

Indexing Soil Physical Parameters and Soil Quality Assessment with Remote Sensing and Geographic Information System for Sustainability

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Abstract Soil quality assessment helps in soil evaluation for better understanding of the soils in terms of their potentials and limitations for sustained agricultural production. Specific indicators of soil quality need to be identified and measured and acceptable limits must be defined. The soil variables like soil texture, soil depth, soil drainage, soil slope and soil erosion status were considered as the parameters influencing the crop yield. Soil quality index in this study is derived by a function of five important factors mentioned earlier for crop growth. The quality rating is based on the guidelines of FAO

(1976). Multiple variables are integrated overlaid into an index. The main aim of evaluating the soil suitability for crops is to identify which parcels of land supports best for different crops. This helps to recommend the farmer the land use and management techniques to be adapted to that particular parcel of land. These spatial variability maps generated for the soil parameters utilizing Arc view GIS 10 software are overlaid to prepare soil suitability maps. The spatial variability of these soil properties were layered and matched with soil suitability criteria for these crops. The resulting soil suitability maps can be prepared for any crop.

Keywords Soil physical parameters, SQI, RS, GIS, Sustainability.

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Introduction

The thrust of agricultural production is shifting from quantity towards quality and sustainability. The primary link between agricultural production and sustainability is the soil health, or quality of the soils. Assessment of soil quality can provide the information necessary for sustainability. Soil quality has many attributes which vary spatially generally these

Table 1. SQI indicators.

	Very low (1)	Low (2)	Indicators Moderate (3)	High (4)	Very high (5)
Texture	Clay, Cracking Clay Calcareous, Clay Calcareous, Cracking Clay,	Gravally Clay	Loam Calcareous, Gravally Loam Calcareous	Loam Gravally Loam	–
Depth	10–25 cm	25–50 cm	50–75 cm	75–100 cm 100–150 cm	>150 cm
Slope	–	15–30% Moderate Steep slopping	8–15% Moderate Slopping	1–8% Very gentle	0–1% Level
Drainage	–	–	Moderately Well drained	Some excessive Well drained	Excessively Drained
Erosion status	Severe Erosion	Moderate Erosion	Nil/Slight Erosion	–	–

attributes are considered individually to form quantitative assessment of soil quality, which leads to wrong assessment. It would be useful to design a more formal, quantitative and repeatable procedure for assessing soil quality considering all the important factors.

The traditional approach to soil fertility management has been to treat field as homogenous units and to make decisions on a whole fields basis ignoring the spatial variability of the soil and thus, the site-specific crop requirements. Such uniform treatment of field ignores the natural and induced continuous variation in soil properties and may result in certain areas being under or over treated, resulting in economic and environmental problems coupled with the ineffective use of inputs. However, it has been reported for at least 70 years that fields are not homogeneous and sampling techniques to describe field variability have been recommended [1].

In earlier days, conventional soil survey methods were used to obtain data on analysis of soil resources. Though the data obtained by such methods are reliable and accurate, it does not help in creating the layers of spatial variability of soil properties. The

rapid development of spatial technologies in recent years has made available new tools and capabilities in agriculture mainly for soil resource inventory. In particular the evolution of Geographic Information System (GIS), Global Positioning System (GPS), Remote Sensing (RS) technologies has enabled the collection and analysis of data in all possible ways to create the accurate field maps and also assess complex spatial relationships between soil quality and fertility factors.

Materials and Methods

Soil quality assessment

Sustainable land management can be achieved through the soil quality assessment by in-depth knowledge of the characteristics, properties, processes occurring in soils which vary spatially. Soil quality assessment can be done by means of suitable indicators. The soil quality indicators for soil physical properties like soil type, soil depth, soil erosion status, soil drainage and soil slope are given in Table 1. The soil quality indicators can be derived by qualitative and quantitative techniques. These soil quality attributes vary spatially and such attributes are con-

sidered individually to form quantitative assessment of soil quality. Soil attributes considered in this study include soil type, soil depth, soil erosion status, soil drainage and soil slope. For each soil attribute, quality indicator based on a quality rating is given in the range (1 to 5) based on the guidelines of FAO [2]. Then soil quality index is computed as the Geometric mean of the five quality indicators using, the formula :

$$SQI = (A1 \times A2 \times A3 \times A4 \times A5)^{1/5}$$

Where, A1 = soil quality indicator for soil texture, A2 = soil quality indicator for soil depth, A3 = soil quality indicator for soil drainage, A4 = soil quality indicator for soil slope, A5 = soil quality indicator for erosion status. The schematic representation of soil quality index is given in Fig.1.

The input data sets used for the quality indicators soil type, soil depth, soil erosion status, soil drainage and soil slope of study area are derived from the soil map of Kurnool district from the NBSSLUP (National Bureau of Soil Survey and Land Use Planning). The spatial variability maps for the study area are prepared for these indicators.

The thematic maps thus generated for the five attributes are converted to their corresponding quality indicators by using the quality rating given by FAO [2]. The reclassified themes are overlaid and soil

quality index is computed. The soil quality index map is prepared using GIS software. From the SQI maps the percentage area for each soil quality type is arrived.

Suitability mapping in GIS environment

In this step the reclassified map (raster format) of each variable has been converted into vector format and has been assigned by the score of each class according to their rating values. Then the vector layers have combined by performing the overlay operation into GIS environment. Finally the suitability maps have been prepared according to the chosen criteria with five suitability categories namely; S1, S2, S3, N1 and N2.

Results and Discussion

Soil quality assessment

Soil quality assessment helps in soil evaluation for better understanding of the soils in terms of their potentials and limitations for sustained agricultural production. Good soil quality is key to sustainable agriculture. As the soil quality declines the agricultural production decreases. Specific indicators of soil quality need to be identified and measured, and acceptable limits defined.

The soil quality assessment is expressed in terms of soil quality index and in this study it is derived by a function of five factors namely soil texture, soil slope, soil depth, soil drainage and erosion status. The quality rating is based on the guidelines of FAO.



Fig. 1. Schematic diagram for SQI

Table 2. Spatial distribution of soil texture in study area.

Category	Nandyal division	
	Area (ha)	% Area
Clayey	41150.48	8.98
Cracking clay	15807.19	3.45
Cracking clay calcareous	231241.80	50.44
Gravelly clay	75208.15	16.40
Gravelly loam	11854.03	2.59
Gravelly loam calcareous	82943.70	18.09

Table 3. Spatial distribution of soil depth in study area.

Category	Nandyal division Area (ha)	% Area
Rock out crop	254.35	0.06
Shallow	157155.73	34.28
Moderately deep	87224.09	19.03
Deep	182741.33	39.86
Very deep	31084.19	6.78
Total	458459.7	100

Multiple variables are integrated, overlaid into an index which can then be used to prepare soil quality maps. These maps indicate areas with a high probability of having good soil quality according to pre-determined criteria. The evaluation of a land unit using soil quality indicators was also done earlier [3—5].

Soil quality index (SQI) was computed using the geometric mean of the five quality indicators, given by

$$SQI = (A1 \times A2 \times A3 \times A4 \times A5)^{1/5}$$

The soil quality index map was generated using GIS (ARC/Info) techniques.

Factors considered for soil quality index

The tools for assessing soil properties and health are taken from the VS-Fast methodology [6] and selected VSA methods of Shepherd [7]. Soil factors considered for calculations of soil quality index of study area is given below.

Table 4. Spatial distribution of soil drainage in study area.

Category	Nandyal division Area (ha)	% Area
Rock/water	254.35	0.06
Imperfectly drained	31084.20	6.78
Moderately well drained	215964.80	47.10
Well drained	167686.63	36.58
Excessively drained	43469.73	9.48
Total	458459.7	100

Soil texture (A1)

Texture refers to the size of the particles that make up the soil. The terms sand, silt and clay refer to relative sizes of the soil particles. Additional texture class names are based on these three basic groups [8]. Texture of the soils play an important role in soil water availability, infiltration rate, drainage, tillage conditions and capacity to supply and retain the nutrients in soils [9]. The percent area of the soils under different categories of texture in study area are presented in Table 2. In the study area (Fig. 2), the maximum are of 50.44% (231241.80 ha) is having cracking clay calcareous texture, 18.09% soils with gravelly loam calcareous, 16.40% gravelly clay soils and 8.98% with clayey soils. Generally, the greater the clay percentage is within a soil, the lower the growth-limiting bulk density of the soil because of the increased pore space in clays [10].

Soil depth of soil (A2)

The depth of the soil is an important factor for crops as it suggests the volume of the soil from which the roots can extract the nutrients and water for their growth [6]. The depth of the soils in study area is shown in Table 3. Deep soils can provide good anchorage to crops especially for crops that have a deep root system. In Nandyal division, 39.86% of area (Fig. 3) is with deep soils followed by 34.28% with shallow soils, 19.03% with moderately deep soils and 6.78% with very deep soils.

Soil drainage (A3)

Drainage factor is a measure of soil air and water relationship and the availability of oxygen for root

Table 5. Spatial distribution of soil slope in study area.

Category	Nandyal division Area (ha) % Area	
Very gently sloping	301049.6	65.67
Gently sloping	113686	24.8
Moderately sloping	254.35	0.06
Moderately steep sloping	43469.73	9.48
Total	458459.7	100

Table 6. Spatial distribution of soil erosion in study area.

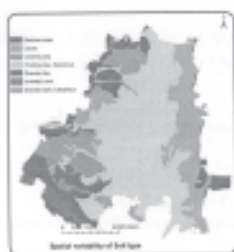
Category	Nandyal division	
	Area (ha)	% Area
Rock/water	72213.61	15.75
Nil/slight erosion	175090.02	38.19
Moderate erosion	95151.11	20.75
Severe erosion	115902.89	25.28
Very severe erosion	102.36	0.02
Total	458459.7	100

Table 7. Spatial distribution of soil quality index.

SQI	Area (ha)	% Area
Very low	43308.95	9.66
Low	41445.68	9.35
Moderate	72453.73	15.92
High	247322	53.39
Very high	53929.37	11.78
Total	458459.7	100

activity depend on soil drainage of study area (Table 4). Moderately well drained soils occupy 47.10% area of Nandyal division (Fig. 4), well drained soils

occupy 36.58%, 9.48% area with excessively drained and 6.78% of soils with imperfectly drained soils. Despite a large variety of soil types, the soil quality

**Fig 2.** Spatial variability of soil type in study area**Fig 3.** Spatial variability of soil depth in the study area.**Fig 4.** Spatial variability of soil drainage in the study area**5.** Spatial variability of soil slope in the study area**Fig 6.** Spatial variability of soil erosion status in the study area**Fig 7.** Spatial variability of soil quality index map in the study area**Fig. 2—7.**

can be improved by artificial drainage, cover crops, structure improvement and biological improvement [11].

Soil slope (A4)

Slope plays important role in selection of the crop because it affects working pattern, irrigation style and increase in land slope is directly proportional to higher erosion risks [12]. Spatial distribution of soil slope of the study area is presented in Table 5. In Nandyal division maximum area (65.67%) has very gently sloping followed by 24.8% of area with gently slope and 9.48% with moderately steep slope (Fig.5).

Soil erosion status (A5)

Soil erosion has adverse effect on the crop productivity. Soil erosion can quickly cause fertile farmland to become unsuitable for agriculture [13]. Higher the erosion status, more is the wash out of the soil fertility nutrients resulting in decrease of crop yield. Spatial variability of erosion status in study area is given in Table 6. Around 38.19% of Nandyal division is with nil erosion, 25.28% with severe erosion and 20.75% with moderate erosion (Fig. 6).

Soil quality type classes based on SQI

The soil quality index is computed using the above soil factors. The soil quality index map of the study area is generated using GIS and the percentage area each soil quality type is given in Table 7.

Soil quality type in study area

The thematic map of soil quality index of study area (Fig. 7) shows that maximum area of 53.39% (247322 ha) is having high soil quality where as 15.92 % having moderate, 11.78% with very high 9.66 and 9.35% with very low and low soil quality respectively.

Soil quality for agricultural production can be

defined by measuring specific soil indicators spatially over landscapes given by Ochola and Kerkides [14]. Several soil indicators have been proposed to monitor soil quality; however, indicators may change depending upon the soil quality monitoring objective.

Awareness of soil quality helps us to assess crop performance in a specific soil quality condition. Soil productivity can be changed from average to good and poor to average by adopting management practices such as addition of organic matter, improving texture by the addition of silt/clay content and by providing good irrigation facilities such as drip/sprinkler methods, besides deep tillage. So, if we take up crop production duly respecting the soil quality, the productivity can be sustained season after season, year after year and generation after generations i.e. sustainability.

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