

# Application of GIS for delineation of landscape classification and soil quality management using innovative modeling approach

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Reduction in cultivable lands is increasing day by day both in quantitative and quality measures due to anthropogenic and natural activities in developing countries such as India. Repeated cultivation of crops, particularly farming of same kind of crops without proper nutrient amendments prior to the successive cultivation may cause nutrient deficiency in the soil and declines the yields. Such unscientific agricultural practices across the developing countries have ruined the yielding potential of the agricultural lands. If the landscape could be delineated and classified in different categories on the basis of the integrated soil quality indices and soil type, appropriate remediation, soil amendments and techniques of optimizing soil health may be adopted to treat the soil and amend the nutrients for effective agricultural practice to raise the yielding potential of the landscape after the estimation of nutrient budget. This research article presents the analysis of soil characteristics of different categories of agricultural land for computing integrated soil quality indices. Further the variation of integrated soil quality indices across the landscape has been interpolated using geographical information system (GIS) and again delineated into different classes on the basis of soil quality indices and taking into consideration the soil pH. The study will be useful for economic and effective management of land resources in sustainable manner through application of appropriate methods for soil treatment and improving healthy soil fertility.

**Keywords:** GIS, Land classification, Soil quality index, Soil texture index, Spatial modeling

## 1 Introduction

The soil is a natural resource as medium for plant growth and it supplies nutrients to plants. Some soils are productive and they support luxuriant growth of plants with very little human effort whereas others may be unproductive which support almost no useful to plant life regardless of every human effort. The soil fertility may be defined as the ability of soil to provide all essential plant nutrients in available forms and in a suitable balance whereas soil productivity is the resultant of several factors such as soil fertility, good soil management practices, availability of water supply and suitable climate. The soil must supply these essentials every day for the survival of the plant. But the applied fertilizers available to the plants are not uniformly distributed across the landscape due to more than 10% slope variation of the topographical area, which drains out the nutrients to the lower area and excess fertilizers and water cause may ruin the roots<sup>1</sup>. The selection of different crops within the same landscape may also cause non-homogeneous distributions in nutrient availability. The spatial

modeling of soil quality variation would be useful to detect the variation in overall quality of the soil and delineate the entire landscape into different classifications in terms of integrated soil quality by assigning appropriate weightages to the individual parameters according to the importance of the parameters for the intended use of the soil. The present study is an attempt made to use a modeling approach to compute integrated soil quality in terms of soil quality scores or indices with respect to the considered parameters based on the soil standards that determine the quality interval of each parameter for the intended use. A study insists on the need of integrated soil quality indices that provide a more holistic status of reclamation potentials of tree species, selected appropriately for the successful remediation of mine spoils<sup>2</sup>.

A scientific report points out that mining activities eliminate existing vegetation as the genetic soil profile is altered and as a result, the wildlife and habitat are displaced or demolished, current land use is altered, and further up to some extent permanently the general topography of the mined out area is changed. The yielding potential of the crops do not

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depend only upon the productivity which is ensured with sufficient water availability, but also the soil fertility, suitable climate and environmental conditions as water quality plays a vital role in irrigation<sup>3</sup>. A scientific study reports that the soil organic matters is accumulated under pasture and have an effect on the soil properties<sup>4</sup>. The American Phytopathological Society, USA has studied nutrient deficiencies and toxicities in crop plants<sup>5</sup>. Studies reveal that interactions between organic matter and aggregation maintain soil functions for sustainable soil quality management<sup>6</sup>. The role of chelating agents and the effect of gypsum and other salts in plant growth have been studied as well<sup>7</sup>. Contrasting concepts in soil test interpretation have been addressed and the sufficient levels of available nutrients versus basic cat-ion saturation ratios have been studied as well<sup>8</sup>. Principles of plant nutrition and management of agricultural soil have been explained in details<sup>9-10</sup>. A study reports that the rate of uptake of a nutrient might be limited by its rate of diffusion through the soil or by the ability of the root to absorb it from low concentration in the soil solution. Further it reveals that uptake of N, P, and K is limited by diffusion in the growth-response range of concentration and transpiration rate and the root might be able to increase the soil solution concentration of sparingly soluble nutrients<sup>11</sup>. The interrelations between soil pH, aluminum and manganese and lime requirement have been addressed as well<sup>12</sup>. The symptoms of nutrient deficiencies have been reported in a research study<sup>13</sup>. The role of nitrogen and manganese in the crop production, the impact of high Ca on poor growth of the plant as one of the reasons and the effect of organic matter and tillage on maximum compatibility of soil have been addressed in the research studies<sup>14-17</sup>. A study reports that borates have low toxicity in mammals, but are more toxic to arthropods and are used as insecticides. Boric acid is mildly antimicrobial, and several natural B-containing organic antibiotics are known. B is an essential plant nutrient and B compounds such as borax and boric acid are used as fertilizers in agriculture, although it only requires in small amounts, with excess being toxic. B compounds play a strengthening role in the cell walls of all plants<sup>18</sup>. A research study on B sorption by soil in the presence of composted organic matter has been carried out and it reveals that although the organic matter content in cultivated soil is relatively low, its

presence may have a significant effect on distribution between the solid and liquid phases in soils. The influence of organic matter in soil on B sorption and to test a B sorption model for soil in the presence of organic matter has been studied as well. The sorption isotherms were linear regardless of the composted organic matter content while pH level is lower than 8 and however, a deviation from linearity has been observed when pH level is higher than 8. The B sorption capacity of the mixture increased with the composted organic matter content. The agreement between calculated values and experimental results indicates that the sorption model can be used to predict B sorption by the mixtures of soil and organic matter<sup>19</sup>. Another study on organic matter reports that the amendment of organic matter affects mechanical properties of soil aggregates<sup>20-21</sup>. A few methods are available for analyzing soil data for soil resource management as one of tasks of environmental impact assessment and management plan<sup>22-23</sup>.

Several research studies on soil conditioning in farming have revealed that it is not merely one of the acts of improving soil physical fertility but it play a great role in nutrient fixation also. The soil conditioners are both synthetic as well as natural substances when added to soil it enhances the soils quality, usually its fertility and the natural biomasses includes such as algae, seaweed extracts, legumes, azolla, sphagnum peat moss and other such biomasses. Shields and Durrell has firstly reported the algae as alternative biodegradable mass in soil fertility<sup>24</sup>. Several studies report the vital role of algae biologically in agriculture where it can be used as bio-fertilizers improve its characteristics such as, carbon content, texture, aeration and also nitrogen fixation and soil stabilizers and the reuse of the detritus generated by dead algae used as fertilizer for crops<sup>25-28</sup>. Algae adds organic matters to the soil when it dies and act as a cementing agent by binding soil particles and thereby reducing and preventing soil erosion. It increases the water retention capacity of soil for longer time periods. Algae help to check the loss of nitrates through leaching and drainage, especially in un-cropped soils. Photosynthetic aquatic biomass (PAB) is a significant source of organic carbon rice crops and a portion of PAB is capable of fixing nitrogen and is also a source of N for crop nutrition<sup>29</sup>.

Nowadays the demand for the fertilizer of seaweed extracts is rising as it contains high quantities of

macro and micro-elements, amino acids, antibiotics, and vitamins, needed for adequate plant growth<sup>30,31</sup>. Legumes and *azolla* have been conventionally used as green manure in some of the Asian countries, permitting yields of 2–4 tons/ha and injection with blue-green algae has been claimed to increase yields by about 10%. Use of biological N fixation as an alternative or additional N source for rice is severely restricted by the factors of environment, technology and socio-economic<sup>32</sup>. Similarly protozoa and its kind are capable as biological agents to improve soil quality and they can withstand adverse soil conditions, as they are characterized by a protected, dormant stage in their life cycle. Protozoans draw their nutrition from feeding or consuming soil bacteria and play an essential role in upholding microbial and bacterial equilibrium in the soil and certain protozoan is also used as control measures against organisms that cause injurious diseases in plants<sup>26</sup>.

Considering all the findings of the above cited research studies, soil is a living matters a potential resource to life on our planet. It covers unconsolidated mineral as skin and organic matter on the surface of the earth and extends gradually from the various minerals and modifies climate condition, micro and macro-organisms, vegetations, and morphological and topographical variations with the course of time. Soil

is a composite combination of minerals, organic matters and living organisms that interact constantly in response to natural and imposed biological, chemical and physical phenomena. An excellent and sustainable agricultural practice must ensure scientific study to select appropriate crops for different types of soil as the yielding potential of any plant or crop depends upon the quality of soil, which is determined by biological, chemical and physical parameters. The present study is an attempt made to apply an innovative modeling approach to compute soil quality scores and further to classify the landscape for remediation, treatment and nutrient amendments, which would improve yielding capacity.

## 2 Materials and Methods

### 2.1 Study area

The study area is located in Dhanbad district in Jharkhand state as shown in Fig. 1. The landscape with total area of 321.048 ha spread between latitude 23°49'00" to 23°51'00"N and longitude from 86°31'30" to 86°33'30"E comprising six villages under Ratanpur village council of Govindpur block in Dhanbad district of Jharkhand state, covering the agricultural land that falls under different land use categorized as agricultural land, agricultural cropping land, agricultural upland, riverside land, residential

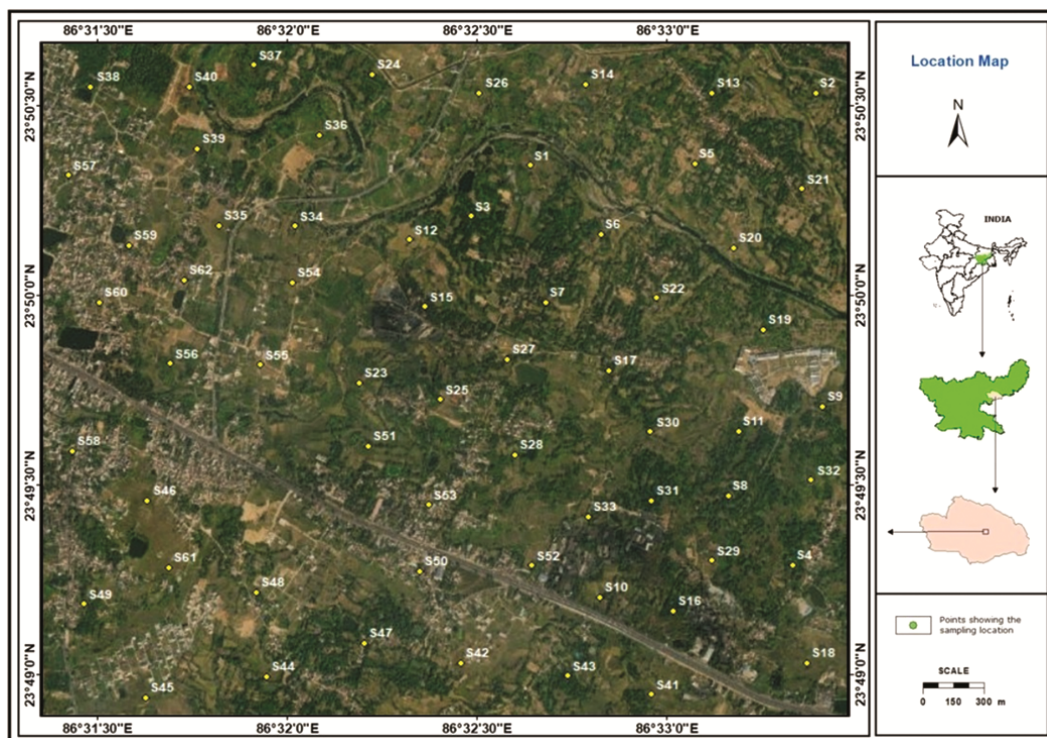


Fig. 1 — Location map of the study area.

land, forest land, fallow land, agro-forest land and barren grazing land.

## 2.2 Sampling and analysis

The sampling of top soil was carried out during January to February, 2016 according to standard method adopted by ICAR-Indian Agricultural Research Institute, New Delhi. Figure 2 shows the soil sampling and collection from study area.

The composite soil samples for each sampling location were prepared by mixing together the samples drawn from 3 to 5 points around the peripheral area of the location in order to prepare homogenous representative material of the top soil, and further the samples were brought to the laboratory for analysis of physico-chemical parameters with standard method adopted by ICAR, New Delhi. The air dried top soil samples were grinded and passed through 2 mm sieve for analyzing 7 physical parameters and 8 chemical parameters. Figure 3 shows the distribution of soil in different particle sizes through the sieve shaker machine. After sieving process different particles of soil sample are separated and sent to particle weight balance measurement equipment to measure weight as shown in Fig. 4.

Evaluation of soil quality comprises the assessment of physical, chemical and biological parameters but the findings of the present study based on only physico-chemical parameters.



Fig. 2 — Soil sampling and collection from study area.

## 2.3 Physico-chemical parameters

The soil quality has been assessed based on 7 physical parameters such as soil moisture (%), water holding capacity (WHC) (%), bulk density (BD) ( $\text{g}/\text{cm}^3$ ), gravel (%), sand (%), silt (%), clay (%) and 8 chemical parameters such as soil pH, electric conductivity (EC) ( $\mu\text{S}/\text{cm}$ ), available nitrogen (N) (%), available phosphorous (P) (%), available potassium (K) (%), Manganese (Mn) (ppm), Iron (Fe) (ppm) and zinc (Zn) (ppm) considered for the present study and they have been presented in Tables 1 and 2 respectively.

## 2.4 Modeling approach

### 2.4.1 Quality interval

Soil as a part of environmental system, it is built up with multiple numbers of physical, chemical and



Fig. 3 — Soil distribution in different particle size through sieve shaker machine.

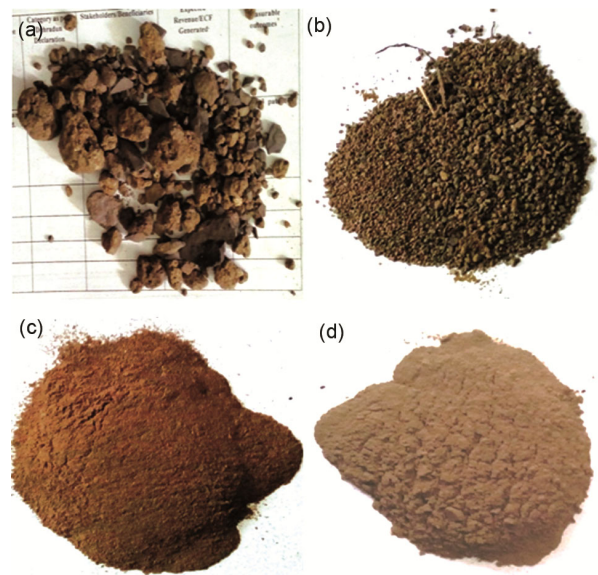


Fig. 4 — Different particles of soil sample.

Table 1 — Physical characteristics of agricultural soil in the study area.

Sampling Station	Moisture (%)	WHC (%)	BD (g/cc)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
S1	4.75	28.732	1.541	16.5	32.5	18.4	32.4
S2	7.75	30.285	1.500	10.4	42.5	23.8	23
S3	6.25	32.609	1.528	44.8	33.7	10.6	10.7
S4	9.75	31.341	1.440	40.8	38.9	14.9	3.9
S5	6.5	32.075	1.477	28	36.4	26.1	9
S6	2.75	10.771	1.619	13	58.7	20	7
S7	7.75	31.825	1.478	43	48.0	4	4.8
S8	8.75	30.757	1.472	56.5	21.0	10.8	10.4
S9	6.75	30.261	1.515	34.5	36.7	16.9	10.2
S10	3.75	30.415	1.533	24.6	28.1	17.9	28.7
S11	7.25	31.173	1.422	37	30.3	21.3	10
S12	12	38.694	1.422	35	39.1	20.3	4.4
S13	3.5	29.395	1.553	20.2	30.0	24.6	24.8
S14	8	32.193	1.428	31.2	36.5	20.4	11.4
S15	6.25	29.955	1.452	38.9	26.9	18.4	14.4
S16	4.5	32.036	1.555	36.9	30.9	10.8	20.8
S17	4	30.493	1.429	14.9	26.9	27.9	30
S18	4	28.898	1.500	14.9	30.8	17.6	36
S19	2.75	29.480	1.604	15.7	22.0	28	34
S20	4.5	36.223	1.471	20	33.9	23.2	21.3
S21	5.75	32.663	1.457	29.2	31.5	32.3	6
S22	2.25	29.592	1.561	14.2	22.0	40.8	21.8
S23	4.75	29.690	1.485	32.5	38.6	2.3	25.6
S24	6.5	33.017	1.437	53.1	30.8	1.3	14.8
S25	4.25	26.119	1.652	28.8	38.8	2.4	28.8
S26	6.75	23.065	1.459	44.2	34.3	1.1	19.5
S27	16	29.925	1.543	43.4	33.6	1	20.9
S28	7	31.704	1.476	42.5	41.9	2.4	13.2
S29	5.25	31.689	1.542	35.6	40.5	2.7	19.4
S30	6.5	23.789	1.393	30.5	42.4	0.3	24.7
S31	9	28.592	1.306	50.4	47.7	0	1.5
S32	4.5	29.582	1.459	30	45.5	1.6	21.4
S33	5	30.030	1.422	28.9	47.4	1.7	20
S34	6.75	36.000	1.475	37	46.5	0.2	15.2
S35	5	35.831	1.503	26.4	47.7	11.2	23.3
S36	6.25	34.720	1.310	33.1	46.8	2.6	16.4
S37	5.75	34.873	1.368	34.9	44.3	0.1	20
S38	4.5	31.075	1.551	32.8	41.5	0.2	24
S39	1.05	29.911	1.419	41.3	50.5	6.1	1.8
S40	17	31.366	1.429	65.5	29.3	3.3	1.7
S41	6.23	39.655	1.482	35.6	27.4	18.4	15.6
S42	5.14	31.184	1.481	48.9	29.2	15.5	5.7
S43	3.62	33.120	1.377	54.7	31.4	10.7	3.1
S44	4.21	32.622	1.476	37.8	32.8	22.2	6.9
S45	8	29.690	1.468	23.3	35.2	26.6	14.4
S46	9.21	26.145	1.388	44.3	32.6	17.4	5.2
S47	11.54	30.712	1.474	45.2	24.3	17.6	12.3
S48	10.18	33.385	1.371	46.2	33.4	15.8	4.1
S49	18	31.555	1.407	47.8	35.5	14	2.3
S50	16.03	30.349	1.309	42.4	48.7	7.3	1.3
S51	15.14	33.385	1.409	44.6	26.5	23.5	4.7
S52	12.36	28.261	1.298	48.2	40.8	9.2	1.8
S53	6.4	28.369	1.565	41.5	25.2	17.3	15.9
S54	10.54	31.522	1.428	47.5	27.7	19.2	5.6
S55	11.02	33.387	1.478	40.7	42.5	14.3	2.1
S56	9.087	34.984	1.397	71.7	26.4	1.1	0.6
S57	20.1	36.020	1.341	46.8	48.1	3.9	1

*(Contd.)*

Table 1 — Physical characteristics of agricultural soil in the study area (*Contd.*).

Sampling Station	Moisture (%)	WHC (%)	BD (g/cc)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
S58	6.52	28.896	1.423	45.7	49.6	3.3	1
S59	6.78	30.441	1.453	52.1	45.6	1.5	0.5
S60	8.6	31.741	1.364	48.5	29.5	18.7	3.1
S61	12.54	27.914	1.470	56.6	37.6	4.4	1.2
S62	9.086	31.045	1.295	50	43.0	5.7	0.9

Table 2 — Chemical characteristics of agricultural soil in the study area.

Sampling Station	pH	EC ( $\mu\text{S}/\text{cm}$ )	N (%)	P (%)	K (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)
S1	6.67	28.7	0.11	0.09	3.7	1.19	0.26	0.12
S2	6.58	67.3	0.18	0.13	4.3	2.65	0.56	0.08
S3	6.04	53.7	0.04	0.1	3.9	1.29	0.26	0.19
S4	6.72	19.5	0.14	0.34	5.4	2.13	0.43	0.17
S5	6.68	15.2	0.08	0.09	2.9	1.21	0.26	0.15
S6	6.73	28.6	0.04	0.04	2.4	1.04	0.19	0.17
S7	6.59	51.1	0.05	0.1	2.6	1.63	0.26	0.11
S8	6.81	58.8	0.04	0.04	1.9	1.24	0.17	0.09
S9	6.78	36.8	0.03	0.03	1.8	0.94	0.13	0.08
S10	6.67	40.6	0.02	0.05	5.2	0.86	0.19	0.13
S11	6.43	46.1	0.05	0.12	6.6	1.42	0.2	0.16
S12	6.31	61.4	0.35	1.25	3.2	7.83	1.67	0.15
S13	6.18	32.9	0.06	0.24	2.1	1.31	0.23	0.13
S14	6.13	36.4	0.11	0.47	4.3	2.1	0.29	0.14
S15	6.86	44.6	0.08	0.28	15.6	1.9	0.32	0.18
S16	6.66	43.1	0.17	0.6	4.2	3.79	0.77	0.19
S17	6.50	44	0.11	0.36	5.9	2.45	0.43	0.18
S18	6.47	35.3	0.06	0.21	6.1	1.25	0.2	0.11
S19	6.28	43.6	0.07	0.26	16.3	1.42	0.26	0.16
S20	6.38	36.4	0.09	0.35	12.4	1.93	0.39	0.18
S21	6.72	55.2	0.18	0.58	16.1	4.31	0.74	0.17
S22	6.41	31	0.04	0.15	13.4	0.85	0.12	0.3
S23	7.04	36.8	0.12	0.49	15.3	2.13	0.56	0.12
S24	7.18	67.1	0.44	1.75	12	7.79	2.03	0.09
S25	7.21	36.6	0.11	0.52	14.2	2.02	0.58	0.11
S26	7.30	29	0.14	0.61	13.6	2.29	0.66	0.19
S27	7.35	25.8	0.02	0.08	15.1	0.52	0.13	0.17
S28	6.54	30.8	0.02	0.05	11.6	0.5	0.05	0.16
S29	6.87	39	0.09	0.35	9.8	1.82	0.49	0.14
S30	6.86	44.8	0.33	1.31	12.1	5.96	1.5	0.13
S31	6.88	29.3	0.02	0.07	10.6	0.5	0.11	0.11
S32	6.90	27.8	0.02	0.05	12.8	0.28	0.06	0.12
S33	6.71	39.3	0.02	0.05	11.8	0.5	0.03	0.09
S34	6.36	32.4	0.02	0.05	4.1	0.48	0.1	1.81
S35	6.27	32.1	0.03	0.08	8.2	0.58	0.13	1.89
S36	6.17	73.6	0.03	0.09	3.8	0.78	0.16	1.49
S37	6.40	46.6	0.03	0.08	15	0.68	0.14	7.8
S38	6.68	28	0.03	0.15	12.6	0.81	0.18	3.3
S39	6.57	34.4	0.26	0.84	17	5.3	1.23	3.43
S40	6.97	39.2	0.02	0.05	14.62	0.34	0.07	2.98
S41	6.70	63	0.11	0.33	35.7	2.51	0.56	4.56
S42	6.65	28	0.04	0.15	7.9	0.96	0.24	3.21
S43	7.36	24.3	0.07	0.24	14.6	1.51	0.38	1.28
S44	6.63	32.4	0.19	0.62	14.48	3.51	0.94	1.79
S45	6.53	32.1	0.02	0.05	13.98	0.35	0.05	1.8
S46	6.85	21.6	0.23	0.71	14.66	4.49	1.23	1.34
S47	6.42	30.4	0.16	0.52	13.6	3.29	0.88	2.11
S48	6.31	59.4	0.01	0.07	14.8	0.43	0.1	2.98
S49	6.58	74.5	0.27	0.77	13.94	5.78	1.44	1.01
S50	6.73	21.5	0.02	0.04	13	0.39	0.06	3.11

*(Contd.)*

Table 2 — Chemical characteristics of agricultural soil in the study area (*Contd.*).

Sampling Station	pH	EC ( $\mu\text{S/cm}$ )	N (%)	P (%)	K (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)
S51	7.12	35.2	0.20	0.65	14.12	4.44	1.16	2.9
S52	7.32	23.8	0.04	0.14	13	0.92	0.23	2.5
S53	7.36	26	0.15	0.48	13.62	2.81	0.72	0.18
S54	6.00	87	0.07	0.16	14.65	0.95	0.22	0.22
S55	6.51	28	0.04	0.05	12.6	0.43	0.1	0.19
S56	6.33	41.2	0.20	0.61	32.9	3.74	0.88	0.15
S57	6.85	73.5	0.25	0.72	14.6	4.97	1.14	0.39
S58	6.41	61.9	0.02	0.07	13.7	0.64	0.12	0.44
S59	6.67	43.9	0.07	0.23	14.2	1.46	0.34	0.12
S60	6.73	51.3	0.03	0.07	12.8	0.53	0.12	0.29
S61	7.00	95.3	0.22	0.65	14.6	4.68	1.14	0.31
S62	6.80	72.5	0.13	0.47	14.3	2.75	0.69	0.41

biological parameters. Its chemistry is so complex as its parameters are interrelated to each other. It is quite difficult to assess the suitability for agricultural purpose. For certain parameter in the soil may be favorable the quality for the intended purpose whereas others may not be favorable while its value increases or decreases. Therefore, an attempt has been made to develop a mathematical approach for assessing the soil quality.

A research article<sup>33</sup> presents the definition of quality interval for each environmental parameter as every parameter has its own desirable or recommended value ( $r$ ) or recommended range ( $r_1 \leq x \leq r_2$ ) and also minimum ( $l$ ) and maximum ( $u$ ) permissible limits (in mathematical language these limits are called lower and upper limits respectively) from the quality point of view for a definite use. The closed interval  $[l, u]$  in which the recommended value or recommended range falls is said to be the Quality Interval of the parameter. The semi-closed -sub-interval  $[l, r_1]$  is called as Increasing Quality Region (IQR) whereas the semi-closed-sub-interval ( $r_2, u$ ) as Decreasing Quality Region (DQR). The closed-sub-interval  $[r_1, r_2]$  is called Excellent Quality Region (EQR) or Excellent Quality Point (EQP) in case of singleton set. The set of ordered 4-tuple  $\{l_i, r_1, r_2, u_i\}$  may be known as standard set of parameter  $P_i$ .

#### 2.4.2 Rank and weightage

Suppose  $n$  parameters of a system are considered for assessing its suitability or quality for the intended purpose, they can be ranked assigning the natural numbers starting from 1 to  $n$  or less than  $n$  on the basis of its significance in comparison with others. One or more parameters may be assigned with same rank if their significance soil quality for the intended use is as same as others. Further weightage has to be assigned to each parameter based on its priority rank.

The total of the weightages assigned to all the parameter must be equal to 100 and the weightage of a parameter is directly proportional to its rank. The following method may be adopted to assign weightage for each parameter.

Let  $r_i$  be the rank of the parameter  $p_i$ . According to the definition of weightage, the weightage  $w_i$  of the parameter  $p_i$  can be assumed to be  $r_i \mu$  where  $\mu$  is proportional factor and further it can be written as

$$\sum_{i=1}^n (r_i \mu) = \mu \sum r_i = 100 \Rightarrow \mu = \frac{100}{\sum r_i} \quad \dots (1)$$

Thus, the weightage  $w_i$  for the parameter  $p_i$  can be estimated as  $r_i \mu$ .

#### 2.4.3 Soil quality score or index

Let  $p_i$  be parameters of the soil considered for assessing the quality of soil for agricultural purpose and  $x_i$  be analyzed values of  $p_i$ . If  $w_i$  be the estimated weightage of the parameter  $p_i$ , then the soil quality score  $S$  of the sample can be obtained as follows:

$$S = \frac{\sum_{i=1}^n x_i w_i}{\sum_{i=1}^n w_i} = \frac{\sum_{i=1}^n x_i w_i}{100} \quad \dots (2)$$

#### 2.4.4 Standards for soil quality score

Let  $\{l_i, r_1, r_2, u_i\}$  be the standard set of the parameter  $p_i$ . In the above equation, the lower limit of standard of soil quality score  $S_l$  can be obtained by replacing  $x_i$  by  $l_i$  as follows:

$$S_l = \frac{\sum_{i=1}^n l_i w_i}{100} \quad \dots (3)$$

Similarly, by replacing  $x_i$  by  $r_1$ ,  $r_2$  and  $u_i$ , the minimum and maximum limits of recommended or

desired range ( $S_{r_1}, S_{r_2}$ ) and upper permissible limit of soil quality score ( $S_u$ ) of the soil quality score as follows:

$$S_{r_1} = \frac{\sum_{i=1}^n r_{1i} w_i}{100} \quad \dots (4)$$

$$S_{r_2} = \frac{\sum_{i=1}^n r_{2i} w_i}{100} \quad \dots (5)$$

And  $S_u = \frac{\sum_{i=1}^n u_i w_i}{100} \quad \dots (6)$

**2.4.5 Classification of soil**

The minimum SQS is obviously the lowest value 0 whereas the maximum SQS ( $S_{max}$ ) can be relatively assumed to be beyond  $S_u$  when the parameter values are the maximum permissible limits of the respective parameters. Therefore, assume that

$$S_{max} = S_u + \frac{\lambda}{100} X S_u; \lambda > 0 \quad \dots (7)$$

The value of  $\lambda$  can be relatively assumed to be the percentage of the difference between  $S_{r_1}$  and  $S_{r_2}$  to the difference between  $S_l$  and  $S_u$ . Since the set of lower and upper limits of recommended ranges for all parameters is not a singleton,  $S_{r_1}$  and  $S_{r_2}$  are always different. Similarly,  $S_l$  and  $S_u$  are also different. Thus,  $S_{r_1} - S_{r_2} \neq 0$  and  $S_u - S_l \neq 0$ . Therefore,  $\lambda$  is estimated as

$$\lambda = \frac{S_{r_2} - S_{r_1}}{S_u - S_l} X 100 \quad \dots (8)$$

Thus, the maximum value of SQS is estimated as

$$S_{max} = S_u + \left( \frac{S_{r_2} - S_{r_1}}{S_u - S_l} \right) X S_u; \lambda > 0 \quad \dots (9)$$

The soil can be relatively classified into different classes based on its quality score. In the present approach, eleven classes have been defined as presented in Table 3.

**2.4.6 Soil quality and pH value**

Land classification has been done on the basis of soil quality score after referring with its soil pH.

Table 3 — Criteria for interpreting the soil quality scores.

S. No.	Criteria	Relative classification	Interpretation
1.	$0 \leq s < \frac{S_l}{2}$	Very poor	Some of the parameters far below the minimum permissible limit
2.	$\frac{S_l}{2} \leq s < S_l$	Poor	Some of the parameters just below the minimum permissible limit
3.	$S_l \leq s < \frac{2S_l + S_{r_1}}{3}$	Fair	Some of the parameters far below the recommended value
4.	$\frac{2S_l + S_{r_1}}{3} \leq s < \frac{S_l + 2S_{r_1}}{3}$	Good	Some of the parameters below the recommended value
5.	$\frac{S_l + 2S_{r_1}}{3} < s < S_{r_1}$	Very good	Some of the parameters just below the recommended value
6.	$S_{r_1} \leq s \leq S_{r_2}$	Excellent	All the parameters fall within recommended range
7.	$S_{r_2} < s \leq \frac{2S_{r_2} + S_u}{3}$	Very good	Some of the parameters have exceeded the recommended range but far below the maximum permissible limit
8.	$\frac{2S_{r_2} + S_u}{3} < s \leq \frac{S_{r_2} + 2S_u}{3}$	Good	Some of the parameters have exceeded the recommended range but below the maximum permissible limit
9.	$\frac{S_{r_2} + 2S_u}{3} < s \leq S_u$	Fair	Some of the parameters have exceeded the recommended range but just below the maximum permissible limit
10.	$S_u < s \leq \frac{S_{max} - S_u}{2}$	Poor	Some of the parameters have just exceeded the maximum permissible limit
11.	$\frac{S_{max} - S_u}{2} < s \leq S_{max}$	Very poor	Some of the parameters have far exceeded the maximum permissible limit

Because, the soil is suitable excellently while soil pH falls within the recommended range and further it can also be considered for cultivation of crops when soil pH is either less than or more than the recommended range but within the permissible limits as some crops prefer the slightly acidic soil whereas others slightly alkaline<sup>26</sup>. The soil may be defined to be highly acidic when  $pH < 5.5$ , acidic when  $5.5 \leq pH < 6.5$ , slightly acidic when  $6.5 \leq pH < 7$  or highly alkaline when  $pH > 8.5$ , alkaline when  $7.5 < pH \leq 8.5$ , slightly alkaline when  $7 < pH \leq 7.5$ .

#### 2.4.7 Soil texture

The percentages of sand, silt and clay in the soil determine soil texture index (STI), which is one of the important parameters of the agricultural soil quality to improve soil fertility. A web page unveils that the soil is considered as sandy type if a soil sample consists of 80 - 100% sand. Sandy soils are sieve-like. They dry out rapidly and so require more regular watering than do clayey soil types and water will infiltrate fast through the porous earth right past the root zone. Once water passes the root zone, it is ineffective. If a sample consists of more than 50% clay, then the soil is considered as clay type. The problem with a clayey type is just the opposite of the sandy soil. Water does not percolate quickly enough through it. Plants in clayey soil types should also be watered over several short periods but for a different reason. The water needs to be given time to soak into the earth. Too much of water has to be poured all at once; water just runs off and is wasted. Because clayey soil types retain water well and positively needs to be watered less frequently, lest the plants' roots drown. Silt is prone to compaction. Peat may be fine for plants that like wet soil, but its water content is too high for many plants. Its pH level is also an issue for many plants, being too low, which means it is too acidic. Loam soil is ideal and has less than 52% sand, 28-50 % silt and 7-27% clay.

A study reports that the mineral composition of the loam by its weight is about 40–40–20% concentration of sand-silt-clay, respectively<sup>34</sup>. These proportions can vary to a degree, which may result into different types of loam soils such as sandy loam, silty loam, clay loam, sandy clay loam, silty clay loam, and loam<sup>34</sup>. In the USDA textural classification triangle, the only soil that is not predominantly sand, silt, or clay is called "loam". Loam soils usually contain more nutrients, moisture, and humus than sandy soils,

possess the characteristics to drain and infiltrate water and air than silt and clay-rich soils, and are easy to till. The different types of loam soils each have slightly different characteristics, with some draining liquids more efficiently than others. The soil's texture, especially its ability to retain nutrients and water are crucial<sup>35</sup>. Loam soil is suitable for growing most plant varieties. Thus, the soil that contains 40% sand, 40% silt and 20% clay has the potential for growth and optimum yields for the crops. Hence, the soil texture indices also can be computed using the following formula:

$$STI = \frac{(40 * SAND \% + 40 * SILT \% + 20 * CLAY \%)}{100} \dots (10)$$

The soil quality assessment for any area may have all the eleven classifications or only a few of them according to its physical, chemical and biological characteristics. After the categorization of the soil as discussed above, the soil expert has to refer the pH values of the soil samples as some soil grow in acidic soil whereas some prefer and grow well in alkaline soil. Therefore, it is essential to refer soil pH in addition to the soil quality score. Further, selection of suitable crops for cultivation in a certain land with known soil quality score must also refer relative yields with respect to the soil pH for the optimized production of the yields<sup>36</sup>.

#### 2.4.8 Geographical information system (GIS)

The spatial modeling for delineating a landscape was carried out using ArcGIS Ver.10.6. The data were entered in Excel spreadsheet in the required format and all kind of analysis such as creating contour maps representing slopes or soil characteristics and spatial modeling importing the data file to ArcGIS.

### 3 Results and Discussion

The required input parameters for the application of the present modeling approach such as priority rank of each parameter and its corresponding quality standards for agricultural soil along with the weightages computed for the respective parameters using the equation (1) has been presented in Table 4.

Although all the above parameters of the soil possess the significant role for improving soil fertility, yet the prioritization of soil quality parameters are essential for applying the present approach. The following steps may be followed for exercising the assignment of tasks to the soil quality parameters

Table 4 — Prioritization ranks, weightages and soil quality standards.

S. No.	Parameters	Priority Rank (r)	Standards for agricultural soil				Weightage (w)
			<i>l</i>	<i>r<sub>1</sub></i>	<i>r<sub>2</sub></i>	<i>u</i>	
1.	pH	1	2	5.5	7.5	10	7.5
2.	EC ( $\mu\text{S}/\text{cm}$ )	2	0	2	8	15	7
3.	N (%)	3	11.33	25.57	50.1	63.1	6.5
4.	P (%)	3	20.01	25	40	42.33	6.5
5.	K (%)	3	35.43	35	50	56.42	6.5
6.	Mn (ppm)	4	20	80	500	10000	6
7.	Fe (ppm)	5	2	10	22	200	5.5
8.	Zn (ppm)	6	1	1.1	2.2	3	5
9.	Moisture (%)	2	17	20	34	45	7
10.	Water Holding Capacity (WHC) (in %)	4	5	20	35	85	6
11.	Bulk Density (BD) (in g/cc)	3	1	1.3	1.5	1.8	6.5
12.	Gravel (%)	1	0	0	0	25	7.5
13.	Sand (%)	1	30	40	40	40	7.5
14.	Clay (%)	1	30	40	40	40	7.5
15.	Silt (%)	1	15	20	20	40	7.5
TOTAL							100

– (i) assign rank to the parameters keeping in mind the importance of the parameter in soil fertility and (ii) two or more parameters may have the same rank if they play equal importance towards soil fertility. It is purely based on the soil chemistry and its influence on plant growth and productivity. Further, the soil quality standards in the format of {minimum permissible limit (*l*), lower limit of recommended range (*r<sub>1</sub>*), upper limit of recommended range (*r<sub>2</sub>*), maximum permissible limit (*u*)} may not be available. Therefore, an agricultural soil expert has to determine the minimum and maximum permissible limits of quality interval and the lower and upper limits of recommended or desirable range within the quality interval on the basis of some practical experience or the values evidently established through scientific studies. The values of quality standards adopted for the present study are instinctive just to demonstrate the present method as a prototype, which requires more experimental studies to establish the standards scientifically. The soil quality of the entire study area relatively falls only under three classifications namely, good, fair and poor as presented in Table 5.

It is clear from the Table 2 that the soil pH of the entire study area varies from 6.0 to 7.36 and hence the landscape falls only under four types of soil such as acidic, slightly acidic, neutral and slightly alkaline. The spatial modeling of distribution of 8 physical characteristics such as moisture, WHC, BD, gravel, sand, silt and clay have been carried out using GIS and respectively presented in Figs. 5 to 11. Different classes of soil textures of the landscape have been delineated with respect to soil texture indices using the equation (10) and presented in Fig. 12.

Table 5 — Classification of the study area on the basis of soil quality scores.

S. No.	Ranges of SQS	No. of samples	Category
1.	$0 \leq s < 6.5125$	0	Very Poor
2.	$6.5125 \leq s < 13.0251$	8	Poor
3.	$13.0251 \leq s < 15.9032$	43	Fair
4.	$15.9032 \leq s < 18.7814$	11	Good

The spatial modeling of distribution of 7 chemical parameters, namely moisture, EC, N, P, K, Mn, Fe and Zn have been carried out using GIS and the spatial distribution of each parameter has been presented in Figs 13 to 20.

The SQS have been computed and those SQS that falls under one of four classifications have been further statistically analyzed to find the minimum, average and maximum, which have been presented in Table 6 along with range of the soil pH, number of samples, percentages. The statistics of soil types categorized on the basis of SQS and soil pH have been presented in Table 7.

The minimum and maximum SQS of the 62 samples have been computed to be 11.10 and 18.69 respectively. There are 16 samples that falls under acidic soil; 37 under slightly acidic, 8 under slightly alkaline and only one samples under neutral. It is very clear that the maximum area of about 60% of the samples falls dominantly under the slightly acidic category; secondly 16% of the land under acidic category; and the samples of slightly alkaline and neutral category are 8 and 1 respectively. The SQSs were interpolated using GIS and the three classifications of the landscape such as good, fair and poor were delineated as presented in Fig. 21. The statistics of the relatively classified samples and

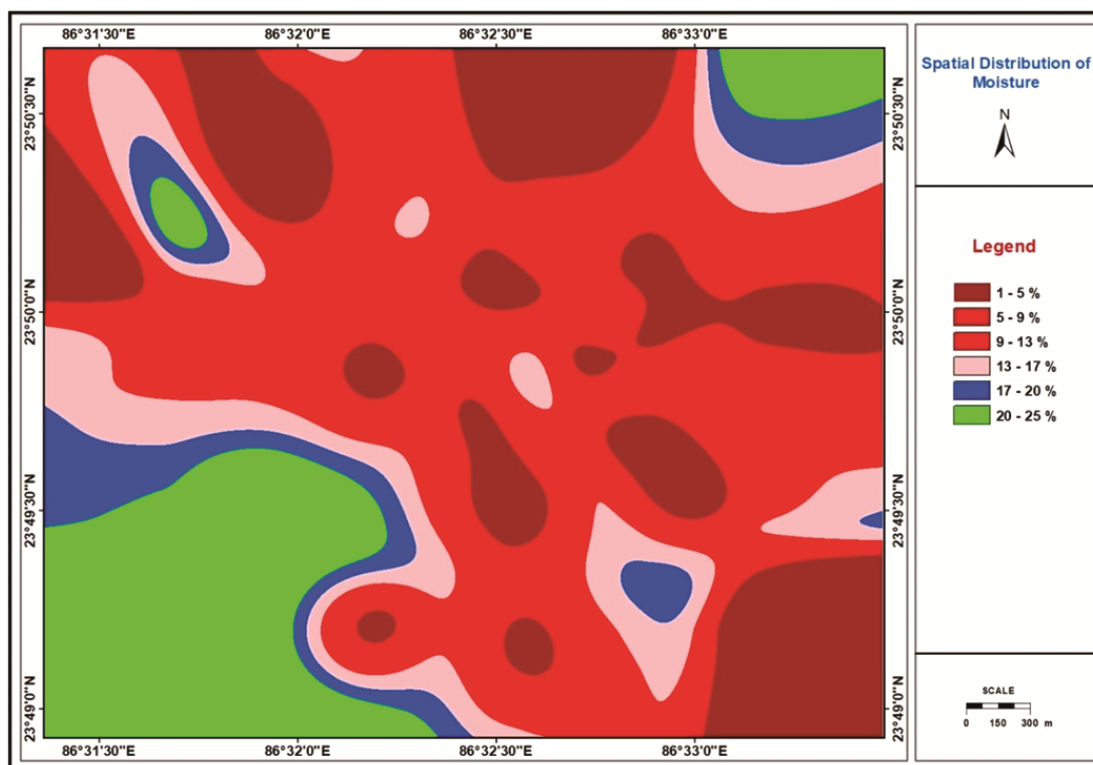


Fig. 5 — Spatial distribution of moisture.

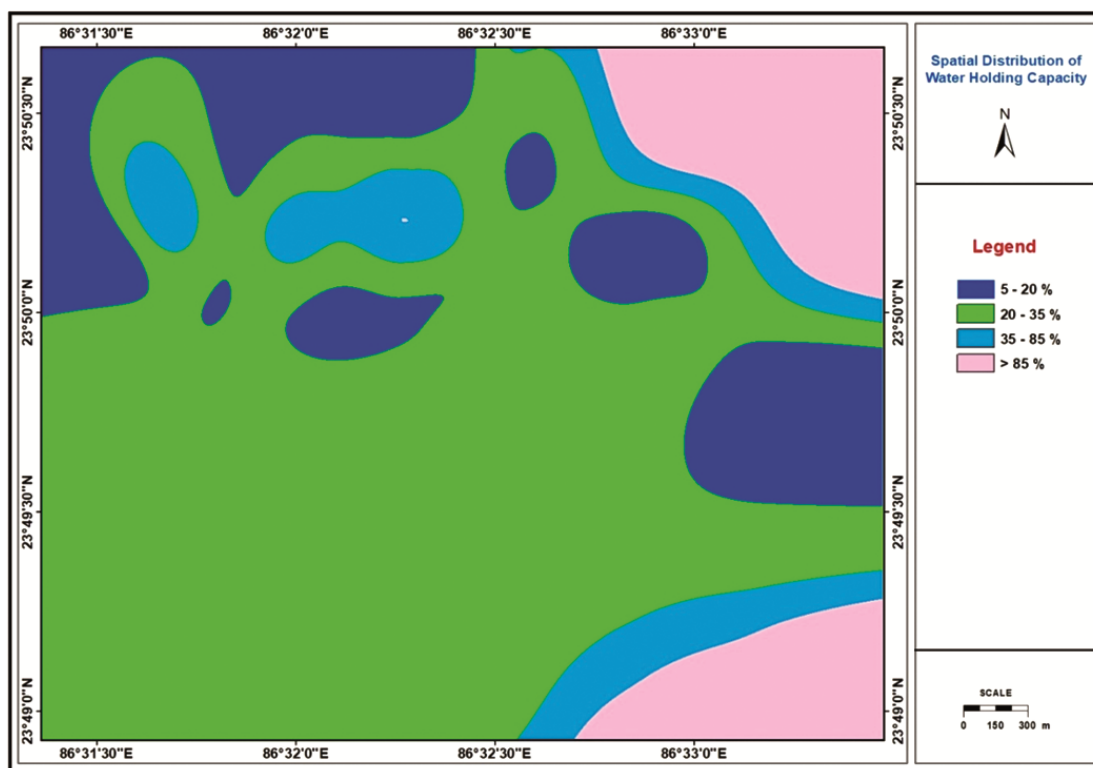


Fig. 6 — Spatial distribution of water holding capacity.

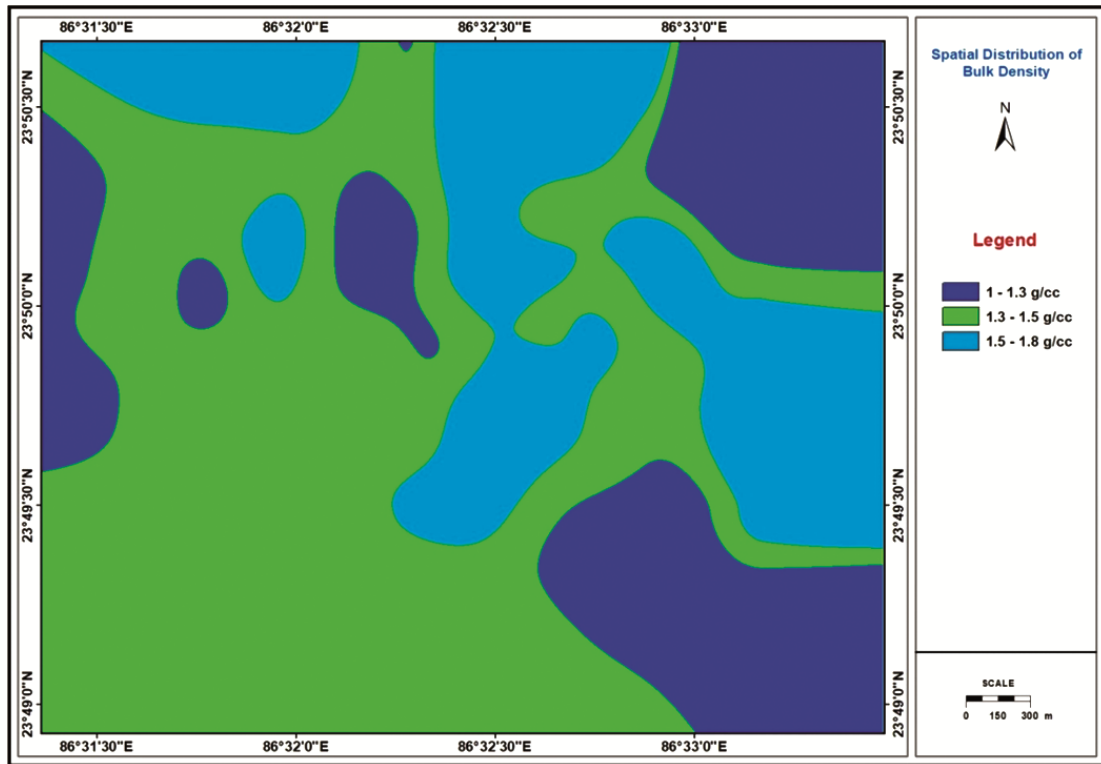


Fig. 7 — Spatial distribution of bulk density.

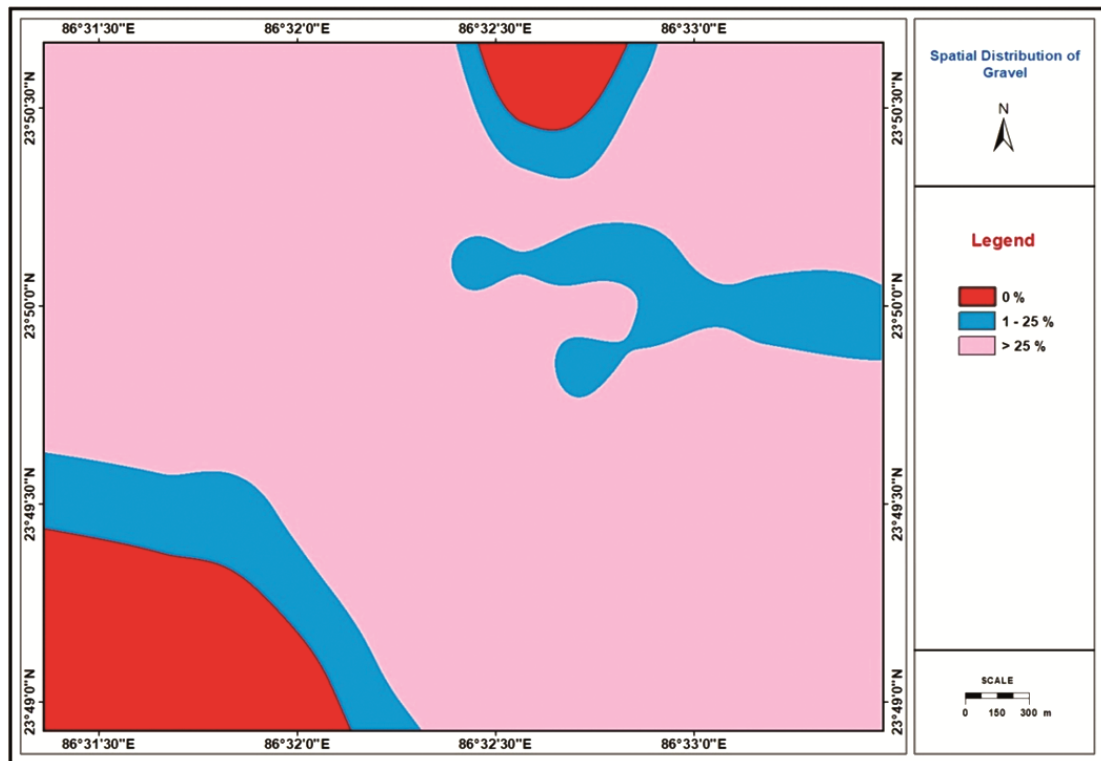


Fig. 8 — Spatial distribution of gravel.

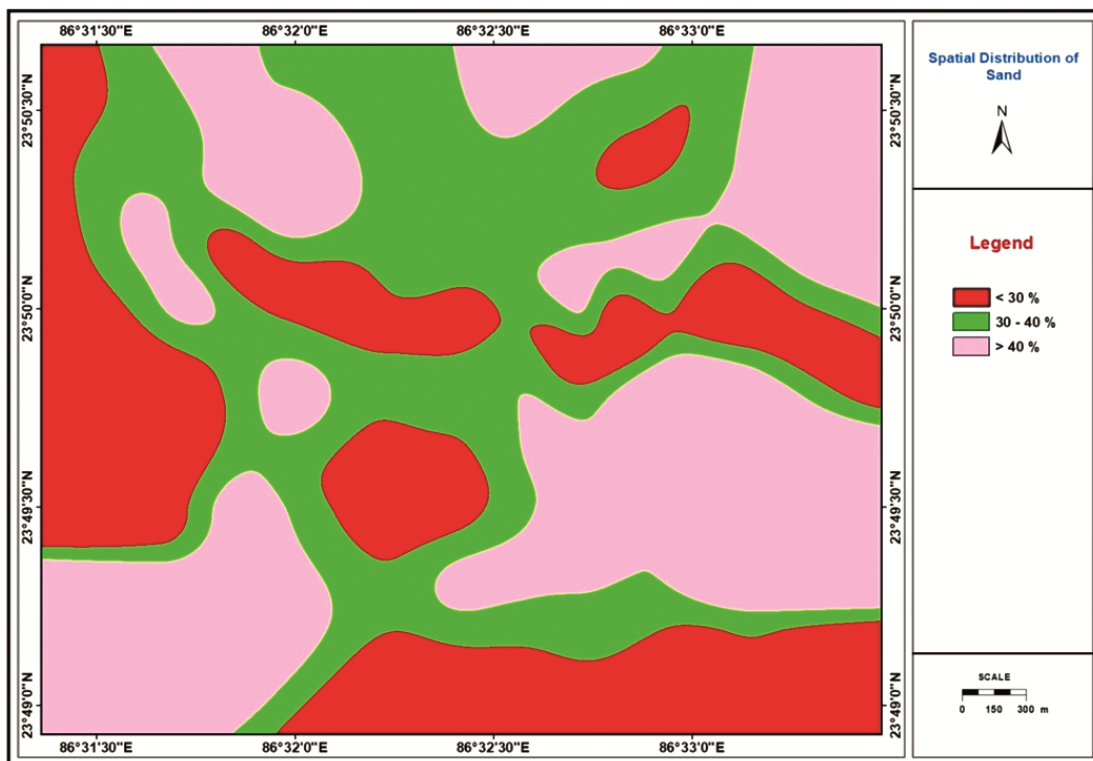


Fig. 9 — Spatial distribution of sand.

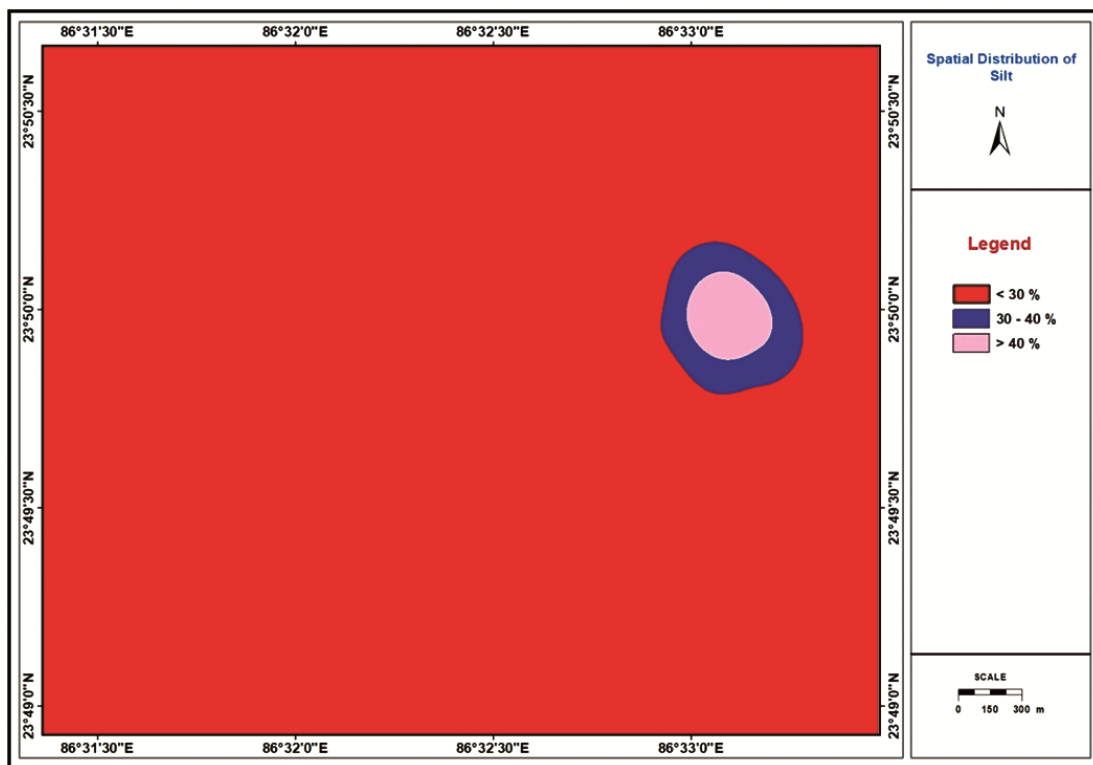


Fig. 10 — Spatial distribution of silt.

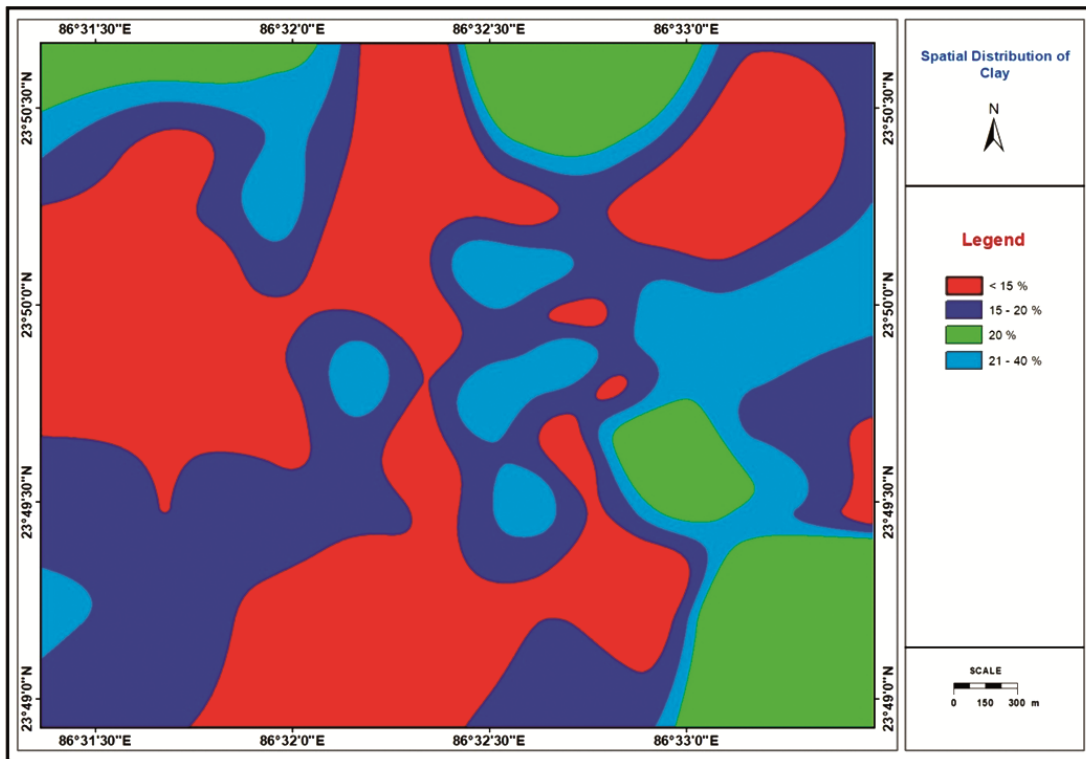


Fig. 11 — Spatial distribution of clay.

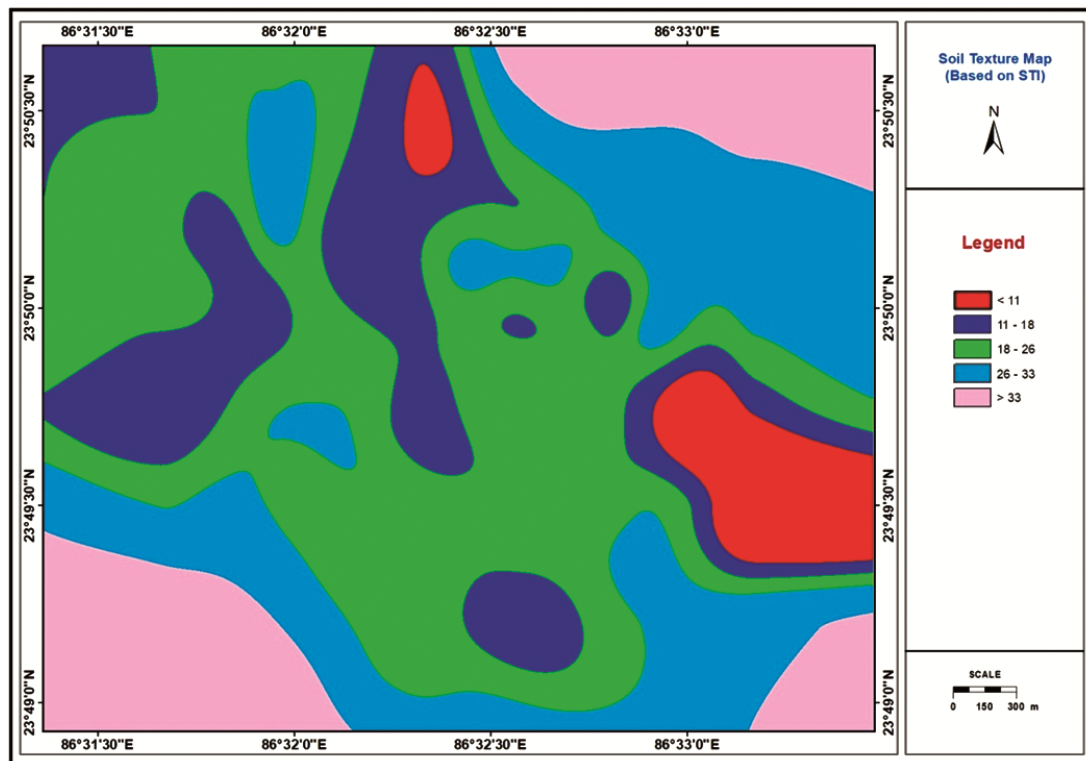


Fig. 12 — Classification of landscape based on soil texture indices.

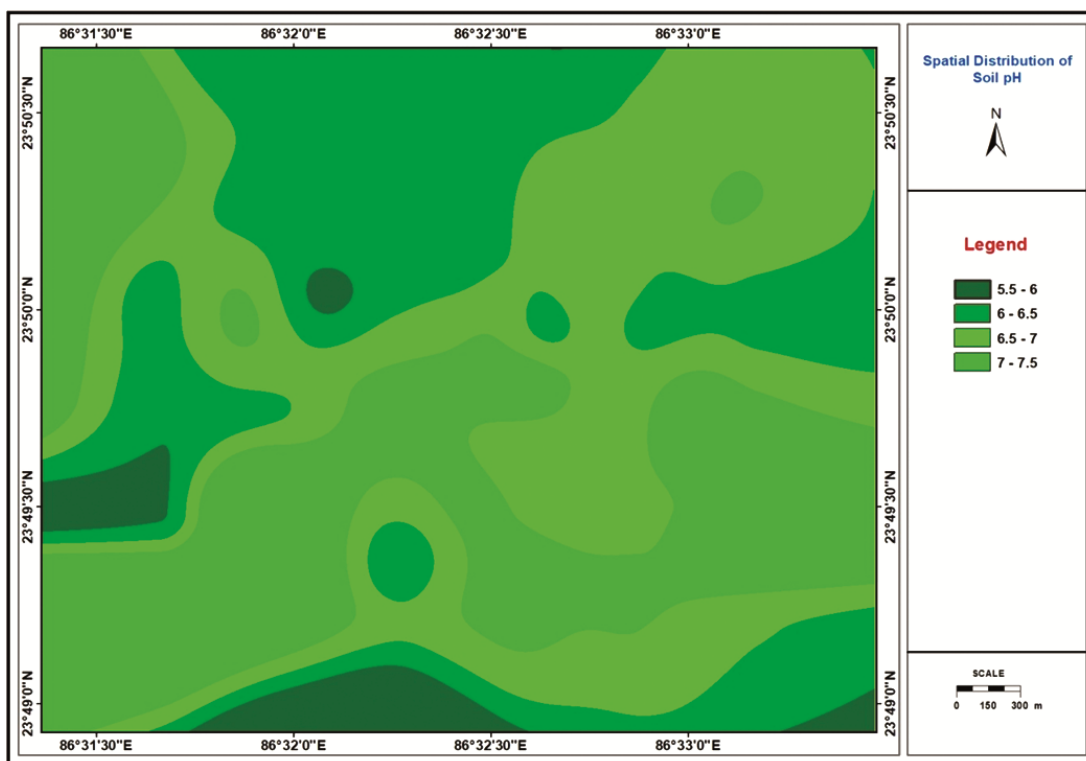


Fig. 13 — Spatial distribution of soil pH.

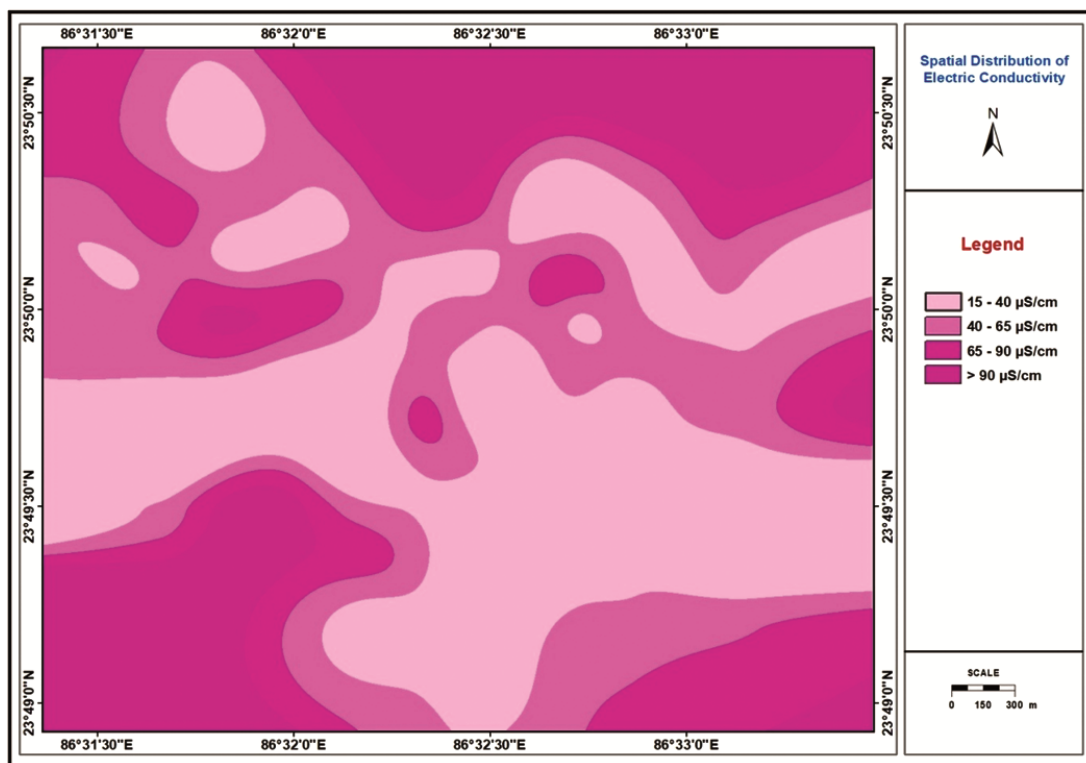


Fig. 14 — Spatial distribution of electric conductivity in soil.

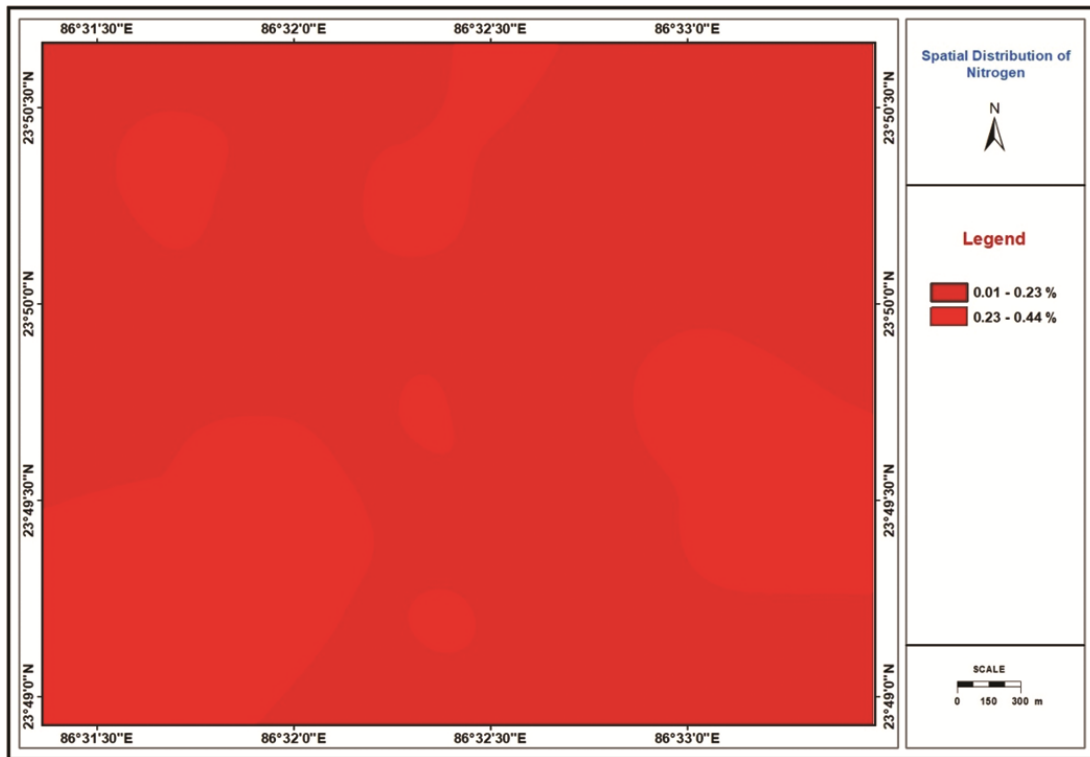


Fig. 15 — Spatial distribution of nitrogen.

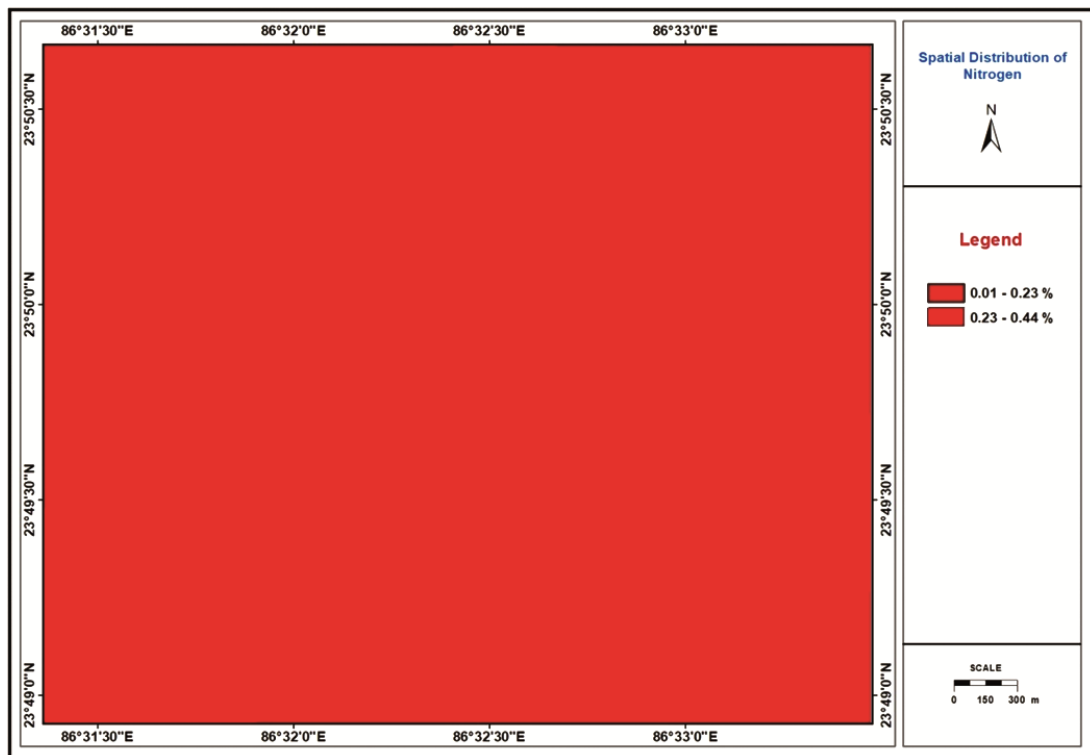


Fig. 16 — Spatial distribution of phosphorus.

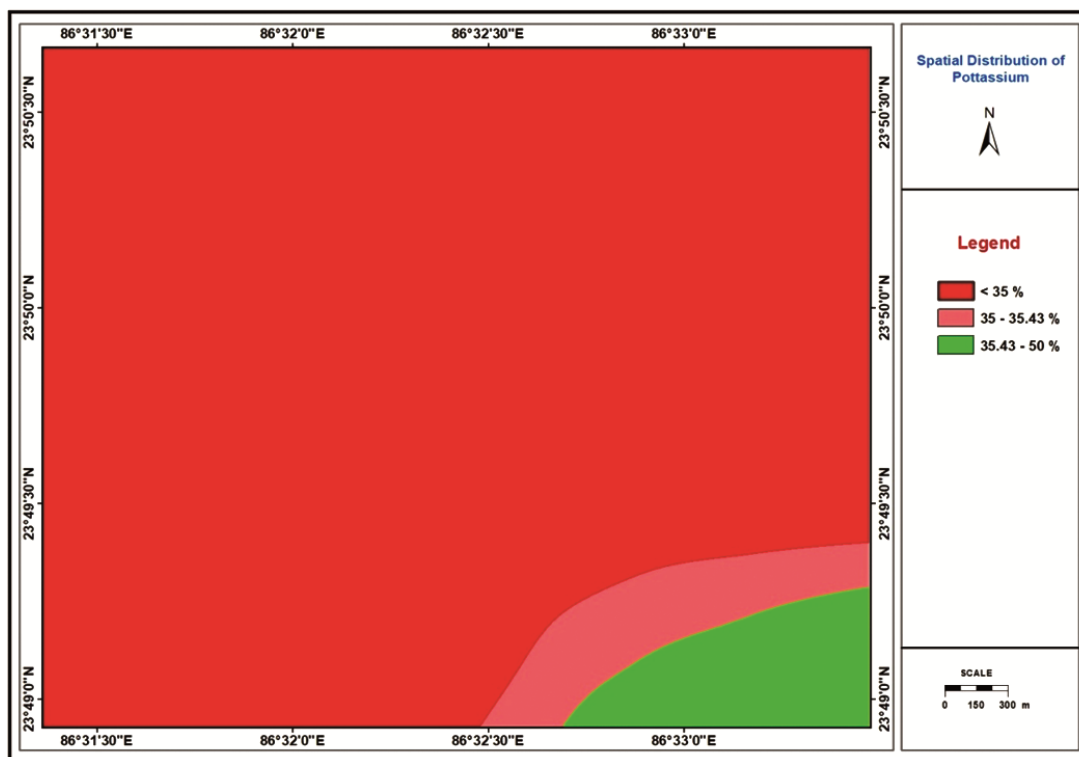


Fig. 17 — Spatial distribution of potassium.

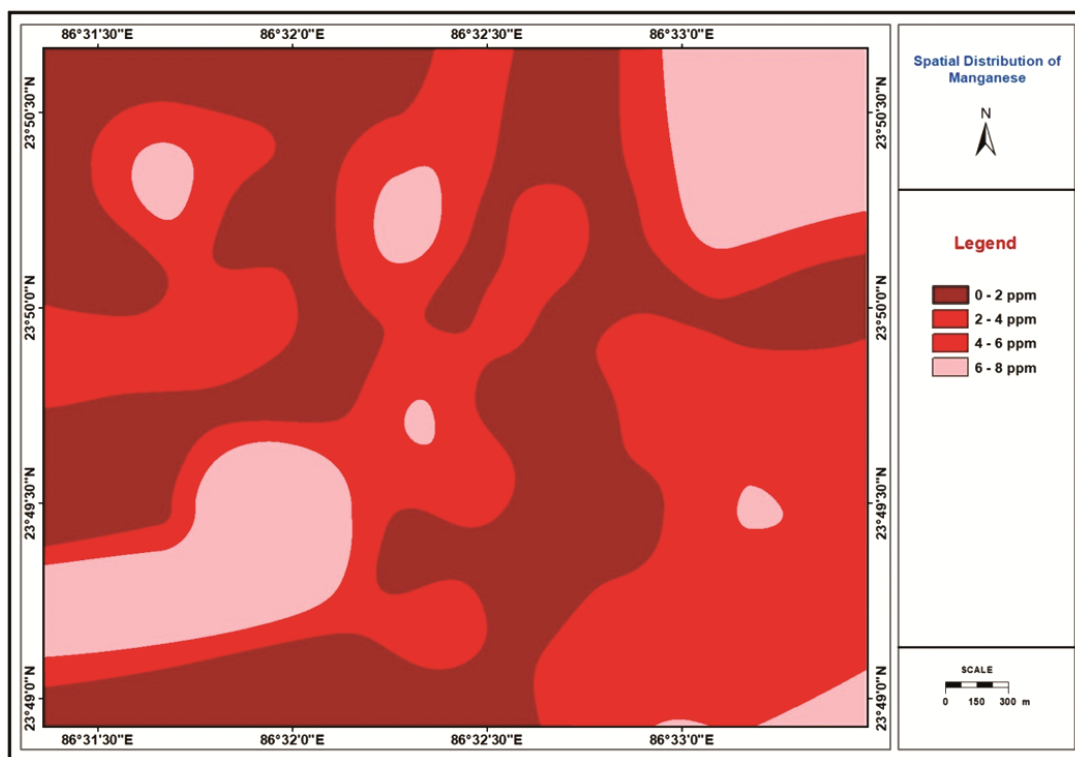


Fig. 18 — Spatial distribution of manganese.

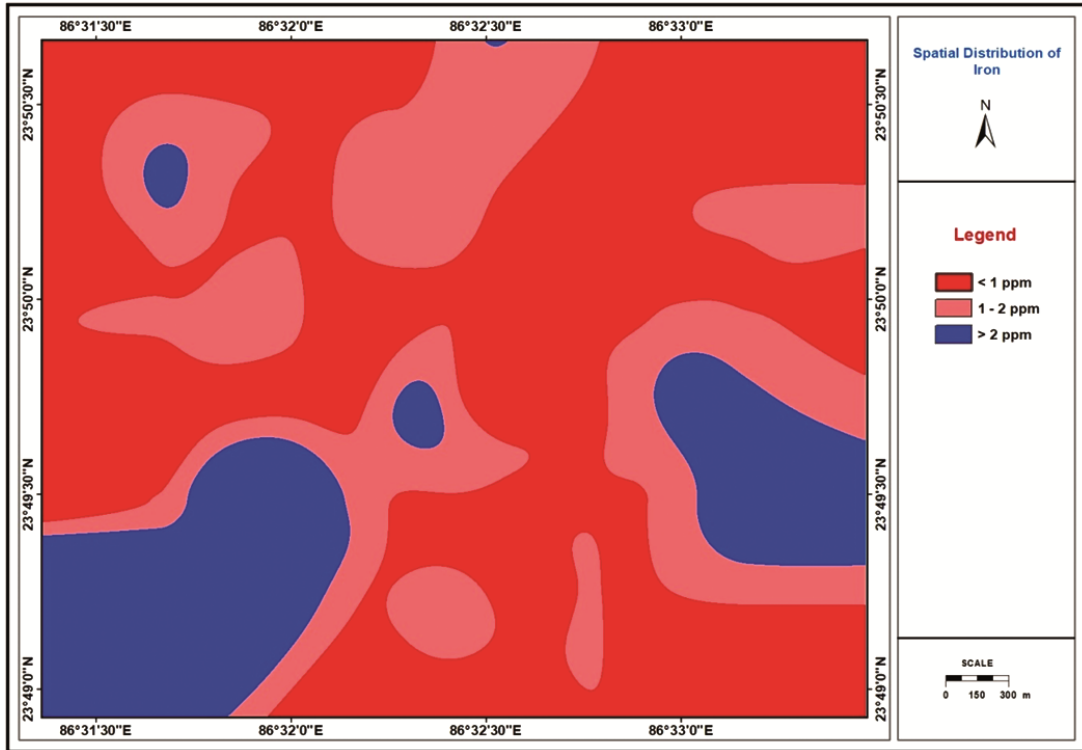


Fig. 19 — Spatial distribution of iron.

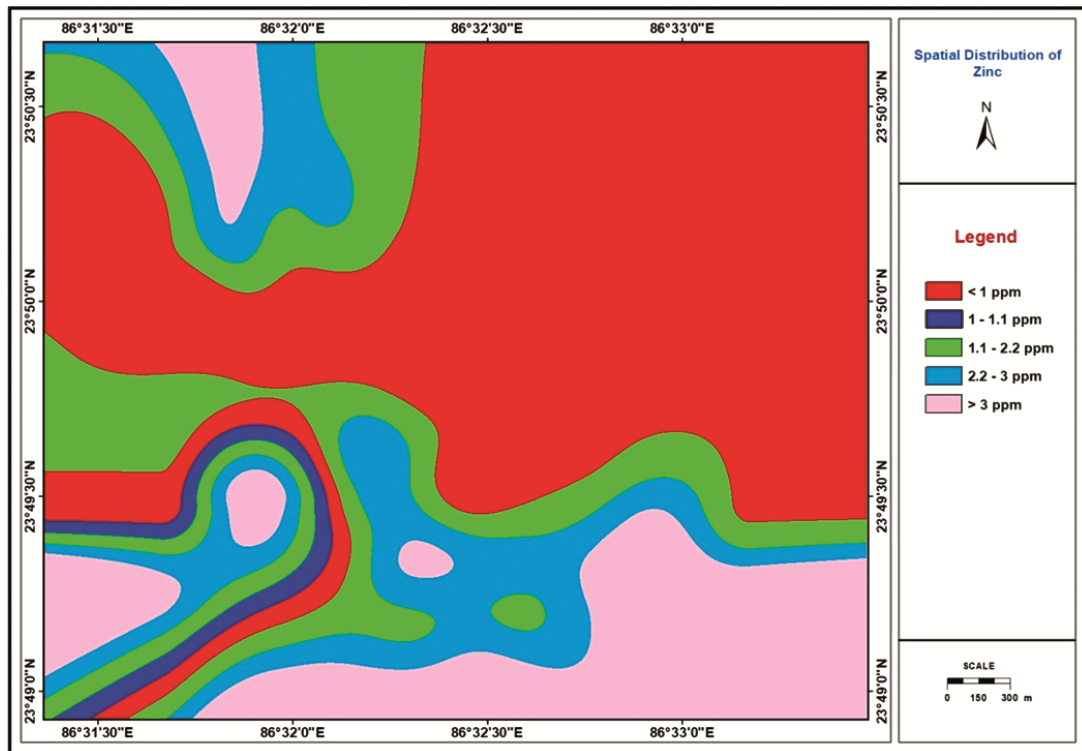


Fig. 20 — Spatial distribution of zinc.

Soil Type	Soil pH	Relative Classification	Location Codes	No. of Samples	%	Soil Quality Score		
						Min.	Mean	Max.
Acidic	<6.5	Poor	S13	1	1.61	12.60	12.60	12.60
		Fair	S3, S14, S19, S20, S22, S34, S35, S37, S47, S58	10	16.13	13.05	14.17	15.53
		Good	S12, S36, S48, S54, S56	5	8.06	16.03	16.47	17.81
Slightly Acidic	6.5-7.0	Poor	S1, S4-S6, S18, S32, S42	7	11.29	11.10	12.40	13.02
		Fair	S2, S7-S11, S15-S17, S21, S33, S38-S40, S44-S46, S50, S55, S59, S60	25	40.32	13.03	14.07	15.65
		Good	S41, S49, S57, S62	4	6.45	16.83	17.69	18.19
Neutral	7.0	Poor	Nil	0	0.00	-	-	-
		Fair	Nil	0	0.00	-	-	-
		Good	S61	1	1.61	18.69	18.69	18.69
Slightly Alkaline	7.0-7.5	Poor	Nil	0	0.00	-	-	-
		Fair	S23, S25 – S27, S43, S51-S53	8	12.90	13.07	13.68	15.06
		Good	S24	1	1.61	16.76	16.76	16.76

Table 7 — Statistics of soil types categorized on the basis of soil quality scores and soil pH.

S. No.	Soil type	No. of samples	%
1.	Acidic	16	25.81
2.	Slightly acidic	37	59.68
3.	Slightly alkaline	8	12.90
4.	Neutral	1	1.61
Total	62	100.00	

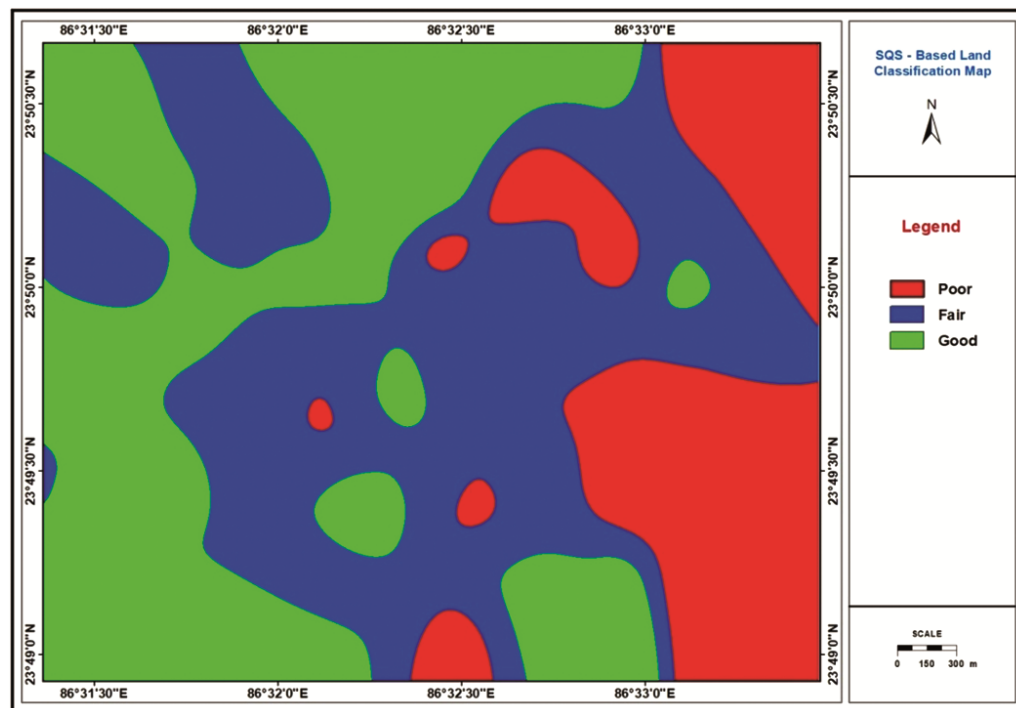


Fig. 21 — Classified landscape based on soil quality score.

estimated area of the landscape that falls under different classifications has been presented in Table 8.

The landscape falls only under three categories such as good, fair, and poor. The statistics of 62 samples pertaining to the classifications and soil types has been presented in Table 6 and 7 respectively. Out

of 62 samples, 11 samples fall under good, 43 under fair and 8 under poor classifications over the landscape of the study area, which comes about 17%, 69% and 13% respectively. Out of 321.048 ha, about 101.582 ha of the landscape falls under good class, about 154.604 ha under fair, and about

Table 8 — Statistics of classified samples and estimated area under different classification.

S. No.	Relative Classification	No. of samples	% (Sample based)	Landscape under different classification	
				Area (ha)	Area (%)
1.	Good	11	17.74	101.582	31.64
2.	Fair	43	69.36	154.604	48.16
3.	Poor	8	12.90	64.862	20.20
	Total	62	100.00	321.048	100.00

64.862 ha under poor classes. Further, 16 samples fall under acidic, 37 under slightly acidic, 8 under slightly alkaline and 1 under neutral soil types, which comes about 26%, 59%, 13% and 2% respectively. The soil type of slightly acidic is dominating in this area under fair category. Although the soil pH falls in the neighborhood of 7 in 46 samples, which is about 74%, the landscape cannot yield much effectively as its soil quality score does not fall under excellent or very good classes only but the SQS varies from 11.10 to 18.69, which covers only good and fair category.

The landscape can be brought to yield effectively through appropriate nutrient amendments in the soil as there is a considerable deficiency of micro and macro nutrients with suitable environmental and sufficient productivity factors. Some of the crops for cultivation have been suggested with necessary treatment and amendments of nutrients along with relative yield percentage. The crops can manage to tolerate and grow in the land that falls under slightly acidic with soil pH varying from 6.5 to 7 and also in the land that falls under slightly alkaline with soil pH from 7 to 7.5. However, nutrient amendments with 10 tons wet manures per a hectare would be sufficient and beneficial for the crops for increasing its canopy level and yield effectively. In case of slightly alkaline soil, adding approximately 8.5 tons of granulated ground sulfur per a hectare in addition to the manures if soil pH is close to 7.5 will be useful whereas approximately 13 tons of ground limestone per a hectare in addition to the manures in case of slightly acidic soil if soil pH is close to 6.5 in order to increase the yields. The landscape that falls under acidic when  $6.0 \leq pH < 6.5$  can be treated through soil amendment with 18 tons of ground limestone per hectare along with 15 tons of wet dairy manures per a hectare prior to the successive cultivations. However, estimation of actual nutrient budget has to be exercised on the basis of crops chosen for cultivation and its nutrient uptake competency. There is no land that falls under alkaline category in the study area. The guidelines

presented elsewhere in the article should be followed to avoid nutrient loss from manures through adoption of appropriate method, right time, and handling technique.

#### 4 Conclusion

Evaluation of integrated soil quality with respect to 7 physical and 8 chemical parameters subject to the minimum and maximum permissible limits, and lower and upper values of desirable value or recommended range of each parameter has been attempted using an innovative mathematical approach. A method of assigning weightage for each parameter based on the ranks assigned to them keeping their significance in the intended purpose. A computational technique has been adopted for integrating the effect of each parameter together for determining the overall soil quality score or index. The maximum limit of the score has been defined mathematically and also the range of soil quality score for excellent category of soil has been computed. Further the soil quality has been classified into different categories such as very good, good, fair, poor and very poor for the both cases of the soil quality score when it is less than lower and greater than upper limits of the range of excellent category. Although a sustainable soil quality management starts from elementary tasks such as soil quality testing and land classification, only its successive tasks such as conservation, amendment and optimal health of soil have been focused and discussed as already the elementary tasks have worked out. The present modeling approach would be useful for optimizing the yielding potential of the crops through classification of landscape on the basis of soil quality indices if appropriate soil conservation measures, soil amendment, soil quality optimizing techs are devised. The present articles may assist the existing guidelines for the best sustainable soil quality management.

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