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Research Article

Spatial Variability Analysis, and Mapping of Soil Physical Parameters and Soil Physical Health

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ABSTRACT

Spatial analysis for mapping of soil physical properties is helpful in developing the soil quality index over a region, which acts as a guide to management decisions and interventions. Spatial variability analysis were performed in wheat fields in Karnal district spread over 50 farms covering an approximate area of 25 ha. Parameters which were analyzed included soil texture, bulk density, water content at saturation, saturated hydraulic conductivity, non-capillary pores and organic carbon content. Spatial distribution of these parameters was mapped, and zones were identified. Based on these parameters, a soil physical health index map was generated.

Key words: Spatial properties, Hydraulic conductivity, Saturation water content, Pores, Soil physical health

Introduction

Various physical, chemical, and biological properties of a soil interact in complex ways that determine its potential fitness or capacity to produce healthy and nutritious food. Soil health is a term which is widely used across sustainable agriculture to describe a general condition or quality of the soil resource. Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world.

Soil quality indicators are used to evaluate how well soil functions. In developing countries in Asia, adverse effects on soil health and soil quality arise from nutrient imbalance in soil, excessive fertilization, soil pollution and soil loss processes. Soil quality cannot be measured directly but soil properties such as bulk density (BD), penetration resistance (PR), soil pH, nutrient content etc. are sensitive to changes in management and can be used as quality indicators. Integration of these properties and the resulting level of productivity are referred to as ‘soil quality’. National Research Council Committee (NRCC) defined soil quality as ‘The capacity of a soil to function within the ecosystem boundaries and interact positively with the external environment’.

Soil properties vary spatially over short distance. The characterization of the spatial variability of soil attributes is essential to achieve a better understanding of complex relations between soil properties and environmental factors. Analyzing parameters of soil properties using geostatistical tools and applying them to predict other soil properties using ordinary kriging is the general procedure to prepare soil maps. In the past, soil variability in the field was defined by classical statistical method, which presumed that

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soil parameters have random variability. It was observed later that soil properties generally show spatial dependence (Webster, 1985). Samples that are close to each other have similar properties than that of samples farther from each other. Soil properties that are spatially variable within the fields include fertility, texture, physical and chemical properties and soil depth (Burgess and Webster, 1980; Oztas, 1993; Saha *et al*., 2017). Variability of these properties within a field affects crop yield e.g., Cox *et al*. (2003) reported that areas in a soybean field with high clay content had higher yield compared to areas with low clay content. Similarly when the application of water is non-uniform in the field, or the water quality (salinity) is varying, it results in spatial variation in crop yield (Sadler *et al*. 2000). Soil water relations can explain >50% of within-field yield variability (Irmark *et al*. 2002). Temporal and spatial management of soil water can significantly increase the water use efficiency (Jin *et al*. 1999).

While some of the indicators of soil quality may be sensitive to change, others are subtle. The overlying question is whether we can measure and quantify these indicators and develop them to a soil quality index that can monitor and assess the impact of farming systems and management practices on soil productivity, environmental quality, food safety and quality, and human and animal health. The ultimate goal is to develop a mathematical relationship or model that could quantify the various attributes of soil quality, and from it derive one or more indexes for simulation and prediction.

Materials and Methods

Site and sampling

The present investigation was carried out in wheat field in Karnal district for 50 farms covering an approximate total area of 25 ha. Climate of the study area is semi-arid, subtropical with moderate summer and cool winter. The mean annual rainfall is 550 mm, 80% of which is received during December-January. The relative humidity is low (~20%) during the season of investigation.

In order to analyze spatial variability and mapping of spatial variation of soil physical health 50 observation sites were chosen at a grid interval of 30m X 45m. The coordinates of each sampling location was recorded using a differential global positioning system unit. In addition, disturbed and undisturbed soil samples were collected from the surface (0-30 cm), sub surface (30-60 cm) and sub surface (60-90 cm) soil layers. Core sampler was used for taking undisturbed soil samples for soil bulk density (BD) determination, while disturbed soil samples were collected by using a screw auger for determination of soil texture, organic matter and saturation percentage. Disturbed samples were air dried at room temperature, and sieved (<2 mm) before analysis. Soil parameters included field saturated hydraulic conductivity (K_{fs}), BD, sol texture, soil organic carbon (OC), available water content (AWC) and water content at field capacity (WC_{FC}) and water content at wilting point (WC_{WP}).

Observations taken

The soil BD was determined by using core method. Bulk density was determined by dividing the weight of oven-dry soil by volume of the core (5.5 cm diameter and 5 cm height). Hydrometer method was used to determine sand, silt and clay percentage and USDA textural triangle was used to determine the soil textural class. Soil organic carbon (OC) was measured by Walkley and Black (1934) method. Soil organic matter was oxidized with chromic acid (potassium dichromate + H_2SO_4) and the unconsumed potassium dichromate is back titrated against ferrous ammonium sulphate (redox titration); OC was expressed as percent of oven-dry soil.

Soil water content at field capacity (WC_{FC}) and permanent wilting point (WC_{WP}) were determined by pressure plate apparatus as equilibrium water content at 0.33 and 15 bar suction. Saturation water percent (WC_{ST}) of each sample was also determined gravimetrically. The saturated hydraulic conductivity was determined by constant head permeameter.

Spatial variability analysis

Spatial variability of above parameters was analyzed on a rectangular grid by using Arc GIS software. Before the analysis, exploratory spatial data analysis (ESDA) was carried out to check the normality, presence of outlier, trend and range of spatial dependence of data.

Computation of soil physical health index (PI)

For a given site, each of these parameters was assigned a rating value corresponding to its actual value by referring to the rating chart (Gupta, 1986). Each of these parameters was given a score of 1 if the value lies within the optimum range. If the value is below or above the critical limit, a score of <1 was given. Greater the deviation of parameter value from optimum range, lesser the score assigned to it. The product of rating values of all the eight parameters gave the physical rating index (PI). The PI was an indicator of overall soil physical health status. For range of PI >0.75, 0.50-0.75, 0.25-0.50 and <0.25, soil physical health status and accordingly its production potential could be labeled as very good, good, medium or poor respectively.

Results and Discussions

The soil texture map indentified five classes: loam, clay loam, sandy clay loam, silty clay loam and clay, of which clay loam occupies the maximum area (Fig. 1). The EC and pH of the soil varied in the ranges of 0.08 to 1.52 dS m^{-1} and 8.0 to 8.8, respectively in 0-30 cm soil depth [RMSE 0.34 for EC and 0.28 for pH] (Fig. 2 and 3).

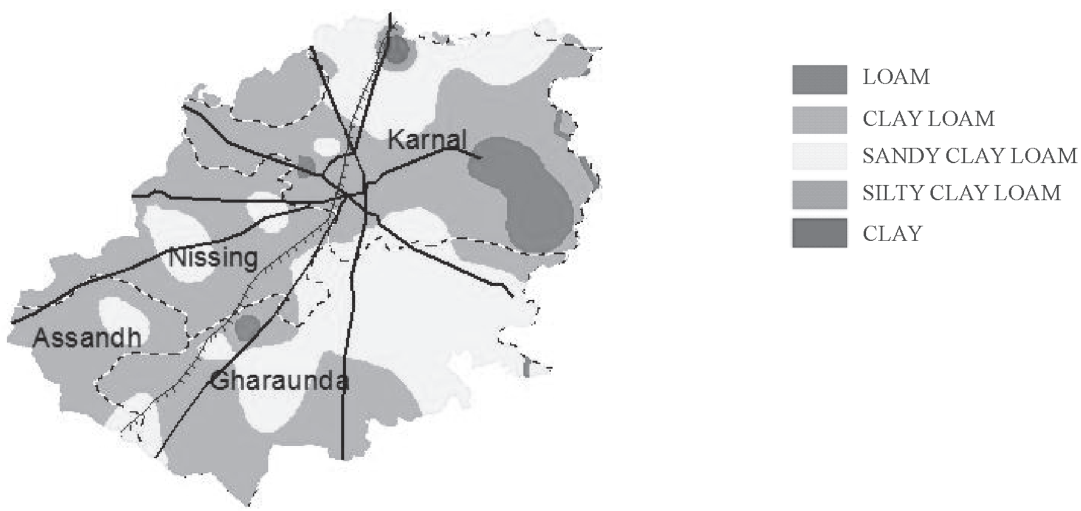

Fig. 1. Soil texture map of the study area

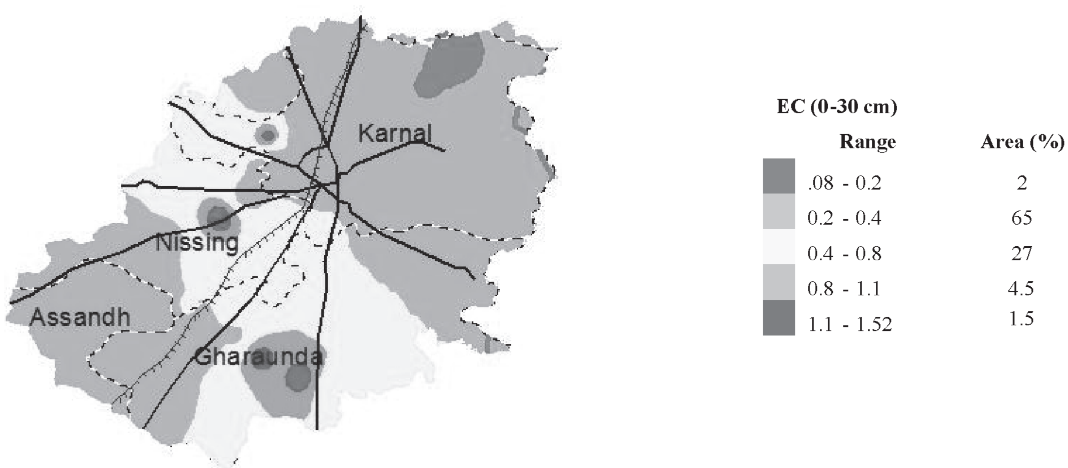

Fig. 2. Spatial variation map of electric conductivity in 0-30 cm layer

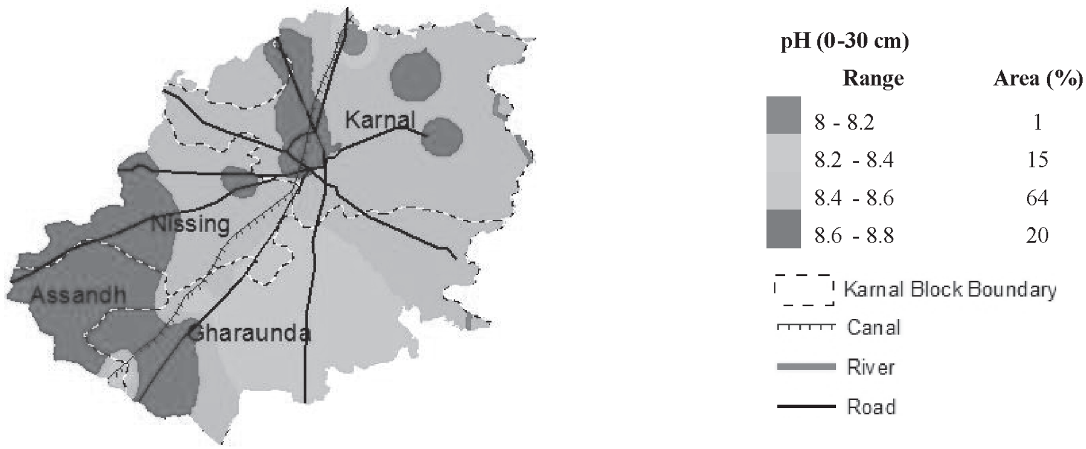

Fig. 3. Spatial variability map of pH in 0-30 cm layer

Spatial analysis of data revealed that the BD varied between the ranges of 1.20 to 1.60 in 0-30 cm depth of soil (Fig. 4). Similarly for the soil depth in 30-60 cm the bulk density varied between ranges of 1.40 to 1.76 g cm^{-3}. Bulk density for around 66% of surface area was in the range of 1.76 to 1.85 g cm^{-3} for the soil depth in 30-60 cm. While calculating the BD, the RMSE was recorded as 0.076 and 0.084 for 0-30 and 30-60 cm layers, respectively.

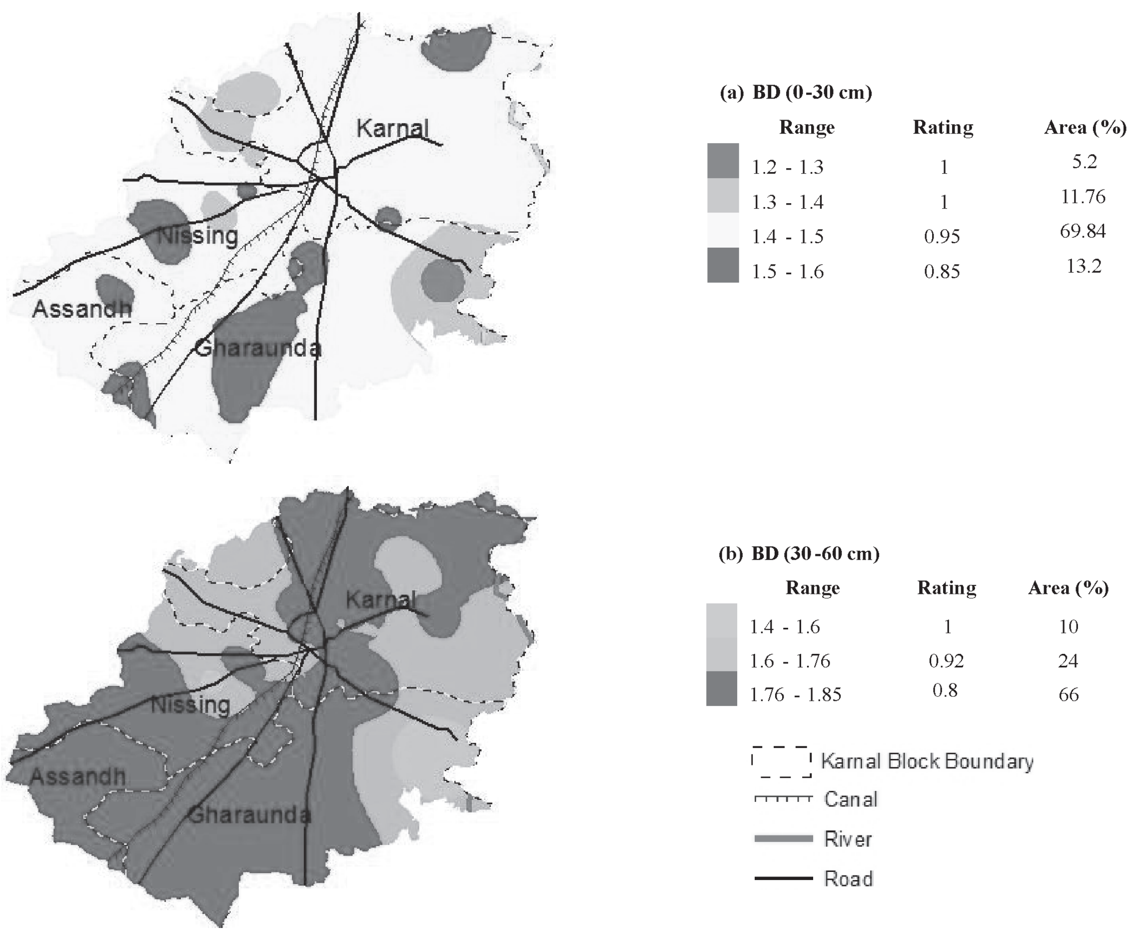

Fig. 4. Spatial variation of bulk density in (a) 0-30 and (b) 30-60 cm depth

Spatial analysis of water content at saturation (WC_{ST}) have mixed ranges of 0.35 to 0.51 $m^3 m^{-3}$ in 0-30 cm and 0.29 to 0.45 $m^3 m^{-3}$ in 30-60 cm layers (Fig. 5) with RMSE of 0.042 and 0.035 for 0-30 and 30-60 cm layers, respectively. Water content at field capacity (WC_{FC}) values ranged between 0.18 and 0.27 $m^3 m^{-3}$ in 0-30 cm, and 0.16-0.25 in 30-60 cm layers (Fig. 6). The RMSE

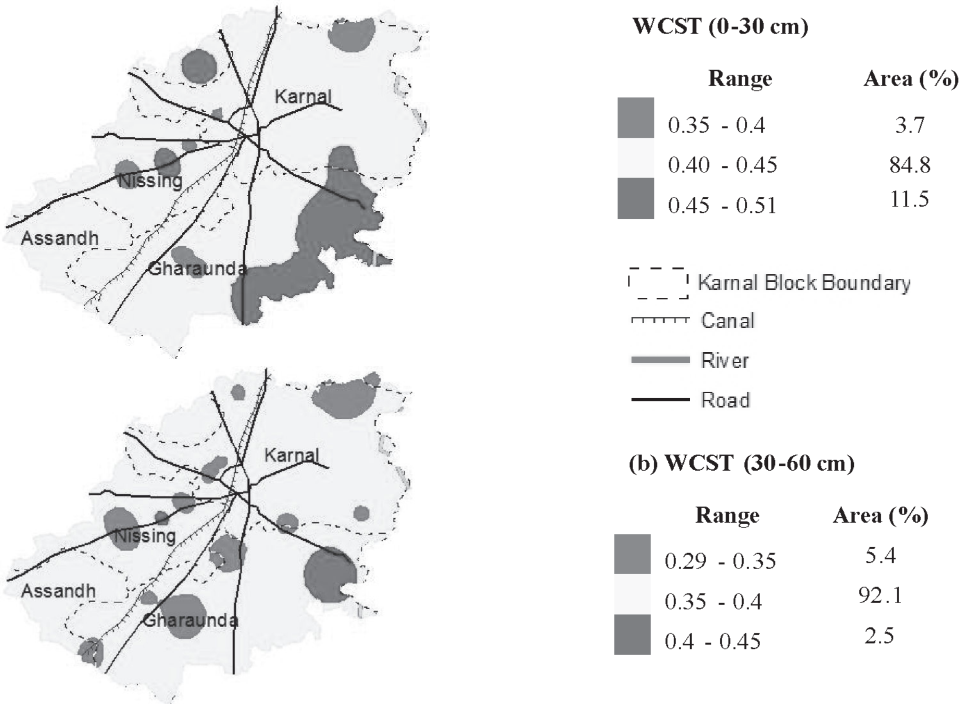

Fig. 5. Spatial variation of volumetric water content at saturation in (a) 0-30 and (b) 30-60 cm layers

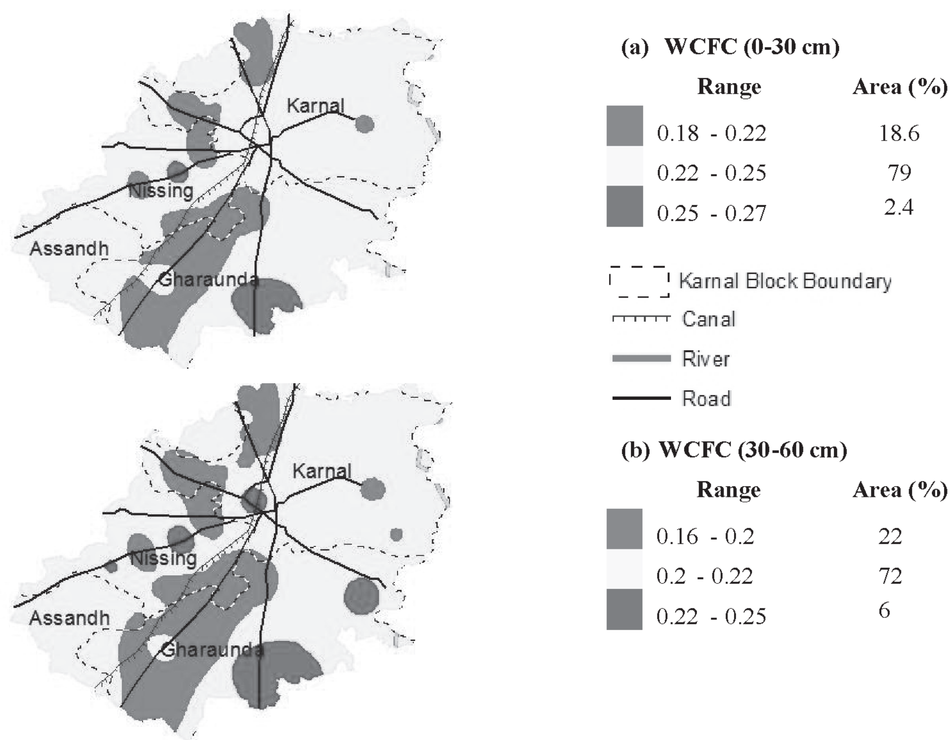

Fig. 6. Spatial variation of volumetric water content at field capacity in the (a) 0-30 cm and (b) 30-60 cm

was 0.076 and 0.084 for 0-30 and 30-60 cm layers, respectively. The WC_{WP} showed ranges of 0.04 to 0.16 m^3 m^{-3} in 0-30 cm soil depth, and 0.03-0.16 in 30-60 cm layers [RMSE of 0.029 and 0.026, respectively] (Fig. 7). Organic carbon (OC) had ranges between 0.10 and 0.90 in 0-30 cm, and 0.20 to 0.75 in 30-60 cm layers (Fig. 8) The RMSE was 0.20 and 0.12 in 0-30 cm and 30-

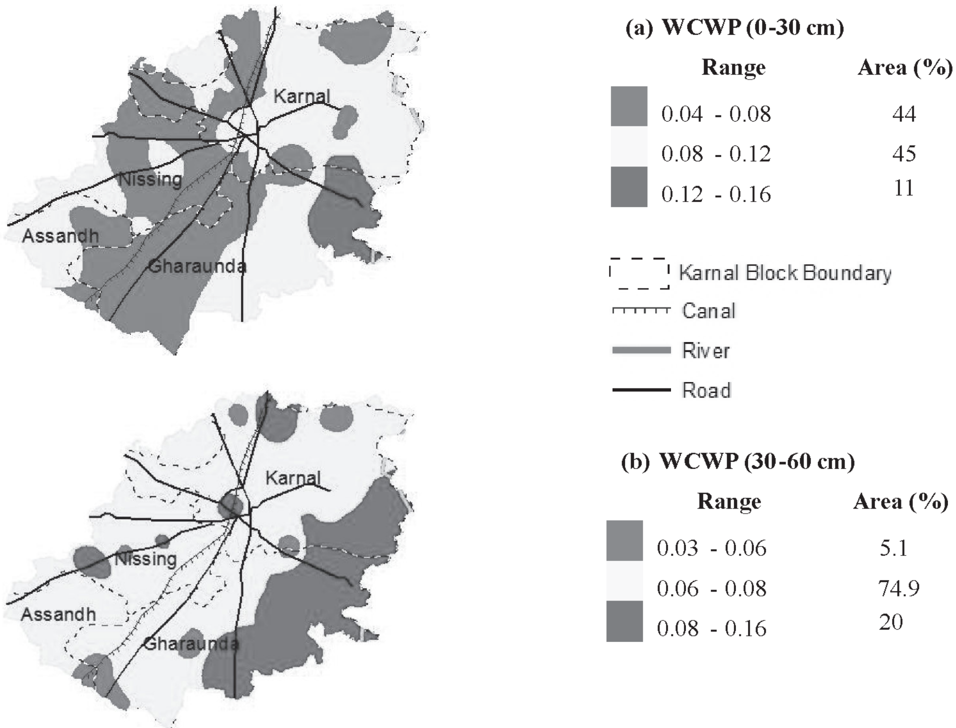

Fig. 7. Spatial variation map of volumetric water content at permanent wilting point in (a) 0-30 and (b) 30-60 cm layers

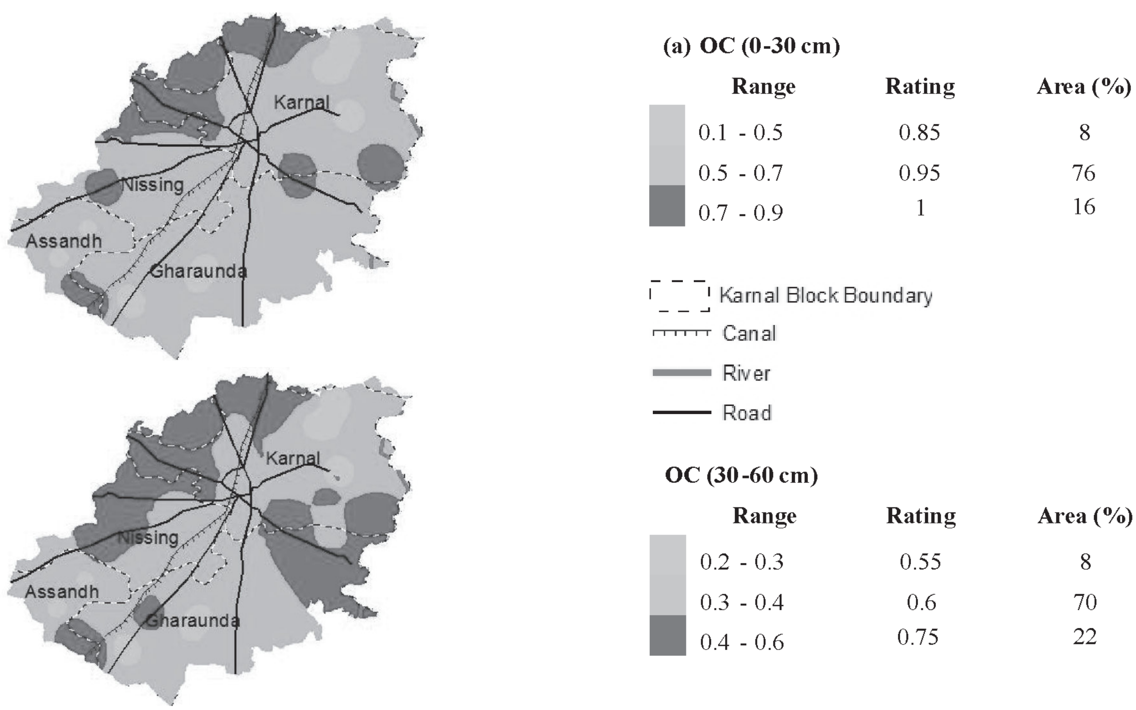

Fig. 8. Spatial variation of organic carbon in (a) 0-30 and (b) 30-60 cm layers

60 cm, respectively. For around 70% of the surface area, the OC was in 0.30-0.40 in 30-60 cm layers.

The saturated hydraulic conductivity (KSAT) varied between 0.06 to 1.32 cm h^{-1} and the RMSE was 0.34 and 0.27, respectively (Fig. 9). For 80% of the surface area in 30-60 cm of soil depth KSAT varied between 0.25 and 0.50 cm h^{-1}. Non capillary pores (NCP) were ranging between 0.13 to 0.26 and 0.09 to 0.21 in 0-30 and 30-60 cm soil layers, respectively [RMSE was 0.03 and 0.02, respectively] (Fig. 10). Available water

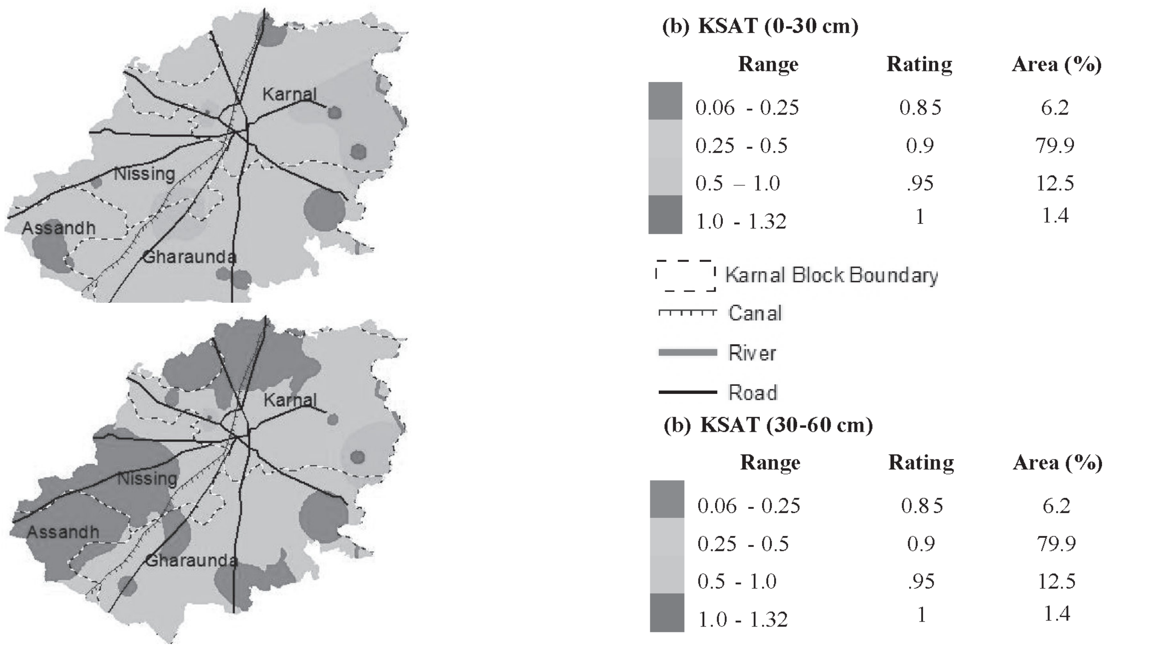

Fig. 9. Spatial variation of saturated hydraulic conductivity in (a) 0-30 and, (b) 30-60 cm soil layer

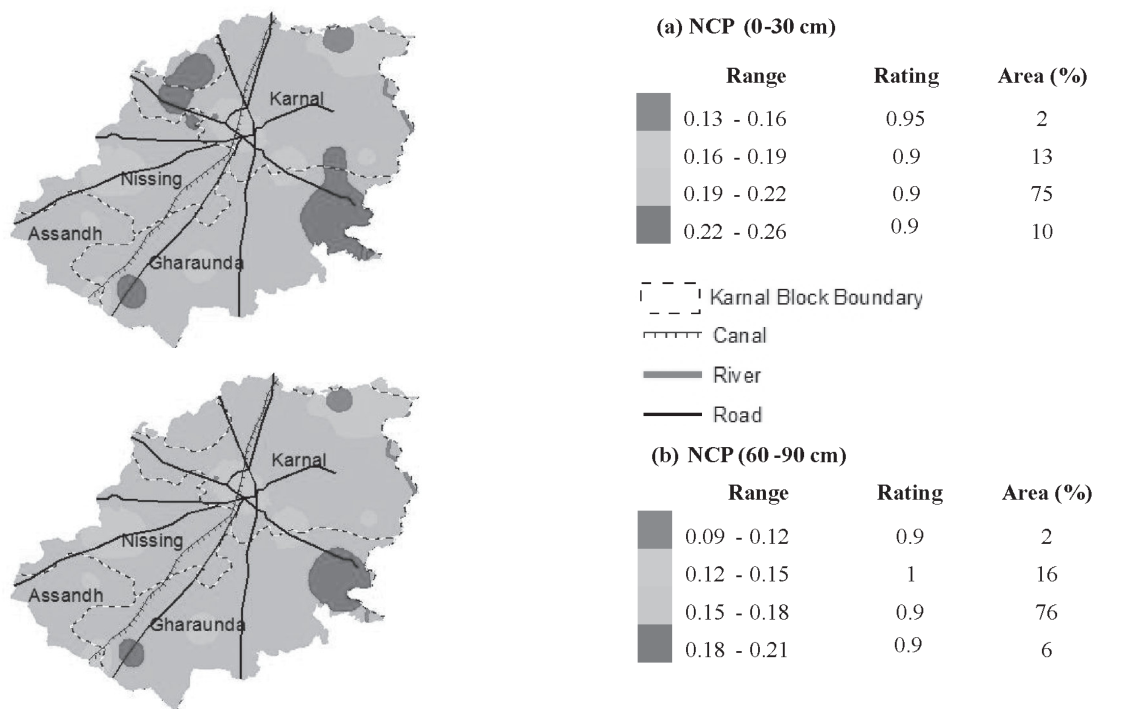

Fig. 10. Spatial variation of non-capillary pores in (a) 0-30 and (b) 30-60 cm layer

capacity (AWC) map (Fig. 11) shows 0.05 to 0.20% variations in 0-30 cm soil layer. Similarly for the soil depth in 30-60 cm it ranged from 0.04 to 0.18 (RMSE 0.02).

The soil quality index has been developed taking these parameters into consideration. Looking at the soil physical health index (PHI) (Fig. 12), it was revealed that approximately 90% of the area was good and 5% of the area was very good for wheat cultivation. Variation in the indices can be useful in generating information on the overall quality of soil in the area, and helps in deciding on management options for areas, where the soil physical health needs attention (Abeysingha *et al*., 2016).

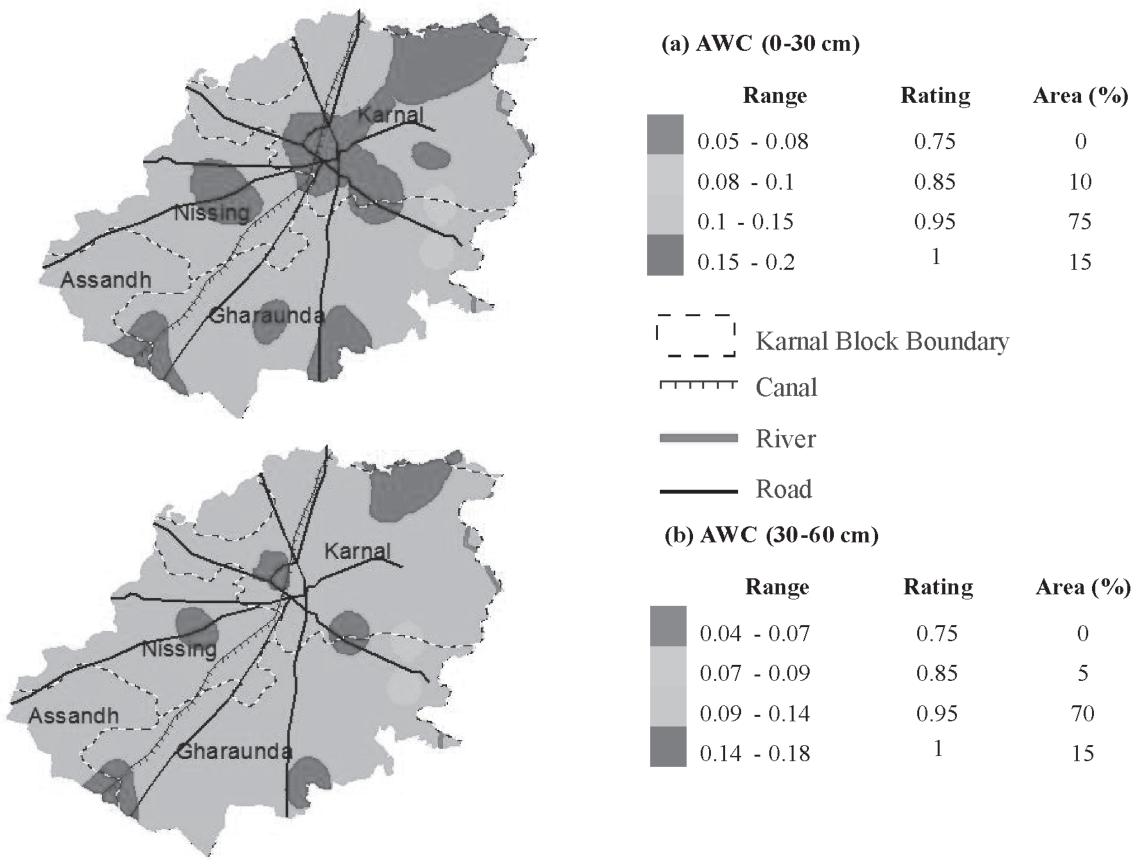

Fig. 11. Spatial variation of available water content in (a) 0-30 cm, (b) 30-60 cm layer

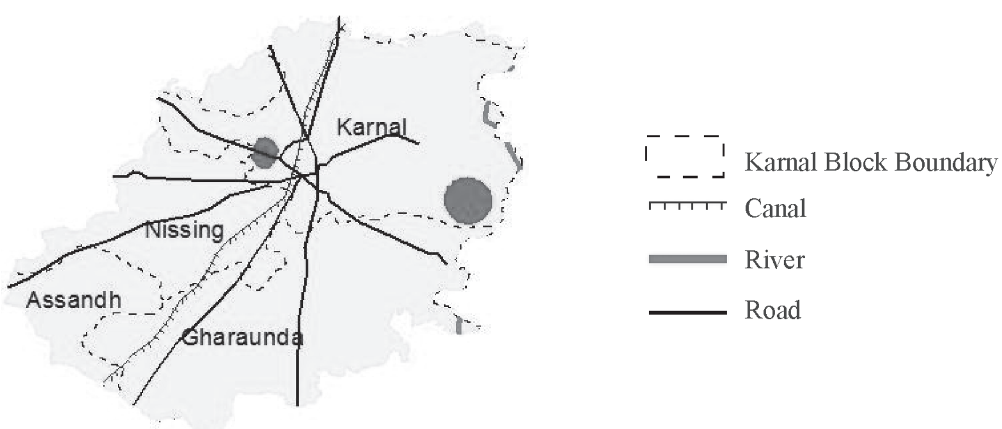

Fig. 12. Soil Physical Health Index [Two zones: Good (yellow) and moderate to poor (red)

Conclusion

In the conclusion it could be stated that overall soil physical health of selected farms in Karnal district was good for wheat cultivation. Looking at the soil physical health index (PHI) Fig – 3.12, it was revealed that approximately 90% of the area was good and 5% of the area was very good for wheat cultivation. Appropriate management practices such as deep ploughing, deep tillage, organic matter incorporation and reducing the intensity of puddling before wheat transplanting can be used for further improving the soil health of the farm resulting increased wheat yield. Based on these findings, appropriate rates of different input and soil management practices should be recommended in different parts of the farm so as to alleviate any soil health constraints.

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