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Assessing soil quality in semiarid tropical region of southern India using GIS and Remote Sensing

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ABSTRACT: Soil quality assessment has been recognized as an important step towards understanding the long term effects of land management practices within a landscape. This case study addressed the spatial variability of soil properties and their quality at the watershed and district level using geostatistical methods. Soils samples were collected from different land use systems of Nalgonda and Warnagal District of Andhra Pradesh in Southern India. An assessment framework that included a minimum data set, linear scoring technique, and additive indices was used to evaluate the soil quality index (SQI). The minimum data sets were chosen using principal component analysis and based on contribution of soil parameters to soil function through expert opinion. The order of calculated SQIs for different land use system was castor< intercrop< redgram< sorghum< cotton< maize< fallow< rice. Among the different soil orders, Vertic Inceptisol and Vertisol had the highest SQI followed by Inceptisols and Alfisols. A krigged map of SQI for the watershed as well as Nalgonda and Warangal districts was prepared. The results indicated that soil having higher soil quality indices were more productive and less erosion prone.

INTRODUCTION

Soils in the semiarid tropical regions are dominated by Alfisols, Inceptisols and Vertisols and soils are typically shallow, inherently low in fertility and organic matter content, -and easily susceptible to wind and water erosion (El-Swaify et al., 1985). Rainfall patterns are erratic and unpredictable, and crops frequently suffer from moisture deficits and drought even during normal rainfall periods. Subsistence agriculture and climatic extremes have significantly contributed towards the land degradation and deterioration of soil quality in these regions. As lack of assured moisture does not support higher cropping intensity in this region, contribution of root biomass towards organic matter is also dismally low. Farmers in rainfed semi-arid tropical regions do not use adequate and balanced amount of fertilizer nutrients because of uncertainty of rainfall, likely risk of failure of crops and poor economical condition. Consequently, low and imbalanced fertilizer use has resulted in multi-nutrient deficiencies. Adoption of appropriate soil, crop, and land management practices may reduce soil degradation and maintain soil quality.

Possible impacts of management practices on soil degradation can be identified in quantitative terms by performing a thorough assessment of the quality of soil resources of this agroecosystem. In this case study, we attempted to develop an overall soil quality index (SQI) at a watershed and district levels with the management goals of increasing crop yields and reducing soil losses using Geographic Information System (GIS) (Mandal et al., 2011; Kausalya et al., 2011).

STUDY AREA

The present study was carried out at 7.2 AESR North Telangana Plateau, hot moist semi-arid eco-subregion (Velayutham et al., 1999) of southern India. This agro-eco subregion constitutes south central Deccan plateau encompassing Telangan plateau of Andhra Pradesh State. Out of eight districts of Andhra Pradesh falling under this AESR Nalgonda and Warangal districts were selected in present study considering it’s agriculturally importance. The agroclimate of the region is characterized by hot, semi-arid moist with dry summers, and mild winters. The mean annual rainfall varies from 700-1000 mm covering 42 to 45% of the mean annual Potential evapotranspiration (PET) ranging between 1600-1800mm. Mid-season agriculture drought is quite frequent in this Telangana zone. Sakaliseripalli watershed in Chintapalli Mandal of Nalgonda district was selected for detailed watershed study. In all 298 georeferenced samples comprising of 154 samples from Nalgonda district and 144 samples from Warangal district from 0-15 cm of soil depth were collected during 2009-2010. For watershed study total 118 soil samples were collected separately from 89 ha watershed. A total 22 physical, chemical and biological properties of soil were analyzed for all the soil samples. Interviews were conducted with the farmers at each sampling site and information was collected on their agriculture management practices such as crop rotation, tillage practices, fertilization, irrigation, as well as yield of each crop. As farmers were growing diverse crop, all crop's yield were converted to paddy equivalent yield by multiplying a factor considering the Indian market price of that crop to that of paddy.

2.1 *Delineation of Watershed and Landuse/Landcover, contour and slope map*

Differential GPS was used to delineate the ridgeline as well as field boundary of each plot within the watershed (Fig. 1). IRS-P6 (LISS-IV) and QuickBird multispectral image was also used for delineating land use/ land cover of the study area (Fig. 2). The DGPS file was imported in Arc-GIS and edited to get a combined map for each field boundary. Based on the elevation for each sampling points and on the hillocks, a contour and slope map was generated using spatial analyst tools of ArcGIS and a contour map of 2 m interval was generated. The slope varied from 1-3% in cultivable area to 3-20 % in hillocks and foothills regions. The entire area was divided into five categories i.e., > 0.8%, 0.8-3%, 3-6%, 6-12% and >12% slope and each category occupied 61.5, 26.1, 5, 6.7, and 0.7% of total area.

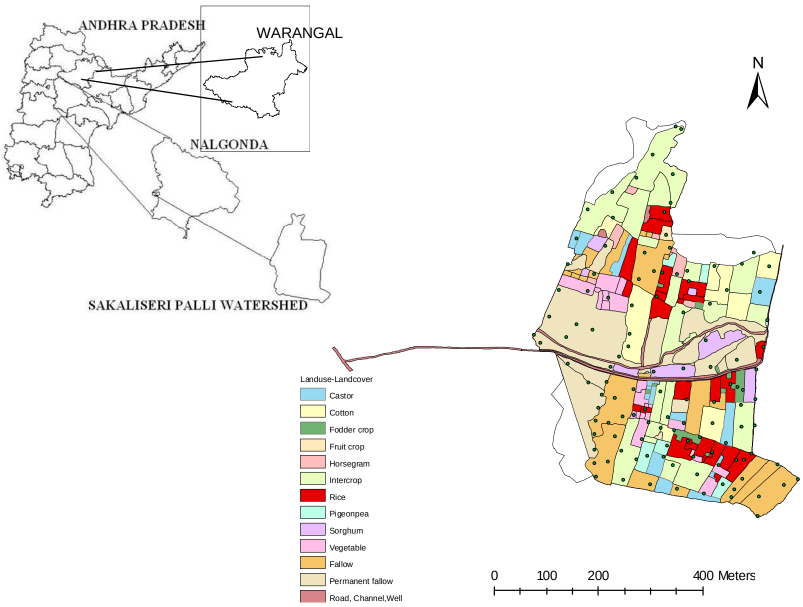

Figure 1. Land use land cover in Sakaliseripalli watershed

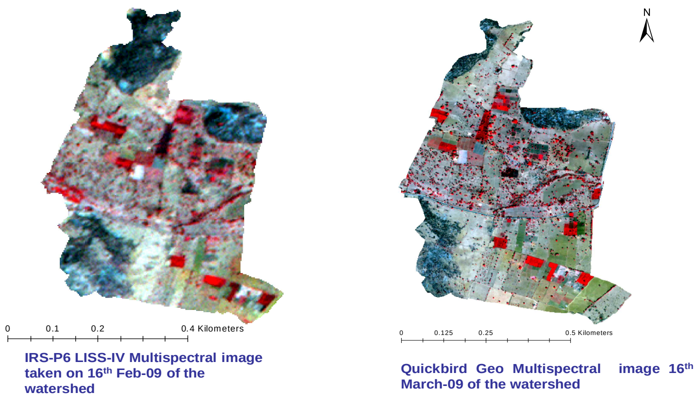

Figure 2. Extraction of study area of the watershed from standard FCC

3 SOIL QUALITY INDEX CALCULATIONS

In present study, to determine the soil quality index (SQI), four main steps were followed: (i) to define the goal(s); (ii) to select a minimum data set (MDS) of indicators that best represent soil function; (iii) to score the MDS indicators based on their performance of soil function; and (iv) to integrate the indicator score into an index of soil quality. This soil management assessment frame work was developed by Andrew et al. (2004).

Standardized principal component analysis (PCA) was performed using SPSS software on each of these soil parameters. Soil samples were identified for Alfisols, Inceptisols and Vertitic Inceptisols and Vertisols soils and three PCA were run for three soil orders, that is i) Alfisols, ii) Inceptisols and iii) Vertic Inceptisols and Vertisols. A separate PCA was carried out for the soil samples of the watershed. The PCA and followed by Pearson's correlation identified soil parameters for each of the soil order as mentioned in the Table 1.

Table 1. Minimum data set or key indicators came out through PCA followed by person's correlation and through expert opinion for each soil order

Soil order	Soil parameters
Alfisols	Soil moisture at 15 bar tension, Available N, exchangeable sodium percentage (ESP), C-mineralization, available P, DTPA extractable Zn, bulk density
Inceptisoils	Soil moisture at 1/3 bar tension, pH, Mineralizable N, available P, C-mineralization, available N, bulk density
Vertisols and Vertic Inceptisols	Soil moisture at 15 bar tension, cation exchange capacity (CEC), Organic C, ESP, mean weight diameter of soil aggregates, Mineralizable N, C-mineralization,
Key indicators identified based on four soil function (nutrient cycling, water availability, resilience characteristics and salinity-sodicity	
All soils	Available N, P, K, DTPA extractable Zn, CEC, organic C, Microbial biomass carbon, C-mineralization, total N, available water capacity, bulk density, percent clay, pH and ESP

Principal component analysis identified CEC, ESP, DTPA-extractable Zn, available P, available water, and dehydrogenase activity as the most important indicators for evaluating soil quality in the watershed. Another conceptual approach to compute soil quality index was based on expert opinion. Here, the minimum data set of indicators were identified that best represent defined soil function. Here four soil functions, nutrient cycling, water availability, resistance to degradation and resilience, and salinity or/and sodicity were considered for overall soil quality index. All the soil functions were weighted according to the relative importance of each function in fulfilling the goal of maintaining soil quality in India, as suggested by experts (an advisory team of scientists from soil physics, chemistry, microbiology and soil fertility disciplines). The choice of soil functions to index was also driven by participating farmers during project work. Sustaining crop productivity is the major goal of long-term agricultural strategies, particularly in a developing country like India. As soil erosion is the major soil degradation process and erosion control has also been considered as vital to the sustainability in agro-ecosystem in the present study, potential soil loss estimated using universal soil loss equation (USLE) along with crop yield were defined as the quantifiable management goals. After determining the MDS indicators, each of the MDS variables was scored between 0 to 1 on the basis of the performance of soil function following a linear scoring technique. A kriged map of SQI for the watershed as well as in districts level was drawn in ArcGIS.

4 SOIL QUALITY INDEX INTERPRETAITON

Kriged maps of each MDS variable were prepared by using their respective scores that were combined in the raster calculator in ArcGIS to get the SQI mapfor the watershed (Fig. 3). The SQI value for each sampling site was extracted from the SQI map and compared with the calculated values. These extracted values were well correlated ($r^2 = 0.671$; $P < 0.001$) with calculated values. The average value of SQI was 2.646 where the maximum and minimum value of SQI was 3.586 and 1.577; recorded in a field under brinjal cultivation and in a fallow plots, respectively. The relative SQI calculated by dividing SQI with 6 (sum of the maximum score value of six indicators) varied between 0.6 to 0.26. Even the best soil in the watershed could account for 60% of the highest value of SQI, which could be achieved through best management practices in vogue in the region. Potential soil loss was estimated at 85 t/ha/yr in hillock regions whereas the average value in cultivable fields is 3.69t/ha/yr (Fig. 3). Among the different landuse systems, highest (8.83t/ha/yr) as well as lowest (0.36 t/ha/yr) soil loss value was calculated in fallow and fodder grassland, respectively.

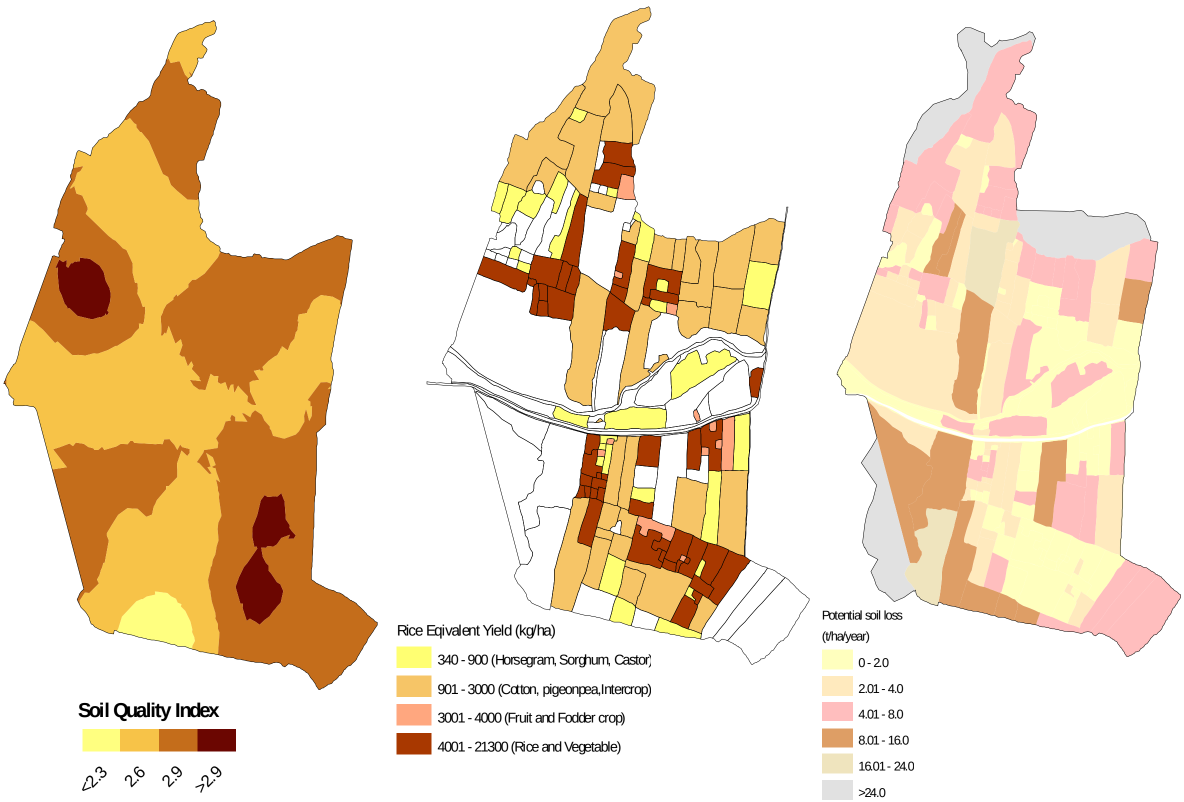

Figure 3. Thematic map for soil quality index, productivity and potential soil loss of the watershed

The soil quality index for Nalgonda and Warangal districts were calculated by using two procedures; 1) using principal component analysis for each soil order (PCASQI) and 2) using four soil functions (SQI). Also a regression equation was determined to know the relationship between two procedures. The higher r^2 (0.572; $p<0.001$) value indicated that both the procedure had good relationship among each other.

Out of four soil functions, on an average nutrient cycling contributed 37.1% to SQI followed by salinity contributed 25.2%, water availability contributed 25.1% and lowest contribution was from soil resilience which was 12.6% towards SQI. Considering the contribution from different soil quality indicators, the highest contribution came from the indicator organic carbon (15%), followed by ESP (14%), pH (12%), bulk density (9%), available water capacity (8.9%), percent clay (7%), exchangeable K (6%), available N (5.7%), C mineralization (3.4%), microbial biomass carbon (3%), total N (2.8%) and lowest from CEC (2.4%).

The percent contribution of each minimum data set or key indicators towards soil quality index (PCASQI) for Alfisols soil, was highest from moisture retention at 15 bar (27.8%), followed by ESP(25.4%), available N (14%), available P (10%), bulk density (8.03%), C mineralization (8.01%), and lowest from available Zn (6.8%). The order of percent contribution of each key indicator towards soil quality index for Inceptisols was, Moisture retention at 0.3 bar (32%) > pH (23.8%0> bulk density (15.3%0> available P (12.1%)> mineralizable N (6.5%) > C-mineralization (5.9%)> available N (4.5%).

The order based on percent contribution of each key indicator towards soil quality index for Vertisols and Vertic Inceptisols was, available P (25.5%)> organic C (23.6%)> moisture retention at 15 bar (18.1%)> CEC (16.9%)> C –mineralization (8.7%)> mean weight diameter of aggregates (4.3%).

A soil quality index (SQI) map for Nalgonda and Warangal districts were prepared using ARC-GIS software using kriging interpolation techniques (Fig. 4). Overall Warangal soils were better than Nalgonda soils.

The average SQI value was 0.488 and maximum value was 0.744 under paddy in a Vertic Inceptisols soils whereas, minimum value of 0.347 was also received in a paddy field under Alfisols soil. Three sites which had SQI more than 0.7, one was under Paddy system and another two were under fallow.

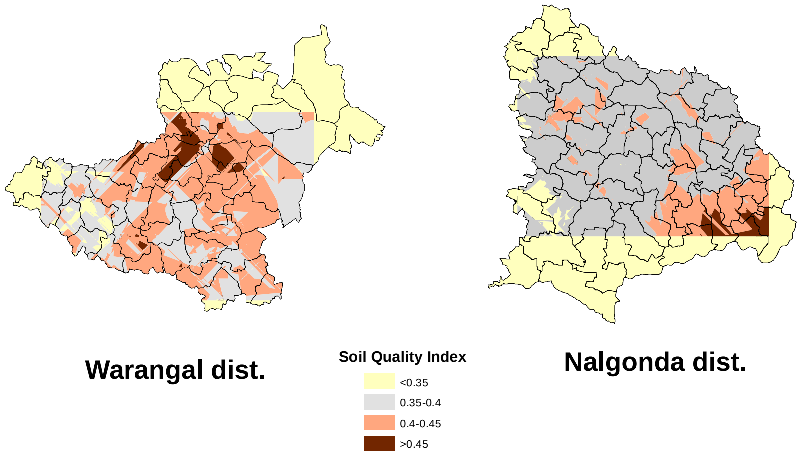

Figure 4. Soil quality index for Warangal and Nalgonda districts

The forty sites had SQI less than 0.4, out of those, 29 sites were under Alfisols and 10 sites under Inceptisols and one site was under Vertic intergrate. Among the different land use system, SQI was highest under paddy followed by fallow, maize, cotton, redgram, intercrop and was lowest under castor system. Among the soil orders, highest SQI was observed under Vertisols and vertic intergrade order (0.546) followed by Inceptisols (0.486) and Alfisols (0.473). Irrigated system had better soil quality than rainfed system.

5 CONCLUSION

We investigated the spatial distribution of soil parameters in a small watershed as well as districts level and produced a SQI and maps of relevant properties with the management goals of increasing crop yields and reducing soil losses. The derive SQIs has the potential to integrate soil biological, chemical, and physical data for ecological management of soils where such integration has often been lacking. This indexing approach can be useful as a tool to monitor the impact of management practices on soil functions that best meet defined management goals. Soil quality indexing may have broader applications for soil reclamation than for agricultural production alone. Geographic information systems, with their geostatistical tools, have the potential to evaluate spatial variability of soil and its quality and to help in designing site-specific resource management strategies. Our case study emphasized that soil quality can be assessed by geostatistical approaches which not only account for spatial variation across a landscape, but are also useful for determining optimal sampling strategies. However, geostatistical approaches require field data with high sampling density for completeness and accuracy.

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