Developing a Soil Quality Index for Vrishabavathi Command Area

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Abstract

It has been known for years that the quality of irrigation water directly influences the quality of the soil and the crops grown on this soil. Protection of the soil quality under intense land use and fast economic development is a major challenge for sustainable resource use in the developing world. The assessment of soil quality is necessary to evaluate the degradation status and trends following different land use and management practices. Increase in human population has increased the stress on natural resources such as soil. The soil pollution is often due to the ingress of harmful chemicals carried by the water, excessive use of pesticides and fertilizers in agriculture. Soil quality index (SQI) describes the goodness of a soil to have higher crop production, better fertilizer response rate and maintenance of good soil environment. In the present study, an effort is made to develop the Soil Quality Index (SQI) of theVrishabavathi command area. The Vrishabavathi stream which used to carry fresh water from the Arkavathi basin on the northern side of Bangalore is now virtually a sewage stream. It is contaminated by an assortment of sewage of Bangalore city, industrial waste, solid waste dumps and other effluents. The farmers use this water for irrigation. The outcome of that study is that the soil quality index falls in the category of Medium to High suitability of soil for growing crops.

Keywords: Soil Quality Index,Chemical Indicators, Spatial Distribution, GIS Mapping.

1. Introduction

The quality of irrigation water directly influences the quality of the soil and the crops grown on this soil. In the last century, the demand for agricultural land and products has grown rapidly as a function of population growth. In addition, experts from all disciplines have agreed that factors such as urbanization, industrialization, poor land management and environmental pollution imposed additional stress on agricultural production. All of these factors have quickly become responsible for the decrease in the amount of land available for agriculture and for the reduction in the quantity and the quality of water to irrigate these lands. A dramatic example for this soil–water quality interaction phenomenon is the salinity problem that is widely experienced in many parts of the world where about 10 million hectares of agricultural land is lost annually. As a consequence, effective use of both the agricultural land and the irrigation water has become an indispensable component, if not the primary objective, of many agricultural development and management plans.

Based on this current situation, soil qualitymanagement has become an important tool to guarantee the required amount of agricultural production forcurrent needs and to maintain the sustainability of the land for future generations. Motivated by this necessity,decision makers have asked the experts to provide non-technical tools to help them come up with better decisions. The index techniques and soil quality mapping have been developed as a result of thisneed.

2. Soil Quality

Soil quality is defined as the continued capacity of soil to function as a vital living system, as it contains biological elements which is a key to ecosystem, within land-use boundaries. Healthy soils give us clean air, water, bountiful crops and forests, diverse wild life and beautiful landscapes. Soil does all this by performing five essential functions of regulation of water, sustenance of animal and plant life, filtering potential pollutants, cycling of nutrients and supporting of structures. The soil is a natural body containing minerals and organic matter of variable depth on the earth’s crust that is capable of supporting plant growth. The soil degradation has an adverse impact on agricultural production and other natural resources. The soils to certain extent can absorb and neutralize many pollutants to harmless components through its various chemical and biochemical process. The pollution of soils beyond certain limits renders the soil unfit for cultivation.

The functions of soil are biomass production, storing, filtering and transforming nutrients, substances and water, bio diversity pool, physical & cultural environment for humans, as a source of raw material, acting as carbon pool and archive of geological and archeological heritage. The four major components of soil are mineral matter, organic matter (OM), soil air and soil water.

The soil quality as per the plant requirements can be assessed based on: soil fertility (mainly N, P, K), soil texture, soil structure, soil water regime and soil temperature.

Soil fertility refers to the inherent capacity of a soil to supply essential nutrient elements to the plants in adequate amount and in right proportion for their optimum growth. The chemical compounds required by the plant are termed as nutrients and their supply and absorption for growth is defined as nutrition. The plant nutrients are further divided depending on their relative absorption and their concentration in the plant tissues as macronutrients and micronutrients.

Macronutrients are those nutrients that are required in large or macro-amounts by the plants such as Carbon (C), Hydrogen(H), Oxygen(O), Nitrogen(N), Phosphorus(P), Potassium(K), Calcium(Ca), Magnesium(Mg) and Sulfur(S). Plants take up C, H and O (60,000 to 450,000 ppm) mainly from air and water which are in abundance. The N, P and K (10,000 to 15,000 ppm) are termed as primary nutrients and Ca, Mg and S (1,000 to 5,000 ppm) are called thesecondary nutrients.

Nitrogen is a primary building block for all organisms. It is essential for plants in making proteins and it helps to keep plants green. Phosphorus is a component of DNA and it plays a vital role in capturing light during photosynthesis and helps in seed germination. It also helps plants to use water efficiently. Plants also use phosphorus to withstand external stress and prevention of disease. Potassium plays an important role in plant's water utilization and also helps to regulate the rate of photosynthesis. It helps in the growth of strong stalks, protection from extreme temperatures, ability to fight stress and pests.

Micronutrients are those nutrients that are required in small or micro-amounts by the plants such as Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl) and Nickel (Ni). The micronutrients are further subdivided as micronutrient cations: Fe, Mn, Zn, Cu, Ni (0.1 to 500 ppm) and micronutrient anions: B, Mo and Cl (0.1 to 500 ppm).

Soil texture is the relative proportions of sand, silt and clay particles in a mass of soil. The clay soils are less porous, stickier, have higher water retention capacity, absorb more nutrients, possess cohesive and adhesive property. In clay soils, the tillage is difficult. The soil containing almost equal proportion of sand, silt and clay are grouped as loams. These soils have good physical character. The pore space, leaching and water holding capacity of loams lies in between sand and clay soils.

The soil structure influences many properties of soil such as rate of infiltration, leaching, water retention, swelling, shrinkage, drainage etc. The granular structured soils have high infiltration than the clustered soil.

Soils with low bulk density exhibit favorable conditions for plant growth. The soils with high bulk density exhibit poor physical conditions for plant growth. The soils having bulk density between 1.4 to 1.6 g/cc is considered to be good for plant growth.

The ease with which the water flows in the soil is represented by permeability of soil. The sandy soils have large and continuous pores having higher porosity, exhibit greater permeability and transmit water quickly. The clay has very small pores with low porosity and less permeability which transmit water very slowly. The fine pores of soil also results in water logging and poor aeration. For the growth of plants, the pore sizes are more important than the total pore space.

The maximum influence on the growth and yield of a crop depends on the availability of soil water which is an essential part of plant food constituting more than 90% plant tissue and is also a solvent as well as carrier of plant nutrients. The soil water also helps in maintaining cell turgidity and regulation of soil temperature.

The plant growth, chemical and biological activities in the soil is greatly influenced by the soil temperature. The microbial fixation of nitrogen is maximum between 27 to 33°C. Soil temperature provides suitable medium for optimum growth of plant, greater activity of microorganisms, nutrient movement, water absorption by plants etc.

2.1 Soil Quality Index (SQI)

Soil quality Index in the agricultural and environmental context describes the goodness of a soil to have higher crop productivity, better fertilizer response rate, stabilized crop production and maintenance of good soil environment. The Soil Quality Index (SQI) integrates the measured physical and chemical properties of soil into a single parameter that could be used as an indicator of overall soil quality for agriculture. Soil quality cannot be measured directly, but soil properties that are sensitive to changes in management can be used as indicators. The soil quality is dynamic in nature and can affect the sustainability and productivity of land use. The soil quality is the end product of soil degradation or conserving processes and is controlled by chemical, physical and biological components of soil and their interactions. It is not possible to develop a single list of quality indicators which is suitable for all purposes. It is emphasized to use a range of likely indicators of soil quality rather than the use of a single indicator.

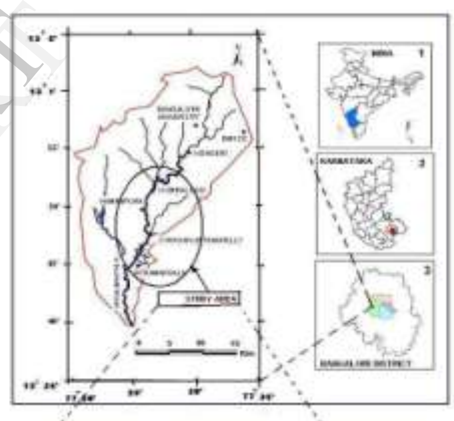
2.2 Soil Quality Indicators

The indicators of soil quality can be grouped as physical, chemical and biological. The physical properties of soil are estimated from soil texture, bulk density (a measure of compaction), porosity and water holding capacity. The physical properties of soil such as porosity, water holding capacity, structure and tilth are improved through addition of organic matter to soil. The physical indicators of soil include soil aggregate stability, infiltration and bulk density. In order to achieve high crop yields, small land farmers have to provide soil nutrients in large quantities.The available soil nutrients can be improved by adding inorganic fertilizers, manures and composts. The capacity of soil to supply mineral nutrients depends on soil pH. The pH is an estimate of the activity of hydrogen ions in the soil solution. This is also an indicator of plant available nutrients. In the soil, biological and chemical activity thresholds depend on plant available nutrients, potential Nitrogen reserve and Phosphorus, loss of Calcium, Magnesium and Potassium. The chemical indicators of soil are pH, extractable soil nutrients like Nitrogen (N), Phosphorus (P), Potassium (K) and the base cations Calcium (Ca), Magnesium (Mg).

Biological indicators of soil quality that are commonly measured include soil organic matter, respiration, microbial biomass (total bacteria and fungi) and mineralizable nitrogen. The soil organic matter plays a key role in soil function, determining the soil quality, water holding capacity and susceptibility of soil to degradation. In addition, the soil organic matter may fix atmospheric carbon dioxide and increase the soil carbon content which is indicated by a higher microbial biomass and elevated respiration. The soil organic matter is also a principal reserve of nutrients such as Nitrogen.

3. Case Study

The case study considered is the Vrishabavathi river, a tertiary tributary of the river Cauvery and drains from an aerial extent of 472 km^2before it joins Suvarnamukhiriver at Bhadragundadoddi near Harohalli of Kanakapurataluk, Bangalore district. The Suvarnamukhiriver in turn joins river Cauvery at Sangam in Kanakapurataluk. The drainage basin length is 51 km with river water course length of 56 km. Vrishabavathi valley extends on topo sheets 57G/8, 57G/12, 57H/5, 57H/6, 57H/9 and 57H/10 published on a scale of 1:50,000. The valley area is encompassed by North Latitude 12.66° to 13.03° and East Longitude 77.33° to 77.57°.The location map of the study area is shown in Figure 1. A database is created for the study area by collecting 259 soil samples from the study area. It may be highlighted that all the physically accessible regions were covered in the sampling area. Soil quality database is then integrated to GIS platform to create data layers. In this study, the samples were taken from the appropriate source of soil for irrigation. Soil sampling points in the study area are shown in Figure 2.



Co-ordinates:

Points	Latitude	Longitude
A	12.66°N	77.33°E
B	12.66°N	77.52°E
C	12.90°N	77.52°E
D	12.90°N	77.33°E

Figure 1: Location Map showing the Study Area

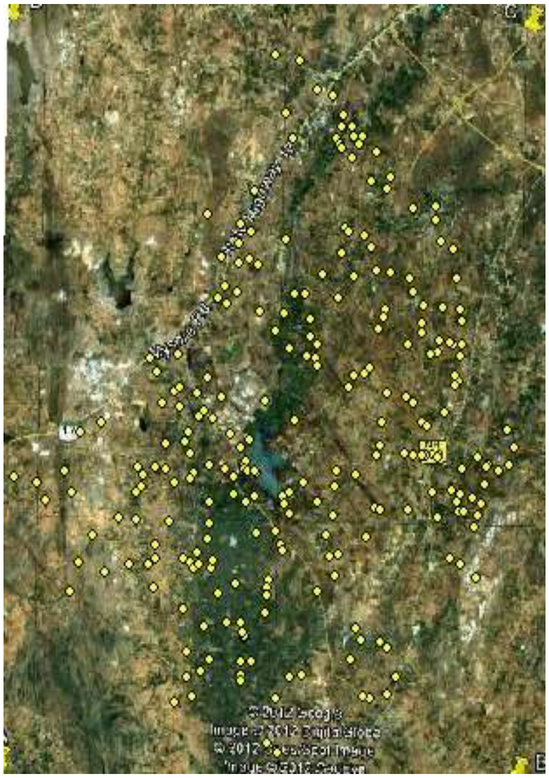


Figure 2: Figure showing the soil sampling points

Soil sampling is an essential component of analysis for parameters of soil. Each sample collected must be a true representative of the area being sampled. Utility of the results obtained from the laboratory analysis depends on the sampling precision.The soil samples were analyzed for pH, electrical conductivity, organic carbon, phosphorus and potassium.

4. Assessment of Soil Quality Index (SQI)

In the present study, the Soil Quality Index (SQI) is developed based on the soil test ratings given in Hand book of Agriculture published by Indian Council of Agricultural Research (ICAR). These guide lines of ratings are in Table 1 and are used in the development of Soil Quality Index.

Table 1: Interpretation frame work of soil quality indicators for agriculture use

Sl. No.	Chemical Indicators	Suitability of soil to grow crops		
		Low (Rating 1)	**Medium (Rating 2)**	**High (Rating3)**
1	Soil pH	< 4.0 &> 8.5	4.0 to 5.5 & 7.2 to 8.5	> 5.5 &<7.2
2	Electrical Conductivity (EC),dS/m	> 2	1.0 to 2.0	< 1.0
3	Organic Carbon, (OC), %	< 0.5%	0.5 - 0.75%	> 0.75
4	Available Nitrogen, (N), kg/ha	< 280	280 to 560	> 560
5	Available Phosphorus (P), kg/ha	< 10	10 to 25	> 25
6	Available Potassium, (K), kg/ha	< 110	110 to 280	> 280

The Soil Quality Index (SQI) incorporates the pH, Electrical Conductivity, macronutrients and Organic Carbon, an indicator of Nitrogen (N), Phosphorus (P) and Potassium (K). The rating for the parameters are presented in Table 1. In the methodology used to assess the Soil Quality Index, equal weightages are assigned to the quality parameters of soil analysis results for pH, Electrical Conductivity, Organic Carbon, available Phosphorus and available Potassium. The SQI for cultivation is based on the linear combination of five chemical indicators of soil quality parameters which have potential impact on crop yield. The parameters used in the analysis are combined to form a single index value, which is then used to determine the suitability of soil for a crop. The SQI so obtained is integrated into Geographical Information System (GIS) platform, which provides a better platform for visualization and making comparative evaluation.

The SQI index is calculated by

$$\textbf{SQI Index}=\sum_{i=1}^{5} G_i \qquad [1]$$

where 'i' is an incremental index and G represents the contribution of each one of the six categories of chemical indicators that are important to assess the quality of soil.

The first category of the soil quality is the Soil pH and is formulated by

$$\mathbf{G_1 = r_1} \qquad [2]$$

The second category of soil quality is Electrical Conductivity (EC) and is formulated by

$$\mathbf{G_2 = r_2} \qquad [3]$$

The third category of soil quality is the Organic Carbon, which is indicative of nitrogen potential of soil is formulated by

$$\mathbf{G_3 = r_3} \qquad [4]$$

The fourth category of soil quality is the Available Phosphorus (P) and is formulated by

$$\mathbf{G_4 = r_4} \qquad [5]$$

The fifth category of soil quality is the Available Potassium (K) and is formulated by

$$\mathbf{G_5 = r_5} \qquad [6]$$

Here r_1, r_2, r_3, r_4 and r_5 are rating values of parameters ranging from 3 to 1 as presented in Table 1. The desirable ranges of the different parameters are given higher rating of 3, moderate ranges with rating of 2 and undesirable ranges with rating as 1.

The values of SQI of different soil samples is obtained by assigning different rating factors (i.e., 1, 2 and 3) to each parameter given in the Table 1 thus yielding three different index values (i.e., 15, 10 and 5). The medians of these values are used to set the upper and lower limits used in each category specified in Table 2. The SQI index is also represented in percentage for better understanding of the soil quality.

Table 2: Soil Quality Index (SQI)

SQI	SQI, %	Suitability of Soil for Crops
< 7	< 46 %	Low
7-12	46– 80%	Medium
> 12	> 80%	High

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5. Thematic Maps

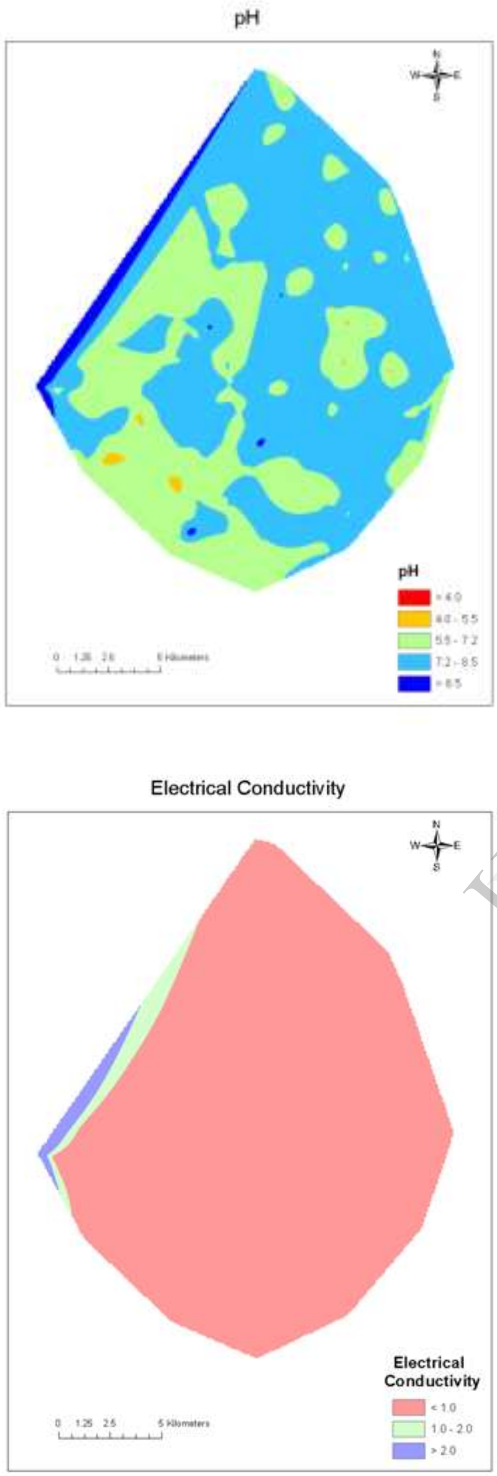

Figure 3: Spatial distribution of pH and Electrical Conductivity of soil

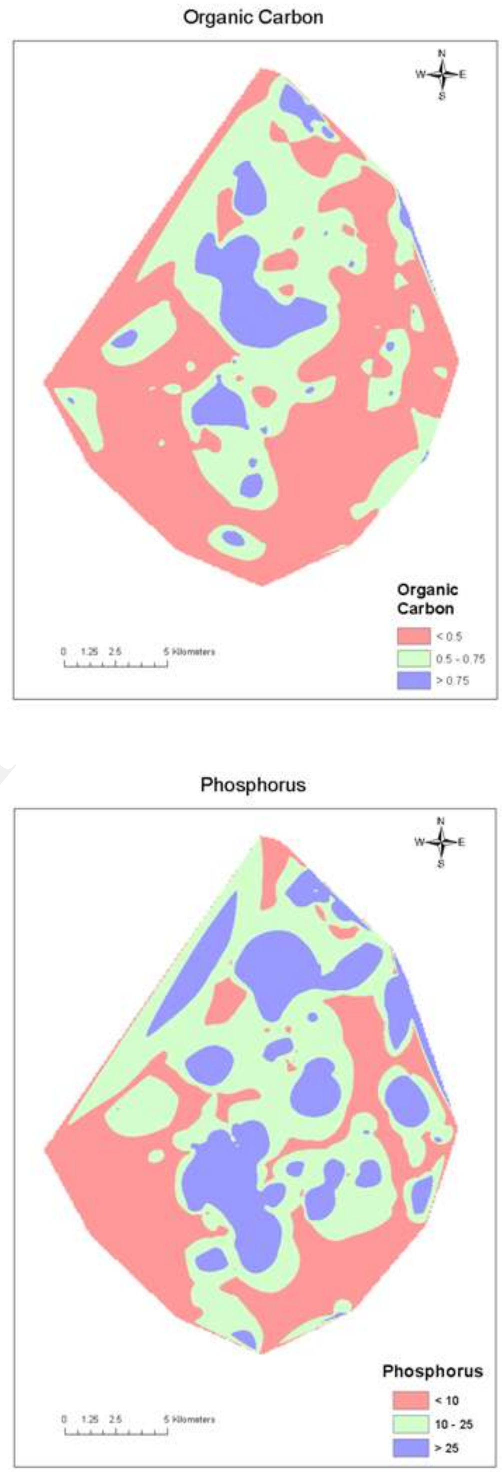

Figure 4: Spatial distribution of Organic Carbon and Phosphorus of soil

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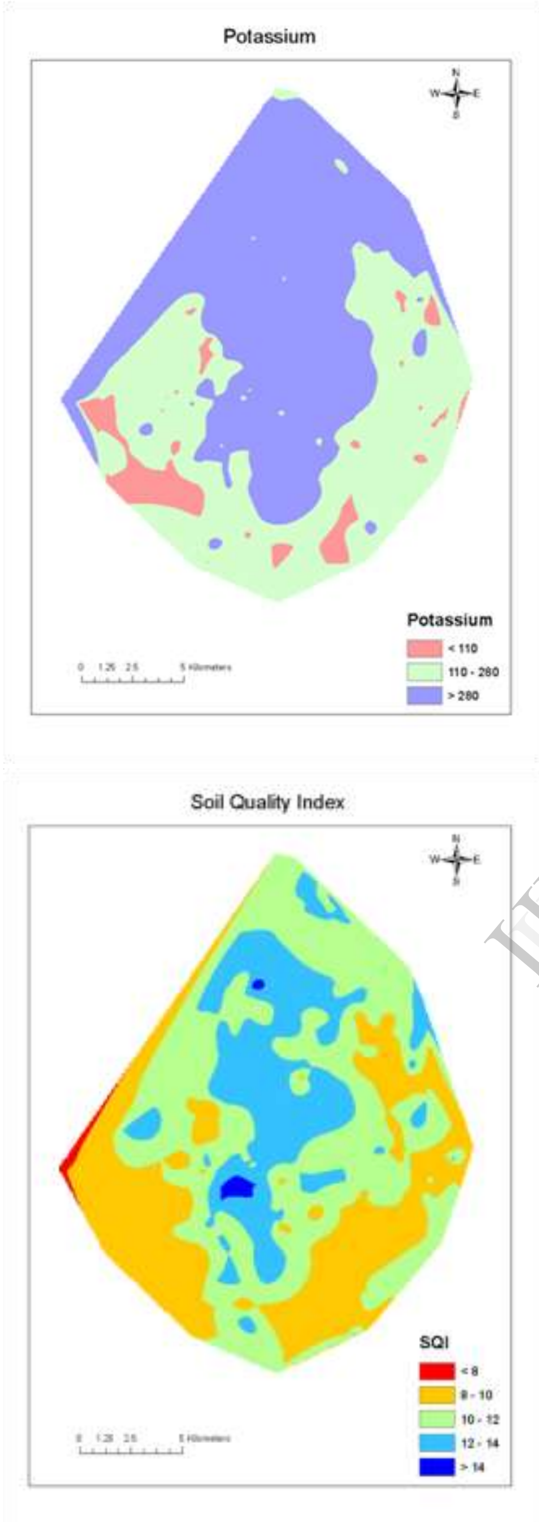

Figure5: Spatial distribution of Potassium of soil and Soil Quality Index

6. Results and Discussions

The following are the observations based on Table 1 and Table 2.

1. The spatial distribution of soil pH in the study area is presented in Figure 3. It is seen that 34% of the region falls under the high suitability category (5.5 - 7.2), 64% falls under the category of medium suitability (4.0 - 5.5 and 7.2 - 8.5) and only 2% is of low suitability (<4.0 and >8.5).
2. The thematic map showing the spatial distribution of Electrical Conductivity clearly indicates that 98% of the region is highly suitable for agriculture (<1.0 dS/m), 1% is of medium suitability (1.0 - 2.0 dS/m) and the remaining 1% is of low suitability (>2.0 dS/m), as can be seen in Figure 3.
3. The spatial distribution of Organic Carbon in the study region indicates that 15% of the soil samples have high suitability for growing crops (>0.75%), 31% is of medium suitability (0.5 - 0.75 %) and the remaining 54% is of low suitability (<0.5%), as seen in Figure 4.
4. Figure 4shows the spatial distribution of Phosphorus in the study region. 23% of the soil samples have Phosphorus content more than 25 kg/ha, which is highly suitable for growing crops, 17% of the samples have Phosphorus content between 10 and 25 kg/ha, which is of medium suitability and 60% of the samples have Phosphorus content less than 10 kg/ha, which is classified as low suitability.
5. The variation of Potassium across the study region is shown in Figure 5. Here, 45% of the samples indicate high suitability (>280 kg/ha), 39% is of medium suitability (110 - 280 kg/ha) and the remaining 16% is of low suitability (<110 kg/ha).
6. All the above mentioned parameters influence the soil quality. The combined effect of all the parameters is given in terms of Soil Quality Index. The variation of SQI across the study area is presented in Figure 5. It is interesting to note that there is no region which is of low suitability (<7). While 23% of the soil samples indicates high suitability (>12), the remaining 77% indicates medium suitability (7 - 12).

7. Conclusions

1. The parameters influencing Soil Quality Index, such as pH, Organic Carbon, Phosphorus, Potassium are found to be varying from low suitability to high suitability, the significant percentage being low and medium suitability. However, only Electrical Conductivity of soil was

found to be of high suitability for almost the entire region.

2. The Soil Quality Index was found to be in medium to high suitability category. There is no region showing low suitability. However, the region of medium suitability is significantly high.
3. There are no well-defined regions of either medium suitability indices or high suitability indices. The range of values is found to be spread randomly across the region. Apparently, there is no influence of the topological profile of the region.
4. The reason for Soil Quality Index, to be less suitable for growing crops in the study area could be due to the continued ingress of variety of effluents into the soil, through water. Another reason for this is that the soil in the study area is sandy loam soil and since the permeability of this soil is high, some of the effluents along with the water enter the soil in the form of deep percolation.
5. For any crop to survive there must be sufficient Organic Carbon, Phosphorous and Potassium reserve in the soil. Analysis of soil samples shows that most of the soil samples spread across the study area is having low to medium suitability of Organic Carbon and Phosphorus content, showing deficiencies in Organic Carbon (OC) and Phosphorus. However, most of the soil samples of the study area are having medium to high suitability of potassium in the soil indicating that there is no deficiency of potassium.

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