The second issue concerns the 1200-year long period dormancy of gold mining activity after 6th century AD[5]. Answers to these issues, perhaps, lay in the episodes of other ancient gold mining activities in the Deccan, which needs to be unraveled.

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Analysis and mapping of soil quality in Khandaleru catchment area using remote sensing and GIS

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The problem of soil quality in and around reservoirs is attracting attention for the last couple of years due to the unscientific and unplanned irrigation practices that are bringing a myriad problems. Modern agricultural practices such as pumping of groundwater for irrigation and indiscriminate use of fertilizers containing toxic substances contribute to environmental degradation. Such anthropogenic activities invariably result in the depletion of water bodies, deterioration of soil quality, contamination of drinking water and various health hazards. Hence there is need to study in a comprehensive manner about the soil quality issues in the catchment areas. The present study is an attempt to analyse the physico-chemical parameters and generate the soil quality index (SQI) in and around Khandaleru catchment, Nellore District, Andhra Pradesh. The soil samples collected at the predetermined locations were analysed for physico-chemical parameters for the generation of attribute database. Based on the results of the analysis, spatial distribution maps of selected soil quality parameters, namely bulk density, moisture content, organic matter, C%, pH, electrical conductivity, Ca, Mg, SO_4, nitrate, phosphorus, potassium and texture were prepared using curve-fitting method in GIS software. The physico-chemical analysis properties and computation of SQI are helpful in the grouping of soil samples into excellent, good, poor, very poor and unfit. The spatial distribution of SQI generated in the current study will be of use for planners in the management and monitoring of land resources.

Keywords: Physico-chemical parameters, remote sensing and GIS, soil quality index, spatial distribution.

SOIL is a living system that represents a finite resource vital to life on earth. It forms a thin skin of unconsolidated minerals and organic matter on the earth's surface. It develops slowly from various parent materials and is modified by time, climate, macro- and microorganisms, vegetation and topography. Soils are complex mixtures of minerals, organic compounds and living organisms that interact continuously in response to natural and imposed biological, chemical and physical forces. People are dependent on the soil, and conversely, good soils are dependent on people and the use they make of the land. Soils are the natural bodies in which plants grow. The soils

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provide the starting point for successful agriculture. Rapid increase in human population has increased the stress on natural resources, including the soil. Soil degradation impacts agricultural production and adversely affects other interrelated natural resources[1–5].

Soil pollution is often thought of as resulting from chemical contamination, such as use of excessive amounts of pesticides and fertilizers that can result in surface water and/or groundwater contamination. However, there are other forms of soil pollution or degradation, including erosion, compaction and salinity. Soils have often been neglected when they are used for on-site land disposal of waste chemicals and unwanted materials. Most soils are capable, to some degree, of adsorbing and detoxifying many pollutants to harmless levels through chemical and biochemical processes. Healthy soils give us cleaner air and water, bountiful crops and forests, product rangeland, diverse wildlife, and beautiful landscapes. The soil does all this by performing five essential functions of regulating water, sustaining animal and plant life, filtering potential pollutants, cycling nutrients and supporting structures[6–10].

The study area is situated in Nellore District of Andhra Pradesh and located between 13°30′–15°06′N lat. and 70°05′–80°15′E long. The Khandaleru reservoir catchment area is about 329 km^2. Total ayacut under Khandaleru reservoir command area is 3 lakh acres, out of which 2.52 lakh acres is covered by the Nellore District. The total length of the earth dam is 10.752 km. The formation of the earth dam has been completed and is being impounded since December 1995. Up-stream revetment work was completed above +62.500 level up to +86.000 level throughout the length of the reservoir. The maximum storage so far made is 15.60 TMC, with a level of +69.00 m. It is proposed to impound 30 TMC during the next flood season, for which foundation treatment works have been taken up in vulnerable reaches, according to the recommendations of the expert committee. The gross, live and dead storage capacities of Khandaleru reservoir are 68.000, 63.327 and 4.730 TMC respectively[11].

The principal rivers of the district are Pennar and Swarnamukhi. Other streams, occasional and potential in character, are Khandeleru and Boggeru. The climate is generally dry and salubrious. The district lies in an area of precarious and uncertain rainfall. The rainfall is received from northeast monsoon only and the average rainfall is considered as 1041 mm.

Minerals generally found in the study area are mica, baryte, limeshell, clay, quartz, copper, feldspar, gypsum, iron ore and limestone. Mica is the major mineral deposit of Nellore District, which is one of the important mica-producing areas of the country. The soils are predominantly red loamy with sand belt running along the sea coast.

The objectives of the study were as follows. (i) To prepare thematic maps of the study area, which form the spatial database using remote sensing and GIS techniques. (ii) To create attribute digital database consisting of selected soil quality parameters derived from the analysis of soil samples collected from predetermined locations in the study area and computation of soil quality index (SQI). (iii) To develop spatial distribution maps showing variations in SQI by integrating the spatial digital data and attribute data in the process of building its topology on ARCGIS platform.

Data products required for the generation of the database include 57N/11 toposheet obtained from Survey of India (SOI) on 1 : 50,000 scale and fused IRS-ID PAN + LISS-III satellite imagery. The study area is delineated from the imagery based on the latitude and longitude values and a final hard-copy output was prepared, which was interpreted visually for the generation of thematic maps, namely base map, drainage pattern and land use/land cover. The methodology adopted for creation of database is given in Figure 1.

Thematic maps like base map and drainage network were prepared from the SOI toposheets and updated using satellite imagery on 1 : 50,000 scale to obtain the baseline data. Land-use/land-cover (LU/LC) map of the study area was prepared using visual interpretation technique from the fused satellite imagery (Figure 2) and SOI toposheets along with ground truth analysis. These thematic maps (Raster data) were converted to vector format by scanning using an A0-Flatbed Deskjet scanner and digitized in AUTOCAD 2000. The map was further edited in ARC/INFO and a final hardcopy output prepared using ARC/VIEW v3.1 GIS software.

The major land-use pattern of the study area is the agricultural land comprising kharif irrigated and kharif unirrigated lands, which occupy 86.51 and 68.25 km^2 respectively. The next major class is the scrub forest occupying 49.82 km^2 followed by land with scrub (36.51 km^2). The total residential or built-up area in the present study area is about 1.807 km^2. Barren rocky/stony waste/sheet rock area occupies 6.29 km^2, which are rock exposures of granites and gneiss devoid of soil cover and vegetation. These rocky areas are generally used for mining to extract construction material. Water bodies comprising lakes, tanks, ponds and rivers occupy an area of 33.08 km^2. The major river present in the study area is the Khandaleru. Figure 3 shows the distribution of land use/land cover.

Fieldwork was conducted and soil samples collected during March, June, September and December based on four different seasonal variations and from predetermined locations based on the LU/LC map in the study area. The soil samples were then analysed for various physico-chemical parameters, adopting standard protocols[12]. Based on this analysis, percentage variation of soil parameters in a year was generated.

The spatial and attribute databases thus generated were integrated for the preparation of spatial distribution maps

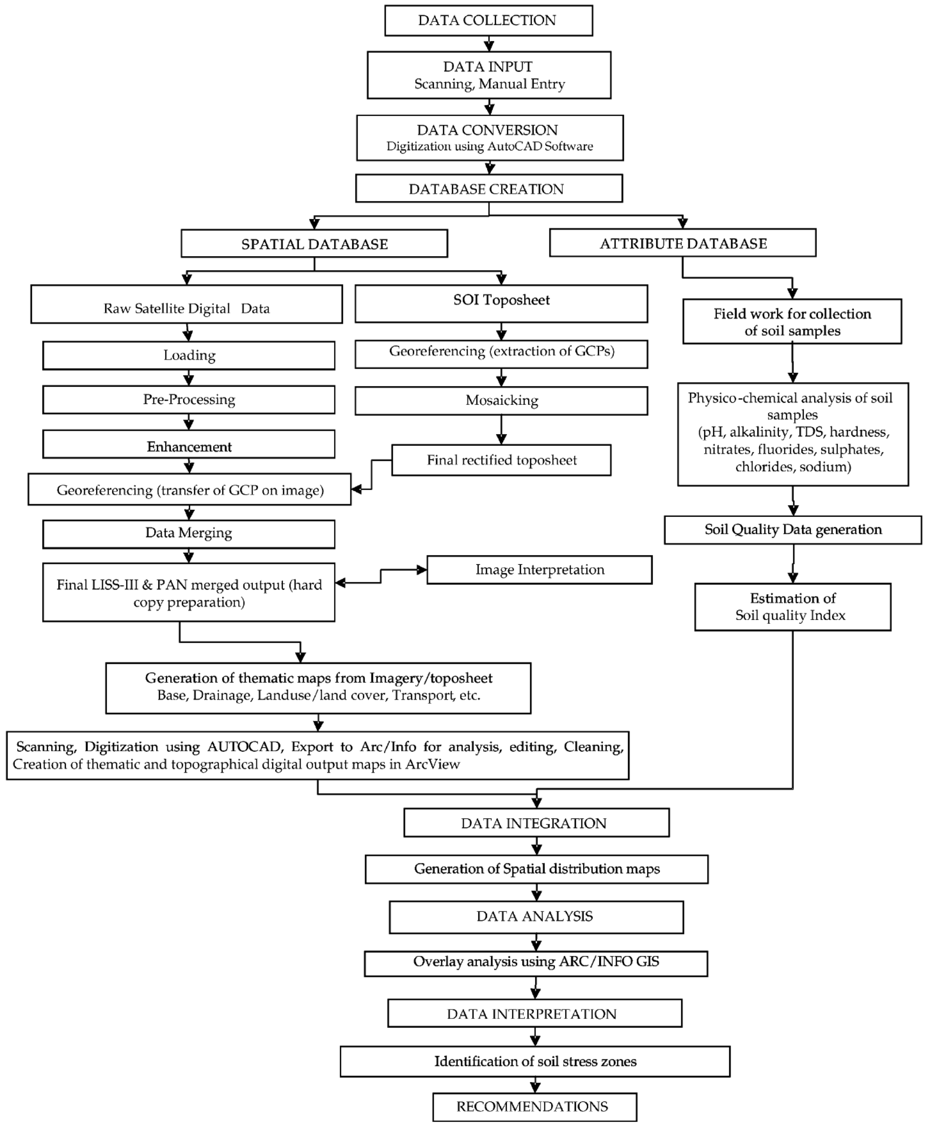

Figure 1. Flow chart showing the methodology adopted for the present study.

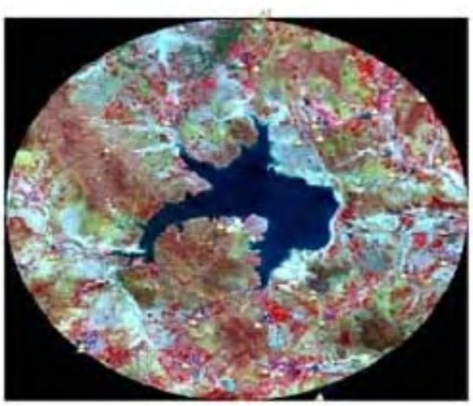

Figure 2. IRS-1D PAN + LISS III fused satellite imagery.

of selected soil quality parameters like pH, electrical conductivity (EC), Ca, C, Mg, SO_4, nitrate, phosphorus, potassium, bulk density, moisture content, organic matter (OM) and SQI. The soil quality data (attribute) were linked to the sampling location (spatial) in ARCGIS and maps showing spatial distribution were prepared to easily identify the variation in concentrations of the above parameters in the groundwater at various locations of the study area using the curve-fitting technique of the ARCGIS software.

Though there are a number of spatial modelling techniques available with respect to application in GIS, spatial interpolation technique through inverse distance weighted (IDW) approach has been used in the present study to delineate the locational distribution of soil pollutants or constituents. This method uses a defined or selected set

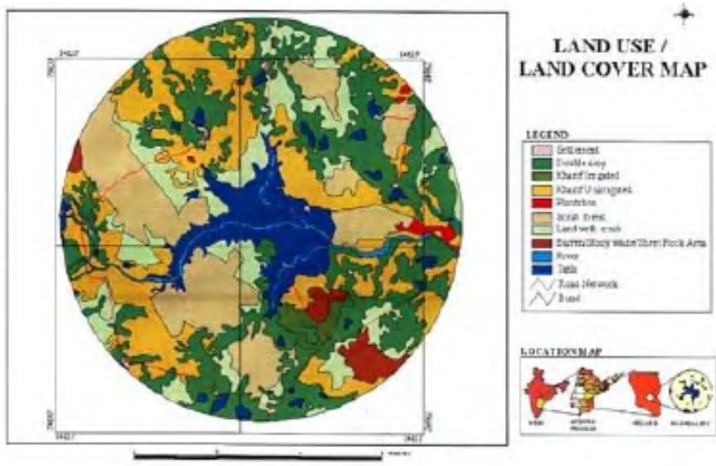

Figure 3. Land use/land cover map of the study area.

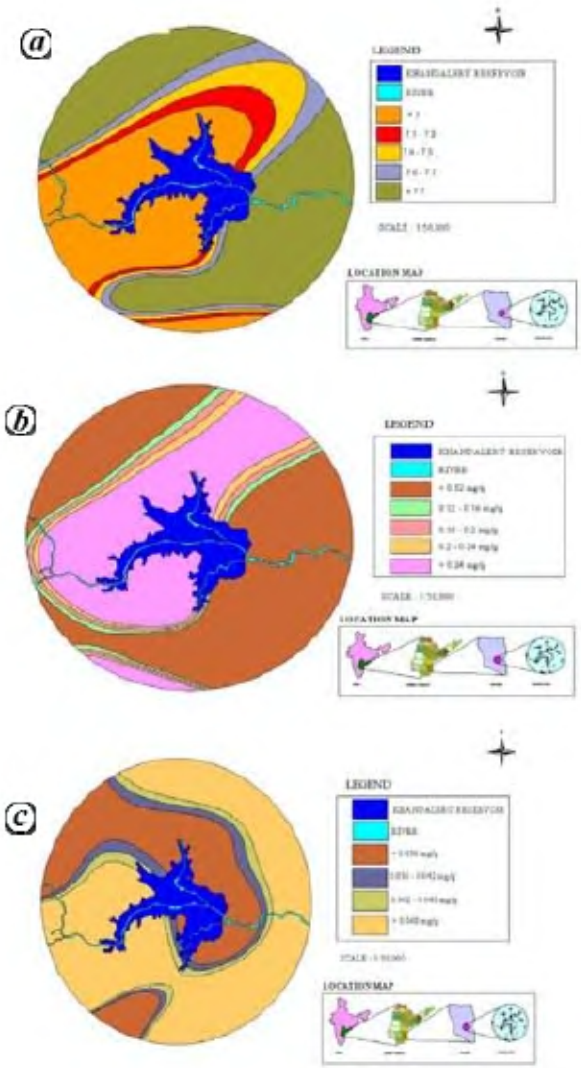

Figure 4. Spatial distribution map of (***a***) pH, (***b***) sulphates, and (***c***) magnesium in the soil.

of sample points to estimate the output grid cell value. It determines the cell values using a linearly weighted combination of a set of sample points and controls the significance of known points upon the interpolated values based upon their distance from the output point, thereby generating a surface grid as well as thematic isolines. Important parameters indicating soil quality and their distribution patterns were studied using cartographic techniques. The generated figures are self-explanatory and obviously convey the quality of each parameter for all the samples. Thus, GIS enables us to look into the cause and effect relationship with visual presentation.

SQI is a useful and efficient method for assessing the quality of the soil. It is a useful tool for communicating the information on overall quality of the soil. Five soil attributes, namely acidity (pH), OM, phosphorus, potassium, and EC have been combined to construct an index to represent the soil quality.

The SQI was constructed using the method given by Abassi[13].

$$SQI = (DpH + DOM + DP + DK + DEC)/5,$$

where DpH = 1, if pH > 6.5 and 0 otherwise; DOM = 1, if OM > 2 and 0 otherwise; DP = 1, if P > 20 and 0 otherwise; DK = 1, if K > 80 and 0 otherwise and DEC = 1, if EC < 2 and 0 otherwise, D = constant.

The SQI was computed for all sites in the study area. SQI is bounded between 0 to 1, and higher the SQI, better is the quality of the soil. Based on the SQI values, the soil quality scale was rated as very good (>0.5), good (0.6–0.7), average (0.5–0.6) and poor (0.4–0.5).

In the present study soil samples were taken four times in a year at 24 well-distributed locations in the study area, 12 samples on the upstream side and 12 samples on downstream side of the reservoir. The samples have been analysed for different parameters like bulk density, tex-

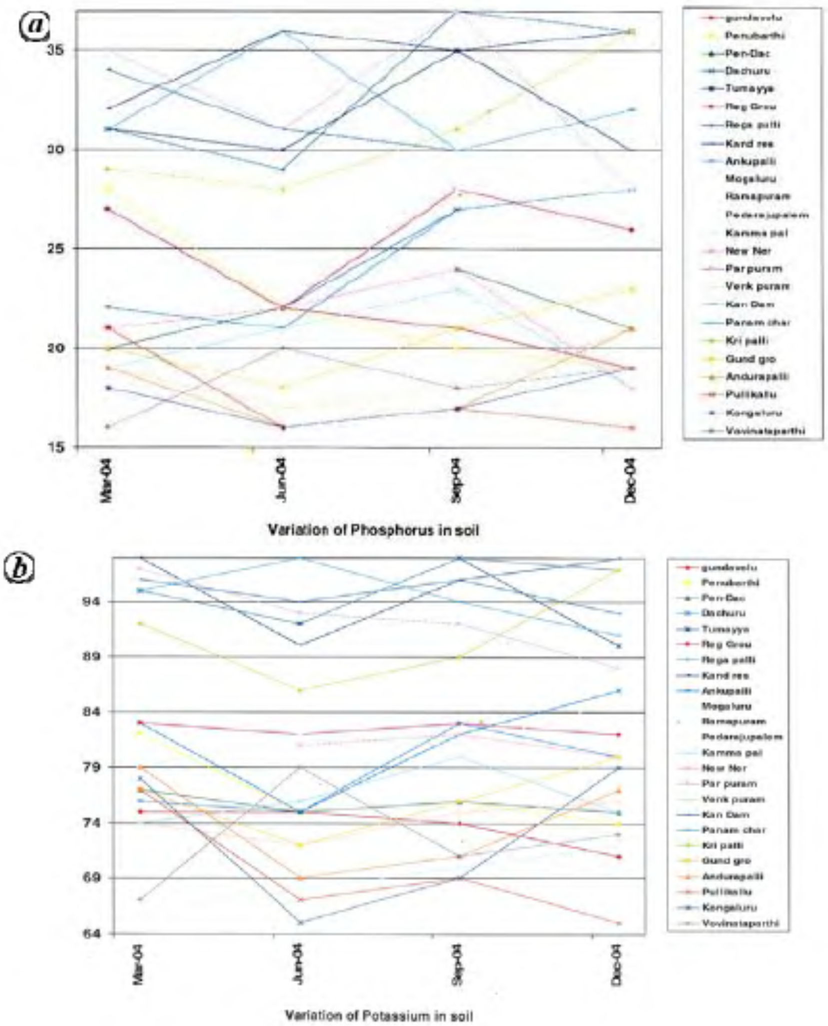

Figure 5. Variation of (***a***) phosphorus and (***b***) potassium in the soil.

ture, moisture content, OM, pH, EC, sulphur, magnesium, calcium, carbon, potassium and phosphorus.

Physico-chemical analysis of 24 samples upstream and downstream of Khandaleru reservoir study area reveals minimum bulk density of 0.923 and maximum of 1.092 at Tumayya. Maximum variation of 15.5% in a year occurs at Tumayya and minimum variation of 1.6% in a year occurs at Thanamcherala. Bulk density values of all the samples were well within the permissible limits.

Minimum value of 0.248 for OM was observed in the Mogalluru sample and maximum value of 1.298 was found at Khandaleru reservoir. OM values observed in all the samples of the study area were lower than the desired values. The variation of OM in a year was higher on downstream side compared to upstream side of the reservoir area. Maximum variation of 11.25% occurred at Ankupalli village and minimum variation of 2.1% at Tumayya village.

EC values of the soil surrounding the reservoir were 0.271 at Regatappalli and 0.08 at Ankupalli village. EC of all the samples in the study area was within the permissible limits. The maximum variation in a year (32.775%) occured at Ankupalli village and minimum variation (3.01%) at Tanamcharla village. The variation of EC was higher on the downstream side, compared to upstream side of the reservoir[14,15].

Minimum pH (6.7) was observed in Gundavolu and maximum pH (7.86) was observed in Tymayya village. pH values for all the samples in the study area were within the permissible limits. The maximum variation of pH in a year occurred at Regatapalli and minimum variation at Khandaleru reservoir (Figure 4 *a*). Values for calcium, sulphate (Figure 4 *b*), magnesium (Figure 4 *c*) and nitrates were well within the permissible limits.

Analysis of phosphorus revealed a minimum value of 15% at Mogaluru, Pedarajupalem and Venkatapuram, and

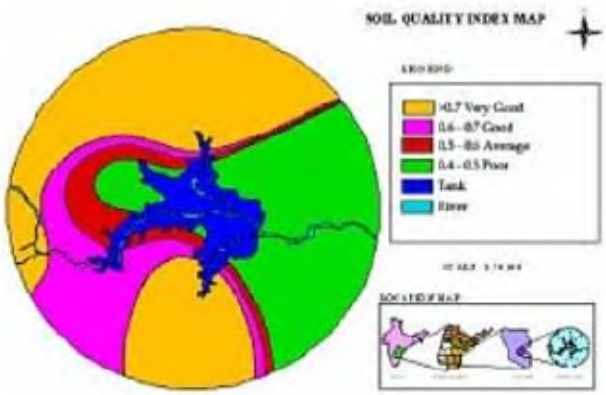

Figure 6. Spatial distribution map of SQI in the soil.

maximum of 37 at Parvathipuram village. In 41.6% of the total samples collected, phosphorus with values greater than the permissible limit was observed. The variation of phosphorus in a year was high compared to the other parameters. Maximum variation of 29.6% was observed at Ramapuram and minimum variation of 16.65% at Tumayya village[16]. Variation of phosphorus downstream of the reservoir was between 25 and 30%, while upstream it was between 9 and 11% (Figure 5 *a*).

A minimum value of 62 was observed for potassium in the Pedarajupalem sample and maximum value of 98 was found in Khandaleru reservoir and Tanamcherla village samples. The samples collected from 10 locations, i.e. 41.66% exhibited potassium with values greater than the permissible limit[17,18]. The variation of potassium in a year was between 9 and 16%. Maximum variation of 16.2% was observed at Pedarajupalem village and minimum of 8.1% at Khandaleru reservoir. Variation of potassium downstream of the reservoir was 15–17%, while upstream it was 9–11% (Figure 5 *b*). Based on the results of the analysis and soil quality rating index on the downstream side of reservoir area, 25% samples were good, 16.6% average and 58.3% were poor. On the upstream side of the reservoir area, 58.3% of samples were good, 33.3% average and 8.33% were poor (Figure 6).

Based on all the above parameters, SQI was computed to determine the soil quality and categorized into good, average and poor[13] soil. Ten samples (41.66%) are good with SQI ranging from 0.8 to 1, six samples, i.e. 25% were rated as average (SQI 0.5–0.7) and eight samples, i.e. 33.34% were considered poor, with SQI ranging between 0 and 0.4. On downstream side of reservoir area, 25% samples were good, 16.6% average and 58.3% poor, while on the upstream side of the reservoir area, 58.3% of the samples were good, 33.3% average and 8.33% poor.

Soil quality is largely a function of chemical proportions such as OM, calcium, magnesium, sulphur, pH, nitrate, potassium and phosphorus. Assessment of these parameters is essential in determining the effect on soil quality. The study reveals that OM, potassium and phosphorus are within permissible limits in the Khandaleru reservoir. Fifty-eight per cent of the samples collected around the reservoir were of poor/average quality, while the remaining 42% were of good quality. The areas of poor soil quality were observed to be located downstream of reservoir, and good water quality was observed upstream of the reservoir.

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