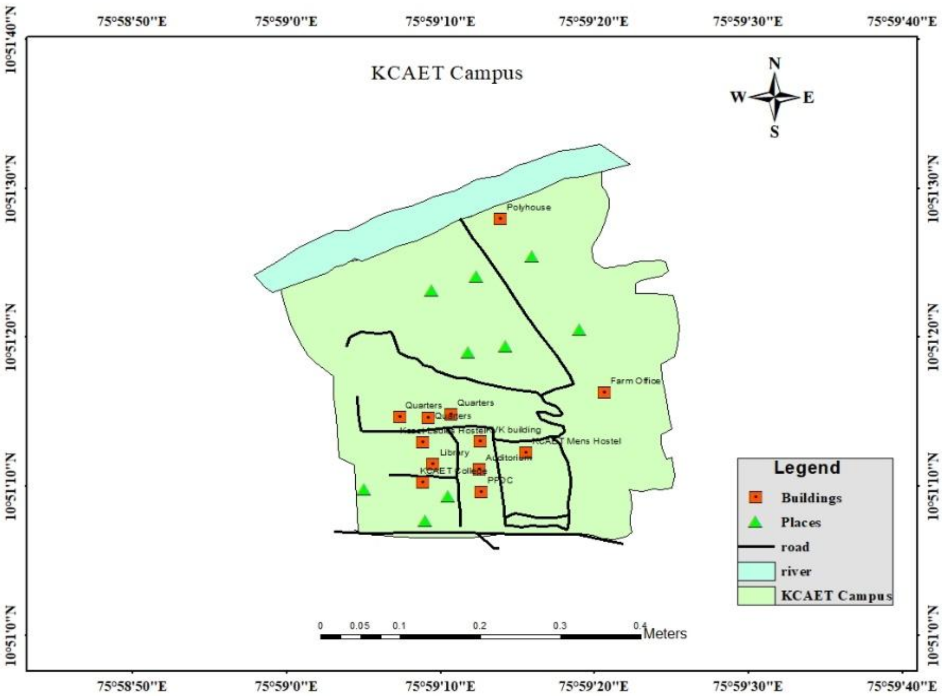


Fig. 1. Shape file of the KCAET campus

Table 1. Methods used for soil analysis

Sl.No.	Soil Parameters	Methodology	Author
1)	Soil pH	pH meter with glass Electrode (1:2 soil- water ratio)	Jackson (1973)
2)	Electric conductivity (dS/m)	EC meter	Jackson (1973)
3)	Organic Carbon	Alkaline permanganate method	Walkley and Black (1934)
4)	Available Nitrogen (kg/ha)	Kjeldhal Method	Subbiah and Asija (1956)
5)	Available phosphorous (kg/ha)	Bray No1 extraction method	Bray and Kurtz. (1945)
6)	Available potassium (kg/ha)	Flame photometry	Stanford and English (1949)
7)	Boron (mg/kg)	Hot water extraction method	Gupta (1967)
8)	Sulphur (mg/kg)	$CaCl_2$ Extraction method	Massoumi and Cornfield (1963)

[4]

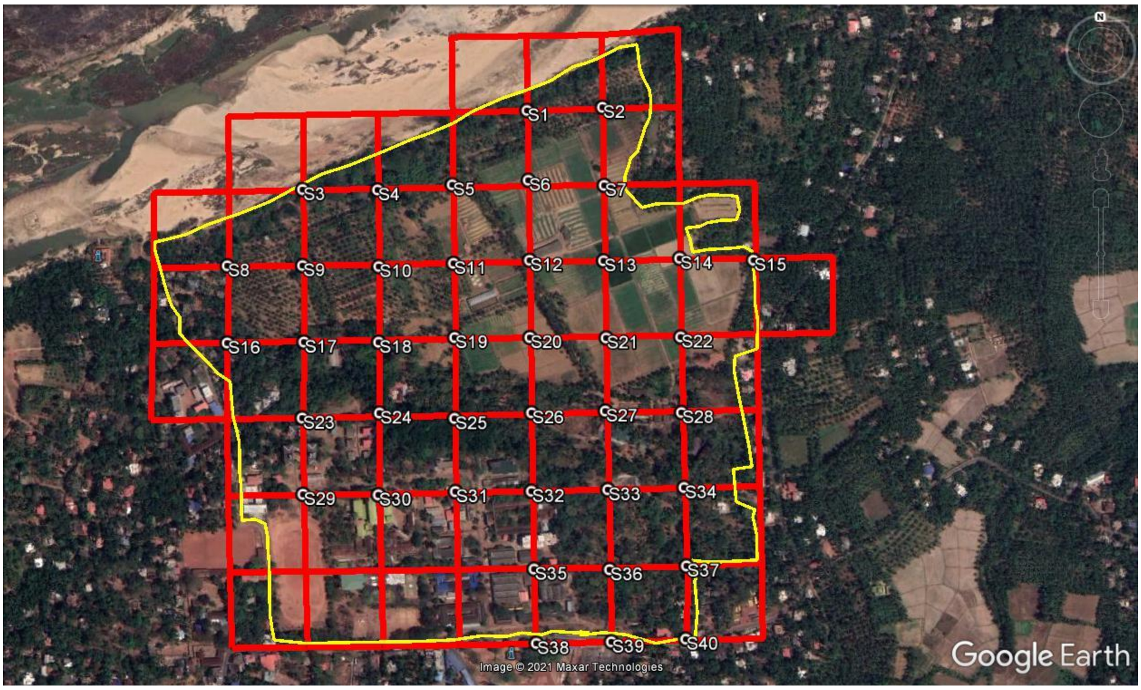


Fig. 2. View of grid map and sampling points in google earth

Table 2. Fertility Rating of soil chemical properties

Soil chemical property	Nutrient status		
	Low	Medium	High
pH	<6	6-7	>7
EC (dS/m)	<1	1 – 3	>3
Organic Carbon (%)	<0.76	0.76 -1.5	> 1.5
Available Nitrogen (kg/ha)	< 280	280 – 450	>450
Available Potassium (kg/ha)	< 115	115-275	>275
Available Phosphorous (kg/ha)	<10	10-24	>24
Boron (mg/kg)	< 0.5	0.5 -1	>1
Sulphur (mg/kg)	< 10	10 – 15	>15

[5]

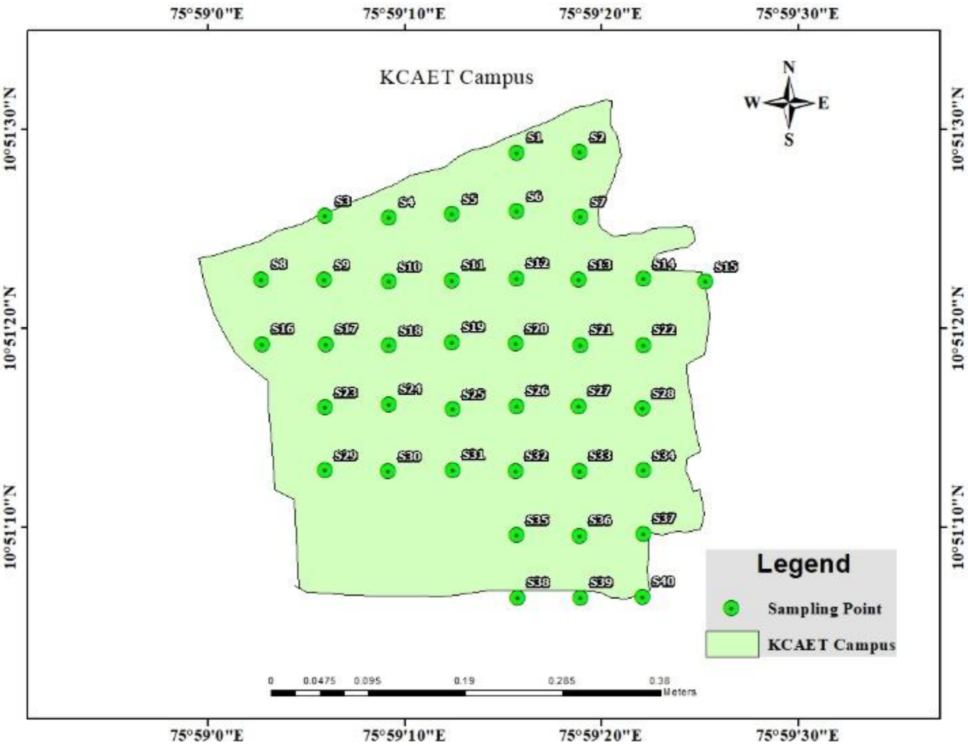


Fig. 3. Sampling points of KCAET campus

3. RESULTS AND DISCUSSION

It is important to assess the fundamental nutrients of the soil to determine the available nutritional status of the soil and to avoid the adverse effects of excess chemical fertilisers in the soil, as well as to the environment. Table 3. showed the percentage of soil samples(40 samples) fall under low, medium and high range for different soil chemical properties. In the study area,97.5% of the soil samples showed acidic in nature and all the samples showed low electrical conductivity. In the case of organic carbon, 55 % of the samples showed the low percentage of organic carbon, 20 % of the samples showed medium percentage and 25% of the samples showed high percentage whereas in case of nitrogen about 75% of the soil samples fall under low range and 25 % of the soil samples fall under medium range. About 32.5 % of samples fall under low and high range and 35 % of samples fall under the medium level for phosphorous whereas for potassium, about 62.5% of samples fall under medium range, 22.5% of samples under low range and 15% soil samples fall under high range of potassium. In case of sulphur, about 85 % of the samples fall under low range and 15% of the samples were under high level of sulphur whereas in case of boron,about 20% of the samples falls under medium range and 80 % of the samples were under high range of boron.

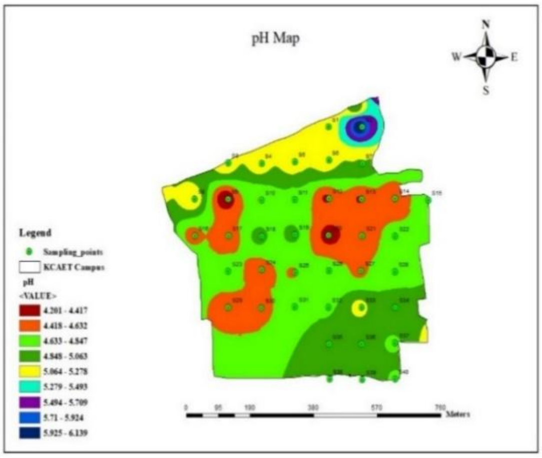
The spatial variability maps of soil fertility parameters helped to find the extent and magnitude of the nutrients. The spatial variability of soil nutrients such as N, P, K, B and S and pH and EC were plotted with the help of Arc GIS software. These maps showed the spatial distribution of soil nutrients in the study area. From the Fig. 4.a, it could be seen that the pH of the soils throughout the study area varied from strongly acidic to slightly acidic in nature. The pH of the major portion of the study area showed strongly acidic in nature. The acidic nature of soil could be due to nature of parent material, micro topography, weather conditions and type of fertilizer used. Lime could be added in order to reclaim acid soils. Lime raises soil pH and provides calcium and magnesium to the soil. Electric conductivity was found to be low (<1 ds/m) in most parts of the study area as shown in Fig. 4b which is mainly due to leaching of salts due to high rainfall.

Organic carbon was found to be low (< 0.76 %) in most parts of the cultivated area of the study area as shown in Fig. 4.c. This may be due to erosion of top soils and decomposition of organic matter. Organic carbon was found to be medium and high in the southern part of the study area. Available nitrogen varied from very low to medium in the study area. Available nitrogen was found to be low (<280 kg/ha) in cultivated parts of the study area (Fig. 5d). This is mainly due to low availability of Organic Carbon, increased rate of mineralisation and removal of N by nutrient exhaustive crops. Nitrogen found to be medium in southern and western parts of the study area. Results of the soil analysis showed that deficiency of nitrogen in most parts of the study area. Therefore, proper soil management techniques should be followed in order to improve the availability of nitrogen in the soil.

From the Fig. 4.e, it can be seen that, available phosphorus varied as low, medium and high status in the study area and it was found to be high in cultivated parts of the study area. This may be due to the application of phosphorous fertilizers or deposition from upland areas. From the Fig. 4.f, it can be seen that available potassium varied from low to high range in the study area. Potassium was found to be in medium range (115-275 kg/ha) in the study area in all parts, except in some pockets, where it was found in the low range(<115k/ha). Major part of the cultivated area showed a medium range of potassium. Low and medium status of potassium may be due to significant loss of potassium due to excessive rainfall. Potassium was found to be high (>275 kg/ha) in some pockets of the southern part of the study area. Sulphur varied from low to high status in the study area. In most parts of the study area (Fig 4.g), sulphur was found to be in low range (<10 mg/kg). This may be due to oxidation of sulphur into sulphuric acid by soil microorganisms which also resulted in low pH and also leaching. In northern parts of the study area, sulphur was found to be high in some pockets. From the Fig. 4.h, it could be seen that boron varied from medium to high range in the study area. Boron was found to be high (>1 mg/ha) in most parts of the study area. This may be due to irrigation of crops with well water and also application of fertilizers. Boron was found to be a satisfactory level in the study area as it was necessary for plant growth. From these maps, it is evident that most of the soils were low in terms of Electrical Conductivity, Organic Carbon, Nitrogen, and Sulphur. Potassium and Phosphorous were in medium range, whereas boron was in the high range in the study area. Based on these maps nutrient recommendations can be given to farmers to achieve site specific nutrient management.

Table 3. Percentage of soil samples (40 samples) fall under low, medium and high range for different soil chemical properties

Sl.No	Parameter	Range	Number of samples	Percentage of samples
1	pH	Low	39	97.5%
		Medium	1	2.5%
		High	-	-
2	Electrical Conductivity	Low	40	100%
		Medium	-	-
		High	-	-
3	Organic Carbon	Low	22	55%
		Medium	8	20%
		High	10	25%
4	Nitrogen	Low	30	75%
		Medium	10	25%
		High	-	-
5	Phosphorous	Low	13	32.5%
		Medium	14	35%
		High	13	32.5%
7	Potassium	Low	9	22.5%
		Medium	25	62.5%
		High	6	15%
8	Sulphur	Low	34	85%
		Medium	-	-
		High	6	15%
9	Boron	Low	-	-
		Medium	8	32%
		High	32	80%


pH Map
N
W
E
S
Legend
Sampling_points
KCAET Campus
pH
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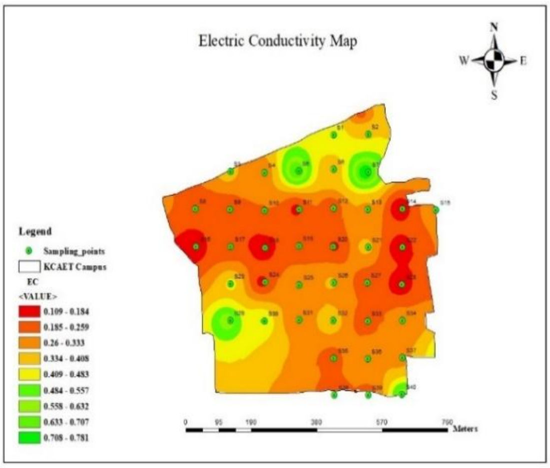
4.201 - 4.417
4.418 - 4.632
4.633 - 4.847
4.848 - 5.063
5.064 - 5.278
5.279 - 5.493
5.494 - 5.709
5.71 - 5.924
5.925 - 6.139
0 95 190 380 570 760 Meters

(a)


Electric Conductivity Map
N
W
E
S
Legend
Sampling_points
KCAET Campus
EC
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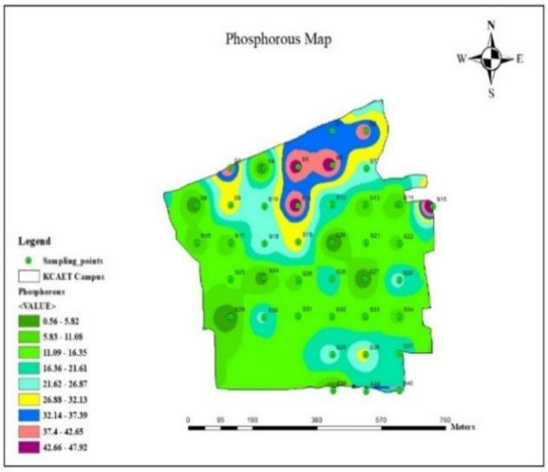
0.185 - 0.259
0.26 - 0.333
0.334 - 0.408
0.409 - 0.483
0.484 - 0.557
0.558 - 0.632
0.633 - 0.707
0.708 - 0.781
0 95 190 380 570 760 Meters

(b)


Phosphorous Map
N
W
E
S
Legend
Sampling_points
KCAET Campus
Phosphorous
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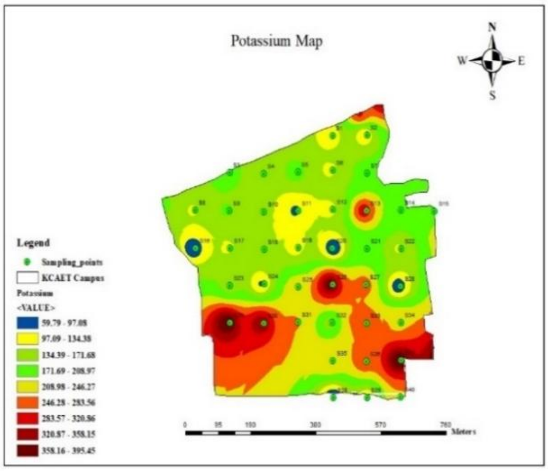
5.83 - 11.08
11.09 - 16.35
16.36 - 21.61
21.62 - 26.87
26.88 - 32.13
32.14 - 37.39
37.4 - 42.65
42.66 - 47.92
0 95 190 380 570 760 Meters

(c)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N
W
E
S
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Sampling_points
KCAET Campus
Potassium
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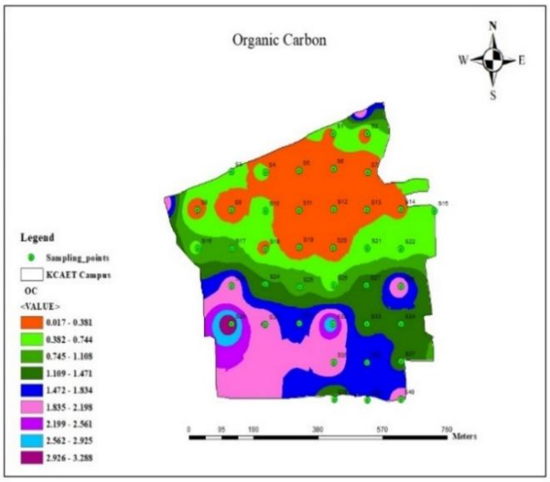
97.09 - 134.38
134.39 - 171.68
171.69 - 208.97
208.98 - 246.27
246.28 - 283.56
283.57 - 320.86
320.87 - 358.15
358.16 - 395.45
0 95 190 380 570 760 Meters

(d)


Organic Carbon
N
W
E
S
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OC
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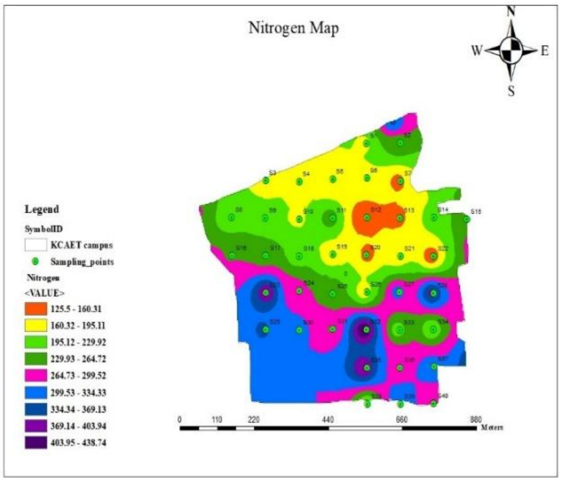
0.382 - 0.744
0.745 - 1.108
1.109 - 1.471
1.472 - 1.834
1.835 - 2.198
2.199 - 2.561
2.562 - 2.925
2.926 - 3.288
0 95 190 380 570 760 Meters

(e)


Nitrogen Map
N
W
E
S
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SymbolID
KCAET campus
Sampling_points
Nitrogen
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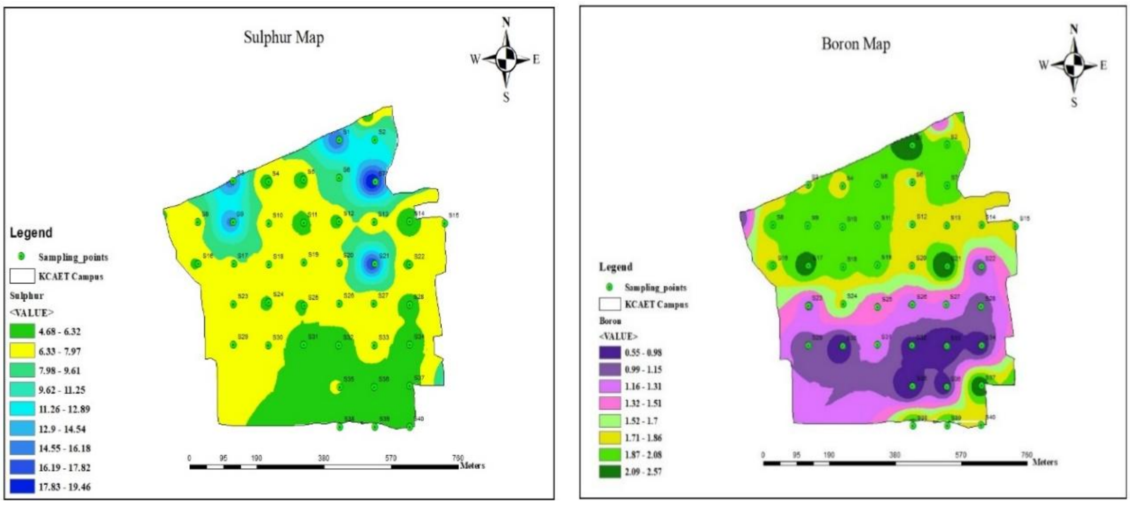
160.32 - 195.11
195.12 - 229.92
229.93 - 264.72
264.73 - 299.52
299.53 - 334.33
334.34 - 369.13
369.14 - 403.94
403.95 - 438.74
0 110 220 440 660 880 Meters

(f)



(g) **(h)**

Fig. 4(a - h). Shows the spatial distribution maps of soil chemical properties

4. CONCLUSIONS

- In the study area, pH was ranging from 4.2 to 6.14 which indicated that soils were acidic and electric conductivity was ranging from 0.109 dS/m to 0.601 dS/m which was considered as low (< 1 dS/m) in the study area.
- Nitrogen (<280 kg/ha) and sulphur (<10 mg/kg) were in low range whereas boron (>1mg/kg) was in high range and the remaining chemical properties such as organic carbon (0.76-1.5 %), phosphorus (10-24 kg/ha) and potassium (115-275 kg/ha) were in medium range in the study area.
- GIS could be used as an effective tool for determining the spatial distribution of chemical properties of soils and thereby we can provide site specific nutrient recommendations.
- GIS based soil nutrient maps provide a better way to achieve right inputs in right quantity at right place at right time.
- GIS based soil nutrient maps, provide a way for achieving site specific nutrient recommendation as it involves lesser numbers of soil analysis and thus reduces the cost of operation compared to plot-to-plot analysis.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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