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Remote Sensing Applications
P. S. Roy
R. S. Dwivedi
D. Vijayan
इसरो isro
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National Remote Sensing Centre

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Soils and Land Degradation

4.1. Introduction

The soil is a life supporting system upon which human beings have been dependent from the dawn of the civilization. Therefore, comprehensive information on soil resources, its potential / limitations / capabilities, is required for a variety of purposes such as command area development, soil conservation in catchment areas, sustainable agriculture, watershed management, reclamation of degraded lands etc. In this context, characterization and mapping of different types of soils, developing rational / scientific criteria for land evaluation and interpretation of soils for multifarious land uses attains greater importance.

Remote sensing technology has been successfully used in studying the various aspects of soils in spatial and temporal domain. The data obtainable from the sensors placed in a satellite or aircraft or ground level could be interpreted as a function of soil properties. Therefore, spectral reflectance of soils plays an important role in extracting information on different types of soils and land degradation. The techniques make use of data obtained from different regions of electromagnetic spectrum viz., visible, infrared, thermal and microwave regions.

A good number of studies carried over nearly three decades testifies the role of remote sensing in soil related studies. The interpretation techniques have also undergone change over a period of time on par with satellite spatial and spectral resolutions. In this chapter, application of geospatial technology (Remote Sensing, GIS, GPS) in the study of spectral reflectance of soils, land degradation mapping, monitoring of degraded lands, soil moisture along with important issues and prospects are discussed.

4.2. Spectral Reflectance of Soils

Understanding the spectral reflectance properties of soils is fundamental to many applications of remote sensing in soils. The soil reflectance data can be acquired in the laboratory or in the field and from air / space. In the laboratory the soil reflectance measurements are made under controlled conditions, which may enable to understand the relationship between the physical and chemical properties of soil and soil reflectance. In the field, reflectance measurements are made with the help of portable field spectrometers / radiometers. Field soil spectroscopy will help in rapid point to point measurement of soil properties. However, the measurements are affected by variations in viewing angle or illumination condition and roughness factors. In the case of soil reflectance from air / space, the soil reflectance values can be obtained over a large area and reflectance can be studied in spatial domain. But factors like low signal to noise ratio and atmospheric attenuations have critical effect on these measurements.

Nevertheless, information about soils from reflectance spectra in the visible (0.4 µm to 0.7 µm), near infrared (NIR – 0.7 to 1.1 µm) and short wave infrared (SWIR- 1.1 to 2.5 µm) regions of electromagnetic spectrum (EMS) represent most of the data the passive remote sensors can provide. Besides this thermal infrared regions (3 to 5 µm and 8 to 12 µm) do provide diagnostic information about soils. Spectrometers, radiometers and polarimeters provide quantitative measurement of reflected energy from soil and have found applications in studying the various aspects of soils as mentioned previously.

The shape and nature of a soil reflectance curve depends upon the physical and chemical properties of soils. The important physical properties are soil colour, soil texture, structure, soil moisture, surface conditions / roughness etc. The chemical properties of soils result in absorption of incident radiation and is seen on reflectance curve as troughs whose positions are attributed to specific chemical groups in various structural configurations. It includes soil mineralogy, organic matter, salinity, carbonates etc.

The most important soil properties that influence the reflectance are soil moisture content, texture, structure and iron oxide content (Hofer, 1978; Stoner and Baumgardner, 1981). These factors are interrelated and the spectral reflectance of soil is a cumulative property of combination of these factors (Baumgardner *et al.*, 1985 and Irons *et al.*, 1989).

Soil color, particularly the Munsell color value component, has been identified in many studies affecting the amount of energy reflected from soil surfaces (Post *et al.*, 1994). Post *et al.*, 1993 also evaluated using a Chroma Meter to measure soil colors and concluded that commercial colorimeters have great potential as tools to precisely measure soil colors. They also demonstrated how color changes from the dry to a wet condition. The greatest change for the Munsell color value component was also strongly correlated with soil albedo. The observed darkening of wet soil is due to the optical effects of a thin liquid layer on the soil surface. Soil color is mostly influenced by mineralogy, chemical composition, soil moisture, and organic matter content. It is an important parameter that allows the diagnosis of soil types and their properties, as well as the detection of changes affecting ecosystems like erosion, salinization and / alkalization. A detailed investigation by Escadafal (1993) revealed that for measuring soil colour, remote sensing sensors capable of sensing in blue (450-500 nm), green (500-550 nm) and red (650-700 nm) are very important.

Organic matter in soils has profound influence on soil spectral characteristics. The increase in organic matter has been found to result in a decrease in reflectance. The organic matter has effect on spectral reflectance of soils throughout the visible, NIR and SWIR region of EMS and many workers have studied organic matter extensively from a remote sensing point of view. The absorption features of reflectance spectra are related to functional groups in the organic matter (Elvidge, 1990; Chen and Inbar, 1994) and models were developed to predict the humus / organic carbon content in soils (Buamgardner *et al.*, 1985; Shepherd and Walsh, 2002). The absorption features representing organic matter were found at 1720 nm, 2180 nm and 2309 nm.

Particle size or soil texture (refers to relative proportions of sand, silt and clay in soil) is another soil property that influences the spectral reflectance of soils significantly (Buamgardner *et al.*, 1985). Finer the particle size, the soil becomes smooth and more incoming energy is reflected. An increase in particle size causes a decrease in reflectance. However, silt content of soil is considered as major controlling factor for spectral reflectance. The spectral reflectance decreases with decrease in silt content. However, it is commonly observed that sandy soil exhibits higher reflectance than that of clayey soil, which is due to abundance of macro pores and air-soil interface. Under field conditions the soil structure play a dominant role in altering the reflectance from soil (Buamgardner *et al.*, 1985).

It was reported that an increase in iron oxide content in soils can cause decrease in reflectance, in visible wavelengths (Obukov and Orlov, 1964; Vincent, 1973). Many of the absorption features in soil reflectance spectra are due to the presence of iron in one or other form (as Hematite) and provide significant evidence on soil weathering process. Soils dominant in ferrous and ferric ions exhibit high response in the red region of spectrum. The ferric ion response bands are approximately at 0.40, 0.70 and 0.87 µm and a sharp and narrow absorption band is evident at 0.9 µm. The ferrous ion on the other hand, has been found to respond at 0.43, 0.45, 0.51, 0.55 and 1.0 µm.

Clay minerals are layered crystalline aluminosilicate minerals and are characterized by hydroxyl bands at 1.4 µm and 2.2 µm. Most of the work done on soil spectral reflectance on clay mineralogy is mostly on pure minerals under laboratory conditions (Mulders, 1987; Kruse *et al.*, 1991). These studies shows that absence of appreciable amount of bound water in Kaolinite shows a weak band at 1.9 µm due to absence of appreciable amounts of bound water while montmorillonite shows very strong bands at 1.9 µm as well as at 1.4 µm. Quartz and feldspar show very high reflectance and the spectrum in the visible and near infrared is almost devoid of spectral features (such as absorption maxima denoted as bands) unless impurities occur. Carbonate response bands were noticed at 1.90, 2.00, 2.16, 2.35 and 2.55 µm. Soils with Gypsic minerals reflect highly because of the inherent reflectance properties of gypsum.

Soil crusting too has influence on soil reflectance. The work carried out by De Jong (1992) and Savin, (1996) shows an evidence that it is feasible to provide information with respect to the crusting status with reflectance spectroscopy. Significant spectral changes resulting from the structural crust formation were detected on the soil surface and these changes were attributed to both particle-size distribution and mineralogical composition (Ben-Dor *et al.*, 2003).

In the Indian context very limited studies has been carried out on spectral behavior of soils (Venkataratnam,1980; Dwivedi et al 1981; Sinha 1986; Kalra and Joshi , 1994; Rao et al 1995). Ravisankar and Rao (2004) studied the spectral response pattern of major soil types in Guntur district of AP. In this study, the MODIS reflectance data was correlated with soil properties using stepwise multiple linear regression (SMLR). Good correlations were obtained for pH (r^2 = 0.87), Organic Carbon (r^2 = 0.71), Cation Exchange Capacity (r^2 = 0.77) and Clay content (r^2 = 0.61).

The study of spectral reflectance of soils has ability to provide non-destructive rapid prediction of soil physical, chemical and biological properties under laboratory conditions, for sensing soil organic matter content in the field and for the discrimination of major soil types from satellite data and hyperspectral data. There has been little focus on development of soil spectral libraries for using in prediction and interpretation of soil properties. In

India, spectral libraries were developed using ASD FieldSpec@Pro radiometer (with spectral range of 350 nm - 2500 nm) for about 600 pedons and 2500 surface and subsurface soils covering all major soil orders in major physiographic units in the country (NBSS&LUP Report no.835) under 'Development of spectral libraries for major soils of India' project. Such hyperspectral libraries will be of immense use for characterization of soils.

4.3. Recent Developments in Soil Spectroscopy

In the recent developments, importance is being given to utilization of hyper-spectral domain for soil physical and chemical characterization. Development of soil reflectance libraries is being given utmost importance with parallel developments in hyperspectral profile matching algorithms. In this direction, an attempt has been made to calibrate soil properties to soil reflectance using Multivariate Adaptive Regression Splines (MARS). Spectral analysis techniques and screening tests were also being developed to address the soil / plant nutrient status and fertility constraints (Shepherd and Walsh, 2002). Since the mid-1980s, developments in instrument technology and chemometrics (the application of mathematical and statistical techniques to chemical data) have led to the increased use of spectroscopy in the laboratory and field and from space platforms (Clark, 1999).

Recent research studies demonstrated the ability of reflectance spectroscopy to provide nondestructive rapid prediction of soil physical, chemical, and biological properties in the laboratory (Ben-Dor et al, 1997 and Reeves *et al.*, 1999). Sudduth and Hummel (1993) could successfully apply reflectance spectroscopy for sensing of soil organic matter in the field. Despite of good potential, there are few examples of the application of reflectance spectroscopy for non-destructive assessment of soils (Janik *et al.*, 1998; Myer, 1998). Although geological spectral libraries exist that include soil mineral spectra (Clark, 1999), there are few examples of soil spectral libraries that include a wide diversity of soils with information on physical, chemical, and biological properties. Development of soil spectral libraries for application to risk-based approaches to soil evaluation explicitly accounting uncertainty in predictions and interpretation of soil properties is need of the hour.

Fundamental features in reflectance spectra occur at energy levels that allow molecules to rise to higher vibrational states. For example, the fundamental features related to various components of soil organic matter generally occur in the mid- to thermal-infrared range (2.5–25 µm), but their overtones (at one half, one third, one fourth etc. of the wavelength of the fundamental feature) occur in the near-infrared (0.7–1.0 µm) and short-wave infrared (1.0–2.5 µm) regions. Soil clay minerals have very distinct spectral signatures in the shortwave infrared region because of strong absorption of the overtones of sulphate, carbonate and hydroxyl combinations of fundamental features of H_2O and CO_2 (Hunt, 1982; Clark, 1999). The visible (0.4–0.7 µm) region has been widely used for color determinations in soil applications as well as in the identification of Fe oxides and hydroxides (Ben-Dor *et al.*, 1999).

4.4. Soil Mapping

Soil mapping comprises of identification, description and delineation of different kinds of soils based on physiography, climate and vegetation of the area, confirmation through field work and laboratory data and depicting on a standard base map. The different soils observed within an area are put into a limited number of groups. Each group of soils is typified by a pedon or their association. A pedon is morphologically described in the field and sampled for laboratory investigations for their characterization and classification. Such groups of soils may occur on the landscape in a repeated manner and are delineated on a map as "map unit". The delineated units on a map will be given a specific symbol, colour and name. Soil maps contain several mapping units along with a legend that give description of each soil unit. The soil maps are prepared on different scales varying from 1:1 million to 1:4,000 to meet the requirements of planning at various levels.

The scale of a soil map is of importance as it has direct correlation with the information content and field investigations that are carried out. Small scale soil maps of 1:1 million are needed for macro level planning at national level for several developmental programmes. Similarly, soil maps at 1:250,000 scale are needed for state / regional level planning by various agencies such as state level Land Use Boards, Department of Agriculture, Irrigation etc. Soil maps on 1:50,000 scale could be generated through standard soil survey consisting of comprehensive data collection on soils / land in such a manner that the data could be used for a variety of purposes. Soil maps at 1:8,000 or larger scales are required for micro level planning and most of these maps are oriented to a specific purpose such as for soil conservation, reclamation, soil fertility studies, trafficability, revenue and taxation, crop suitability etc.

4.4.1. Status

The Food and Agriculture Organisation published (FAO, 1970- 78) 1:5 Million scale soil maps of the World. In western countries, soil mapping at appropriate scales is completed or nearly done and the emphasis is towards specific, project oriented surveys and innovative application. Survey of literature reveals that many countries have same kind of general soil map at very small scale usually at or smaller than 1:250,000. Soil maps at scales 1:50,000 or 1:25,000 scale, appropriate for project planning, are not available with many countries. The soil maps for operational planning at scales larger than 1:25,000 are very scares. This shows that there is a requirement for medium and large scale soil maps in most of the countries including India. At larger scales, soil information can significantly contribute to micro level land use planning and solution to problems in soil.

In India, soil survey is carried out both by central and state level organizations. However, there is no regular system of recording and periodic updating of the areas covered by soil surveys by various central and state organizations / agencies. Soil surveys done by various agencies usually lack uniformity with respect to scale of base maps and published maps, kinds of survey and intensity of observations, units of mapping and soil correlation. According to report of the Task Force (1984) the total areas surveyed in the country up to 1983 under detailed soil surveys was 33.5 million hectares and reconnaissance soil surveys was 115.0 million hectares. NBSS&LUP had prepared soil map of the entire country at 1:250,000 scale using satellite imagery and published them at 1:500,000. According to DOS (1999), the status of soil mapping at 1:50,000 scale was 119.37 million hectares for the whole country. Information on larger than 1:50,000 scale may be available for very limited area and statistical figures are not available at country level.

4.4.2. Survey Methods

General soil survey methods comprises non-systematic, grid, continuous, physiographic and free surveys. In non-systematic survey, soil boundaries are determined from published maps such as geology and physiography. Broad field checks are made to determine typical soil properties. There is no estimate of internal variability. In Grid survey, a systematic sampling scheme is designed, taking into account the expected range of spatial auto-correlation. Sample points are located in the field and characterized. Standard statistical and geo-statistical methods are used to estimate spatial variability of soil properties. Continuous survey provides very accurate estimates of internal soil variability. Remote sensing methods come under this category.

In the case of physiographic survey, interpretation of landforms with the help of aerial photographs is carried out followed by field checking of map unit composition; sometimes only in sample areas, i.e. not all the delineations are actually visited. Sampling is biased towards ‘typical’ landscape positions. This method is used for scales: 1:50,000 to 1:200,000. The utility of soil maps at various scales and the remote sensing data suitable are appended as Table 4.1. Free survey starts with a detailed physiographic interpretation and all boundaries are verified and possibly modified by field investigation. In areas with poor correlation of geomorphology to soils, the field observations themselves are used to locate the boundaries. There should be enough observations to obtain a fairly good estimate of internal variability. Typical scales of free surveys range from 1:12,500 to 1:25,000. Initially the surveyor analyses the soil forming factors of a given location in a top sequence and locates observations to confirm his hypothesis. Initially, a few field observations in terms of soil profile will be made to

Table 4.1: Mapping scales, sensors and levels of soil mapping

Soil Survey Scale	Sensors	Soil Classification	Useful For
1:250,000	LANDSAT-MSS, IRS-LISS-I , WIFS	Subgroups/ Families and their association	Resource Inventory at Regional Level
1:50,000	IRS-LISS-II/III LANDSAT-TM SPOT	Soil Series and their association	District/ Sub-District Level
1:25,000	IRS-IC/ID (PAN+LISS-III MERGED DATA)	Soil Series and their association	Block / Taluk / Mandal Level
1:8000 or larger	IKONOS / LISS-4 / CARTOSAT	Types and Phases	Village Level

test this hypothesis and assess the variability. Depending on requirement, more observations will be recorded, if variability is not properly addressed.

4.4.3. Geo-Pedological Approach to Soil Mapping

The 'Geo-pedological Approach' to soil survey was developed by Zinck (1988) and is essentially a systematic application of geomorphic analysis to soil mapping. This approach can be used to cover large areas rapidly, especially if the relation between geomorphology and soils is close. It is based on two hypotheses. The first one is, boundaries drawn by landscape analysis separate most of the variation in the soils. This will be the case if the three soil-forming factors (parent material, relief, time) which can be analyzed by this approach are dominant (not organisms, climate), and also if the mapper has correctly interpreted the photo / imagery and sample areas. The interpreter must form a correct model based on the geomorphology (soil-landscape relations) and apply it correctly and consistently. If sample areas are representative, soil pattern can be reliably extrapolated to unvisited map units. In addition, the geo-pedological approach has advantages in legend construction and structuring. The geo-pedological approach is a hierarchical system applied in semi-detailed studies.

4.4.4. Remote Sensing and Soil Mapping

Before the advent of remote sensing techniques, the soil surveys were conventionally carried out at reconnaissance, detailed and detailed-reconnaissance level depending upon the requirements. In all these three methods soil mapping is done after field observations. Later, aerial photographs were used as remote sensing tool in soil mapping and because of some technical limitations they could not be operationalised in soil mapping. Application of satellite remote sensing data from satellites for soil studies began with the launch of Landsat-1 in 1972. Remote sensing techniques have reduced fieldwork to a considerable extent and soil boundaries are more precisely delineated than in conventional methods. While mapping the soils using remote sensing technique, the stereo data is highly useful in identification of different landforms, which have got close relationship with the soils associated with them. The stereo data from panchromatic (PAN) cameras aboard SPOT/ IRS-1C/ Cartosat-1 enabled the delineation of physiographic units and soil maps derived there from in a better way.

4.4.5. Visual Interpretation for Soil Mapping

The approach for soil mapping using visual techniques has been summarized in Figure 4.1. The Figure 4.2 gives the schematic approach for soil mapping using satellite data. The broad methodology for mapping soils has been explained hereunder.

Satellite Data

The satellite data with minimum crop cover / vegetation better aids in the identification of soil patterns from the remote sensing imagery. The data of summer months is in generally good for soils study. However, under certain terrain conditions the data of monsoon in association with summer season helps to better extract information on soil types. The scale of soil map determines the sensor that has to be employed in the project. For example, Landsat – MSS and IRS – LISS –I sensor data with a spatial resolution of 80 m and 72.5 m were more useful for soil mapping at 1:250,000 scale or smaller scales. Similarly, for mapping soils at 1:50,000 scale remotely sensed data from Landsat – TM and IRS-LISS II / III sensors will be of greater help.

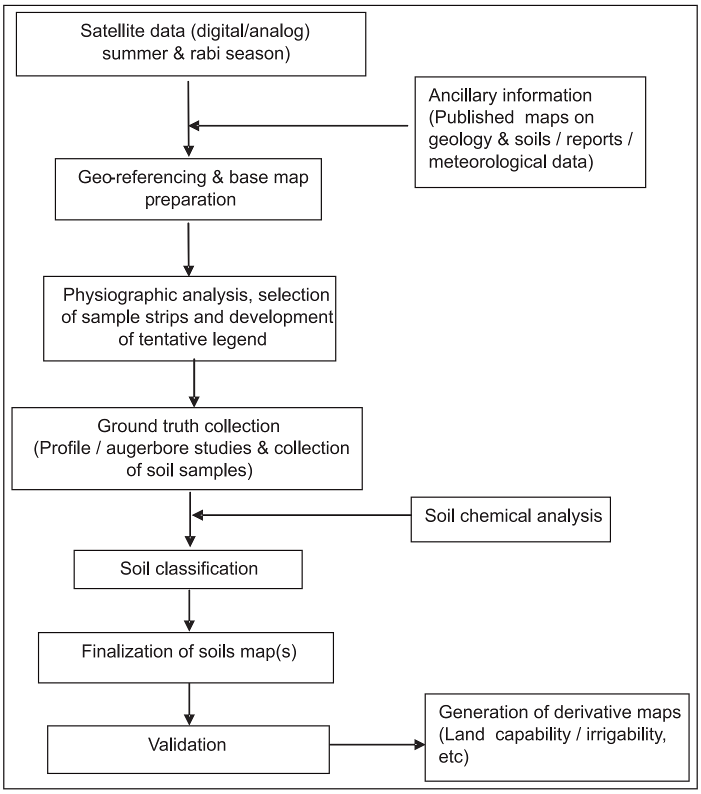


Figure 4.1: Flow chart for soil map preparation

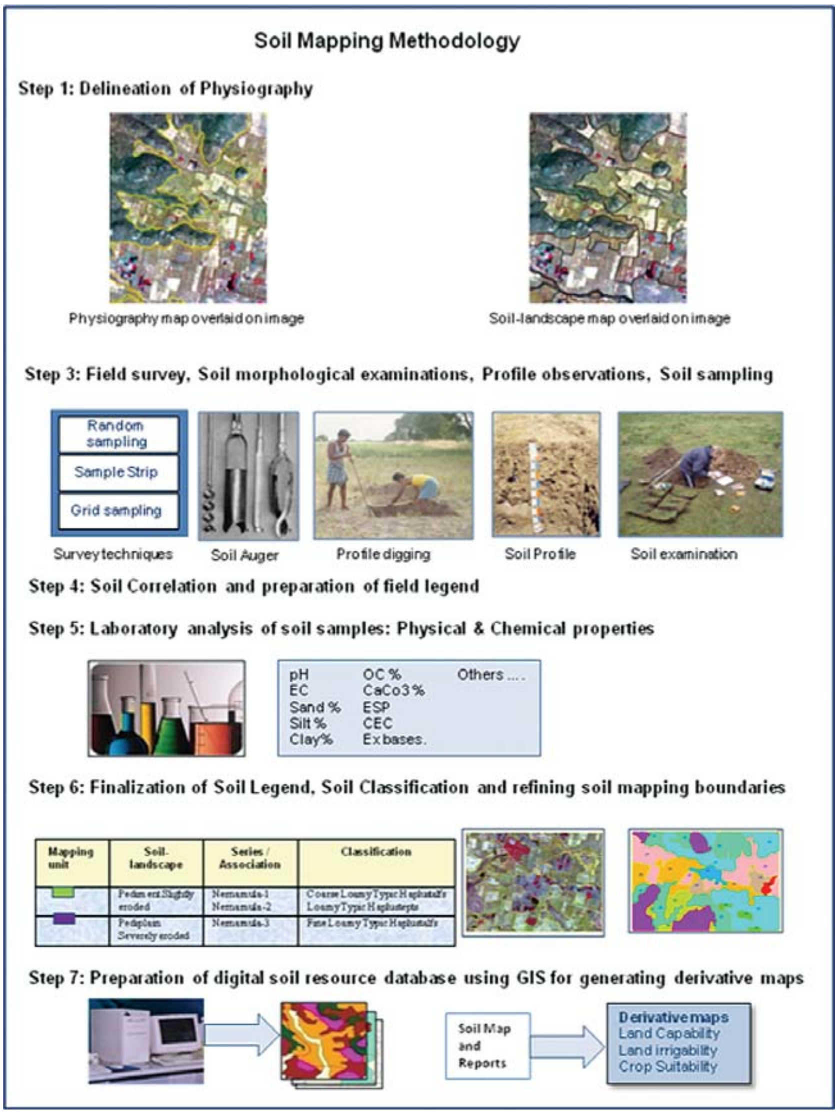


Figure 4.2: Schematic diagram of soil mapping methodology

Ancillary information

The ancillary data required for preparation of soil map consists of topographical maps, published soil maps, geological maps, reports, climatic data (rain fall, temperature etc). Topographical map sheets of the study area are required for preparation of base maps, ground truth collection, in the selection of sample stripes and geo-coding of satellite data.

Preliminary interpretation

The principle of 'geo-pedological approach' as discussed earlier is employed in preparing soil map. Initially the False Colour Composites (FCC) print of the study area will be interpreted for broad physiographic units by placing a translucent film over FCC prints under a light table or on computer screen. On the basis of available lithological information through ancillary data, the different physiographic units are attached with the geological information. The sub division of broad physiographic units will be carried out based on drainage network, erosion, land use etc., as manifested on the satellite data. A tentative legend will be developed for the preliminary interpreted map in terms of physiography, lithology and mapping units.

Selection of soil sample areas

On the basis of preliminary interpretation, sample areas covering all mapping units in the legend are selected in the form of sample strips of suitable size. The size of sample strip is usually about 2 x 5 km covering at least 2 or more mapping units. The number of sample strips may vary depending upon the variability in lithology, physiography, vegetation cover etc. Through sample strips, a minimum of 10 per cent of total study area is covered in a toposequence. This may be increased depending upon the heterogeneity in the terrain conditions. Besides, in each sample strip, random observations in the form of auger bores or mini pits are taken to account for variability in the soils within the mapping unit. The selected sample strips are transferred on to the base map for field sample collection.

Ground truth collection

Initially a rapid traverse of the entire study area is under taken to adjust the sample strips. Subsequently, in each sample strip, soil profiles, mini pits, auger bores etc., are studied along with morphological characteristics, existing land use / terrain parameters. The information recorded systematically by noting the place of observation, topographic conditions, existing land use / land cover, geology of the area, physiographic unit, natural vegetation occurring in the area and morphological characteristics of the soils. Random observations are also made in the study area to confirm the soils in different mapping units. The soil samples are collected from soil profile horizons with proper labeling to determine various soil properties later in the laboratory.

Soil sample analysis

The soil samples collected during the filed work are processed after air drying of the soils. They are pounded and grinded so that soil sample passes through 2 mm sieve. These soil samples are analysed for various physical and chemical properties like pH, EC, texture, organic carbon, exchangeable cations, CEC etc., that aid in the taxonomic classification of soils and also to identify any salinity or alkalinity like problems.

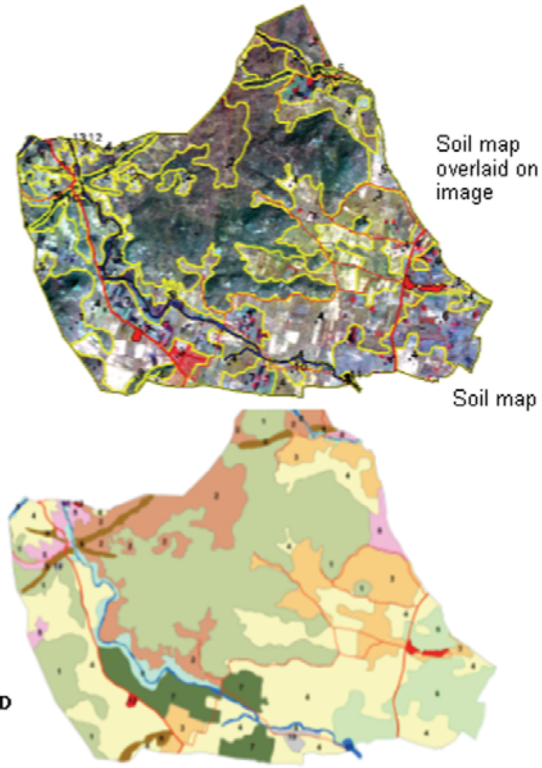
Classification of soils

The soils are classified, based on the morphological, physical and chemical properties collected in the filed work and laboratory analysis, following the Soil Taxonomy of USDA. The scale of mapping determines the level of classification of soils. For example, the soils are classified up to association of sub-group level at 1:250,000 scale or at soil series at 1:50,000 scale or up to phase level at 1:8,000 or 1:4,000 scale. For each soil mapping unit there will be association of soil taxonomic classes up to 1:12,500 scale as it is very difficult to establish a pure soil taxonomic class at small scale.

Finalisation of soil maps

The preliminarily interpreted maps with landscape units are finalized in light of ground truth collected and soil analytical data. The physiographic / landscape units are converted to soilscape units by incorporating the soil classification information into the mapping units. A final comprehensive legend showing the relationship physiography, lithology, relief, vegetation, land use along with description of soils and soil classification are developed and adopted for all soil mapping units in the study area. The final mapping units are transferred on to a suitable base map and final soil map is generated with appropriate legend.

The geo-pedological approach based on physiographic / landscape analysis work well upto 1:50,000 or 1:25,000 scale under most of the terrain situations. However, at larger than 1:25,000 scale, this may not be suitable because the micro relief or locale specific conditions or soil phases play dominant role. The conventional method of interpretation of satellite data under a light table by placing a translucent film on FCC print is almost replaced by on-screen drawing of soil polygon boundaries using PC based GIS software. This enables preparing soil digital data base for further processing of soil information. A soil map of Mohammadabad village prepared using the above approach has been appended as figure 4.3.



Map unit	Soil-landscape unit	Soil Series	Classification
1	Hill	Yenagandi	Loamy Skeletal Typic Ustorthents
2	Undulating plains	Channagiri	Loamy Skeletal Typic Haplustalfs
3	Slightly eroded plains	Puttapaka	Fine Loamy Typic Haplustalfs
4	Moderately eroded plains	Kottaguda	Coarse Loamy Typic Haplustepts
5	Severely eroded plains	Sarvel-1	Loamy skeletal Typic Haplustepts
6	Burried pediplain	Puttapaka	Fine Vertic Haplustepts
7	Burried pediplain	Pipalpahad	Fine loamy Typic Haplustepts
8	Valley	Sarvel-2	Fine loamy Fluventic Haplustepts
9	Dyke	Rajkonda	Loamy skeletal Lithic Ustorthents
10	Rock outcrop		
11	Water body		
12	Settlement		
13	Quarry		

Figure 4.3: Soil map of Mohammadabad village, Nalgonda district, AP

4.4.6. Digital Techniques for Mapping Soils

Digital techniques allow exploitation of full range of image radiometry, spatial resolution and spectral channels; and thus facilitate better discrimination of soil classes and their phases of degradation. Digital analysis of satellite data solely depends on spectral response of soil surface and the spectral signature for same type of soils was found to vary with the change of solar elevation angles, vegetation cover and moisture conditions. Many studies in literature are reported that attempted for digital classification of soils solely using spectral properties yielded poor results (Evans, 1975; Fagbami 1986; Cruickshank and Tomlinson, 1988) due to overlap of spectral signatures and lack of established procedures for extracting physiography information. Further it was also observed that more number of mapping units can be delineated by visual interpretation techniques as compared to digital techniques. Digital analysis leads to generalization of mapping units and the associated soil information. Most of these classification approaches were attempted to map soil using spectral properties alone. However attempts were also made using Digital Elevation information also.

The conventional classification techniques like maximum likelihood rely on the assumption that input data is having normal distribution. However, while using topographic information, which is generally a non-normal distribution, these classification procedures fail to deliver a satisfactory result. In such cases, the classification algorithms which do not make any assumption on data distribution and can consider the data from other discrete data will be of immense use for preparing soil maps though digital approaches. To overcome difficulties in conventional digital classification that uses the spectral characteristic of a pixel as the sole parameter in deciding to which class a pixel belongs to, new approaches like context classifiers, decision tree classifiers, neural network algorithms etc. are being employed during recent times to digital classification of soil resources.

In the contextual classification, classification is performed by considering a pixel in the context of its neighbouring pixel. Other ancillary data may also be incorporated in order to improve the classification like incorporating a digital elevation model as its derived parameters like slope and aspect. In one of the studies at NRSA (1997), digital elevation model is developed for using elevation information in generating colour coded soil map. The inclusion of slope and elevation information in digital classification of IRS-1C LISS-III data substantially improved overall classification accuracy as compared to LISS-III data alone.

In Fuzzy classification, each pixel a membership function is assigned for each class, ranging from 0 to 1, which indicate the proportions of the different classes which have contributed to the observed spectral signature. Some image processing softwares incorporate digital classification techniques which use the fuzzy logic approach to classification. A limitation to this program is that the number of end-members that can be employed must be less or equal to the number of input bands. Thus, if the six reflective Landsat TM bands are used, a maximum of six classes can be employed. However, fuzzy logic is more relevant to soil mapping to address the fuzziness across soil boundaries in spatial domain.

Neural network classification algorithms are extensively being used in remote sensing. Unlike the maximum likelihood classifier, they do not rely on the assumption that data is normally distributed. A surface class may be represented by a number of clusters in a feature space plot rather than a single cluster. At NRSA (1998a), Artificial Neural Network (ANNs) technique was attempted to classify the soils as the maximum likelihood (ML) classification algorithm was not giving satisfying results to classify various soil classes. The lithology, slope, and elevation information of the study area was incorporated along with spectral response to an ANN classification technique. The comparison of ANN classification results with ML classification revealed that the classification accuracy was improved by 7% from 88% to 95% due to integration of multi source information in ANN technique.

4.5. Land Degradation

In general, it implies temporary or permanent regression from a higher to a lower status of productivity through deterioration of physical, chemical and biological aspects The information on the extent and spatial distribution of various kinds of degraded lands is thus essential for strategic planning of development of degraded lands. Development of degraded lands in India is one of the options available to increase food production for growing population and to restore the fragile ecosystem. Land degradation has numerous environmental, economic, social and ecological consequences, such as decline in land productivity, reduced agricultural or forestry production, siltation of rivers, canals and drainage systems, decline in income of agricultural populations leading to worsening of a poverty situation, increased rural-urban migration, increased frequency of natural disasters such as floods and landslides and loss of biodiversity.

The physical processes which contribute to land degradation are mainly water and wind erosion, compaction, crusting and water logging. The chemical processes include salinisation, alkalisation, acidification, pollution and nutrient depletion. The biological processes, on the other hand are related to the reduction of organic matter content in the soil, degradation of vegetation and impairment of activities of micro-flora and fauna.

4.5.1. Status

The first quantitative spatial assessment of desertification was made on the basis of information available with UNCOD and the total area affected by desertification was estimated at 3.8 billion hectares (Mabbut, 1978). But five years later the figure reported was 4.7 billion hectares (Dregne, 1983) and the increase is being attributed to the inclusion of the areas of true hyper deserts into the total area. A study of three agencies of United Nations viz., FAO, UNDP and UNEP (1994) estimated that altogether 140 million hectares, or 43% of the South Asia's total agricultural land, is suffering from one form of degradation or more. Of this, 31 million hectares were strongly degraded and 63 million hectares moderately degraded. The worst affected country was Iran, with 94% of agricultural land degraded, followed by Bangladesh (75%), Pakistan (61%), Sri Lanka (44%), Afghanistan (33%), Nepal (26%), India (25%) and Bhutan (10%). The study also concluded that these countries are losing at least US$10 billion annually as a result of land degradation.

According to National Commission on Agriculture (1976), about 175 million hectares of land constituting 53.3 per cent of the total geographical area of 329 M ha is subject to various kinds of degradation. According to the latest reports of Department of Agriculture and Co-operation (DAC, 1994) shows 107 million hectares of land is under various types of degraded lands.

In India, the largest category is water erosion, which account for 80 percent of degraded land and the remaining categories include salinization, waterlogging, and loss of top soil due to wind erosion. Of these, reliable time series data are available only for salt affected land, which has grown from 7.18 million hectares in 1987 to over 10 million in 1993 (Annon, 2002). It may be pertinent to add here that according to NRSA / DOS project on, 'Mapping of salt affected soils of India', the area under salt affected soils in the country is 6.727 million hectares (NRSA, 2008), based on satellite remote sensing and adequate ground truth for the period 1986-'87.

For the assessment of land degradation, on a global level at 1:5 million scale FAO/UNEP/UNESCO (1979) had used direct observations, parametric methods as well as remote sensing techniques and according to this study remote sensing provides a rapid, relatively inexpensive means to gather land information where no other sources are available or where the quality of available information is low. It permits an exact delineation or clear physiographic boundaries. It gives the opportunity for repetitive, annually or seasonally multi-spectral examination.

Remote sensing data from satellites like Landsat, SPOT and IRS, were employed subsequently to derive information on the nature, extent, spatial distribution and magnitude of various types of degraded lands like salt affected soils, waterlogged areas, ravinous lands, eroded areas, shifting cultivation etc., and also to monitor them periodically (Venkataratnam and Ravisankar, 1992, Karale *et al.*, 1988, Dwivedi and Ravisankar, 1991, Dwivedi and Sreenivas, 1998). Besides, remote sensing data has been used as an input to derive the parameters required for spatial modeling of soil erosion (Sreenivas, 2000). Stereoscopy from IRS-1D PAN stereo can give perspective view of depth of ravines, which enabled improved delineation of ravines into their reclamative groups (Sreenivas and Dwivedi, 2006)

4.5.2. Land degradation processes

Land is the most valuable natural resource, which needs to be harnessed according to its potential. Due to over exploitation and mismanagement of natural resources coupled with socio-economic factors (like land shortage, inappropriate land use, severe economic pressures on farmers, poverty, population growth etc.). The problems of land degradation are on the rise. Therefore, management of land resources is essential for both continued agricultural productivity and protection for the environment. This requires inventory of degraded lands to initiate appropriate reclamation / treatment plans. The information on the extent and spatial distribution of various kinds of degradation/ degraded lands is thus essential for strategic planning of development of degraded lands.

Water Erosion

Water erosion is the most widespread form of degradation and occurs widely in all agro-climatic zones. The displacement of soil material by water can result in either loss of topsoil or terrain deformation or both. This category includes processes such as splash erosion, sheet erosion, rill and gully erosion. The result is more loss of fertile topsoil and plant nutrients. In some cases where subsoil has kankars, lime nodules, etc will get exposed on the top there by altering the pH regime of the surface soil and subsequent nutrient holding capacity and their availability to plants. In wind erosion too, the surface soil is lost and gets deposited in other fertile areas thereby altering the fertility and nutrient as well as water holding capacities.

The off-site and downstream effects of erosion include siltation of dams and waterways, nutrients in runoff causing Eutrophication, and pesticide in runoff causing pollution of water bodies and aquatic flora and fauna.

Wind Erosion

It implies uniform displacement of topsoil by wind action. It can result in loss of topsoil and the deposition of the eroded material elsewhere leads to formation of dunes. The uniform displacement of topsoil by wind action occurs in thin layers / sheets. The uneven displacement of soil material by wind action leads to deflation hollows and dunes. The lifted medium to coarse soil particles may reduce the productivity of adjacent fertile land when they are deposited in the form of sand castings.

Water logging

Water logging is considered as physical deterioration of land. It is affected by excessive ponding / logging of water for quite some period and affects the productivity of land or reduces the choice of taking crops. Either because of topography, flooding or poor drainage condition, water logging occurs in some areas. The major consequence in these areas include lack of proper oxygen supply to plants leading to rotting, development of soil borne diseases, reduction in nutrient supply, non-availability of certain nutrients, etc. However, the magnitude of impact depends on the duration of water logging. The water logging could be surface (ponding of water) or sub-surface. While surface logging could be noticed, the sub-surface water logging mostly goes unnoticed.

Salinization / Alkalization

Salinization and alkalization are problems of semiarid and arid areas. They could be of natural or manmade. This is a major problem resulting in the desiccation of plants due to high osmotic potential exerted on plant because of high concentration of salts. Nutrient imbalance due to non-availability of essential nutrients to plants is also an associated problem. While, salinization is mostly associated with the coastal areas and younger alluvial plains, alkalization happens mostly in inlands and older alluvial plains. Generally, alkalization is associated with waterlogging due to poor permeability of soil by presence of sodium.

Salinization can result from improper management of canal irrigation water resulting in the rise of water table and consequent accumulation of salts in the root zone in arid, semi-arid and sub humid (dry) conditions and ingress of sea water in coastal regions and/or use of high-salt containing ground water.

Acidification

Any soil process or management practices which lead to buildup of hydrogen cations (also called protons) in the soil will result in soil acidification. It also occurs when base cations such as Calcium, Magnesium, Potassium and Sodium are lost from the soil leading to high hydrogen ion concentration. This results in decrease of soil pH below 6.5. Increasing acidity through selective removal of calcium cations on the exchange complex affects the balance in nutrient availability, encourages P-fixation and induces free aluminium causing severe toxic effects. It is also associated with iron toxicity at places. It generally occurs in regions of very high rainfall.

Glacial

These are the areas under perpetual snow covered areas in Himalayan region. It degrades an area by two processes namely frost heaving and frost shattering. Frost heaving is defined as a process in glacial and periglacial environment where intense frost action and freezing of water evolves peculiar forms of rock, regolith and soil. The water crystallizes to ice below the surface horizon leading to micro-relief variations on the surface. This process affects the germination and root growth of several crops there by limiting the productivity of land. Generally, these regions remain fallow during winters.

Anthropogenic

Human economic activities like mining, industries etc., have also contributed to decreased biological productivity, diversity and resilience of the land. Mining, brick kiln activities and industrial effluent affected areas are included under this type of degradation. Nutrient depletion or nutrient mining from fertile agricultural fields, without replacement through manure or fertilizer, results in nutrient deficiencies. Removing plant residues also reduces soil organic matter content. Removal of topsoil while mining for precious metals and affecting its surrounding agricultural fields is another dimension of land degradation. Hence, the top fertile soil is almost permanently lost, if properly not conserved. Chemical toxicity from industrial effluents and soil contamination with poisonous chemicals affects the plant growth significantly.

Others

Some of the degraded lands, which could not be included in the above type of land degradation, are included here. They are mass movement/ mass wastage, barren rocky / stony waste areas, riverine sand areas, sea ingression areas.

Land degradation assessment is often not a simple task. It requires continuous monitoring of the ecosystem for several parameters, which are often difficult to collect and monitor. Several indicators are in vogue to describe soil quality like pH, organic matter content, available nutrients to plant, soil depth, soil texture, bulk density / porosity, water permeability, water holding capacity, nutrient retention capacity, presence of chemicals toxic to plants or their primary consumers, and so on. Added to this, there will be several complex interactions among these properties. Thus soil quality cannot easily be described by one variable or an index.

It is the complicated interaction and cumulative effect of land degradation processes which ultimately translates to an actual decline in farm production. Only farmers' upon keen observation may recognize some of these individual processes. Reduced soil depth, exposure of sub-surface gravel / kankar, poor seed germination are often cited as changes, but rarely do farmers relate them directly to water erosion or any other land degradation process. Further, the toxicity of elements, most often, do not exhibit any perceptible visual impact on surface, such as aluminium / iron toxicity, resulting in significant crop failures. Thus the ignorance of farmers is also responsible for unnoticing the effects of land degradation.

The above-mentioned soil properties and their interactions do affect the crop yields, sometimes very significantly. Hence, some people consider crop yield as one of the proxy indicator to assess land degradation. However, crop yield is not a good indicator since human management in terms of seed variety, seed quality, water availability, fertilizer inputs, etc., also influences it. However, measuring yield trends with control on other inputs and management practices can provide an observable and credible measure of trends on land degradation.

4.5.3. Remote Sensing, GIS and Land Degradation

For the assessment of land degradation, on a global level at 1:5 million scale FAO/UNEP/UNESCO (1979) had used direct observations, parametric methods as well as remote sensing techniques and according to this study:

- Remote sensing provides a rapid, relatively inexpensive means to gather land information where no other sources are available or where the quality of available information is low
- It permits an exact delineation or clear physiographic boundaries
- It gives the opportunity for repetitive, annually or seasonally multi-spectral examination
- Interpretation of satellite imagery can be at several levels of intensity / scales

The role of remote sensing and GIS in land degradation has been summarized as Table- 4.2 (Sreenivas, 2007).

Table 4.2: Remote Sensing and GIS in land degradation studies

Theme	Geographical Representation	Attributes required	Method
Land Degradation	To show the major types of land degradation operating	• Type of land degradation • Severity / level • Cause description • Topography • Land Use type • Notes on solutions to tackle the problem	Visual interpretation of satellite imagery with adequate field verification / checks
Land degradation hotspots	Show the extents of areas, which are degraded during period range, classified according to the degree of degradation	• Degradation type • Degradation level • Major causes • Current Land Use type. • Period elapsed to reach critical threshold of degradation • Notes on solutions to tackle the problem	• Preparation of land cover and NDVI maps of a historic and current year using multi-spectral remote sensing data • Identification of land degradation hot-spots based on type and degree of land transformation and NDVI change matrix in GIS domain • Classification of areas into various type and degree of degradation based on above information • Analysis of land transformations with available livestock and human census data details • Investigation and understanding of the desertification by domain experts and suggesting solutions
Land degradation prediction	Show the extents of areas most likely to degrade in the near future and their classification according to the probability of its tendency to get degraded	• Grade of expected land degradation • Level of Confidence • Predicted period in to reach the threshold level of degradation • Current Land Use • Topography	• Main drivers of land degradation to be identified from land degradation change maps / hotspot maps • Using historical and current land degradation areas data, rate of desertification need to be studied and confidence levels will be estimated • Scope should be given to accommodate proposed alternate land utilization plans, if any, or land transformation policies to be implemented in near future • The general approach for prediction could be through spatial modeling

4.5.4. Mapping land degradation

The following section provides outlines of the procedure involved in mapping land degradation using satellite data which consists of input data, preparatory work and methodology. The methodology normally adopted for mapping at any scale consists of preparation of base map, on –line visual interpretation of satellite data, development of legend, ground truth collection, analysis of soil samples, classification of degradation classes and finalisation of maps in light of field information and analytical data. The methodology is given in the form of a flow chart (Figure 4.4). The major steps are discussed here under:

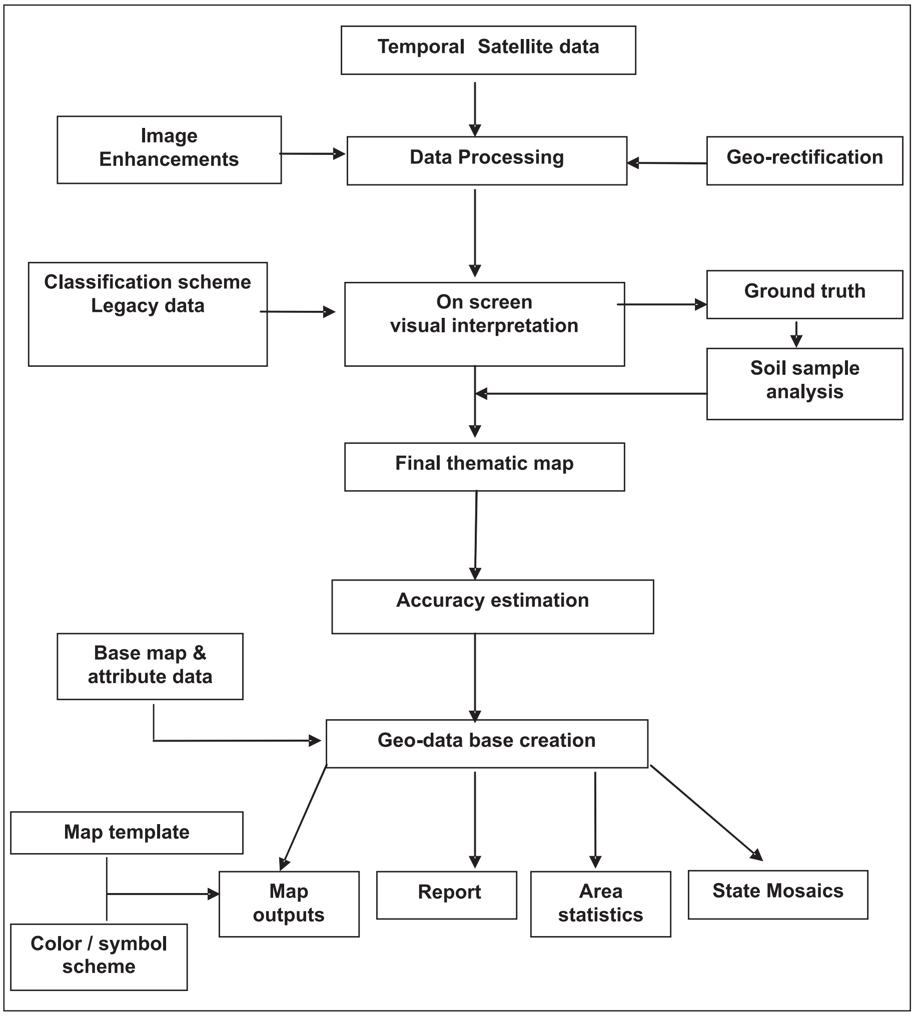


Figure 4.4: An overview of the land degradation mapping methodology

Input data and its preparation

For delineation and mapping of land degradation classes, multi-temporal geo-rectified data acquired during major cropping seasons like kharif, rabi and zaid seasons are used. Such a temporal data set helps to address the seasonal variability in intensity of problem in degraded lands. The satellite data is geometrically corrected for further processing, like visual interpretation, ground truth collection and land degradation map preparation.

Besides, while mapping land degradation, ancillary data in the form of topographic maps, existing land use land cover data, wasteland data, district and any other published relevant material are used as reference data. Survey of India digital topographic maps at suitable scale are used for identification of base features and for planning ground data collection. Any legacy data sets in the form of maps can also be used for substantiating land degradation process.

Interpretation cues

The methodology involves standard visual interpretation techniques that are followed in any other mapping exercise. The image interpretation key provides a critical reference base for advanced interpretation. It helps the interpreter in evaluating the information in an organized and consistent manner. An image interpretation key for the study area has to be designed prior to interpretation, which can be further refined in course of interpretation. A general visual interpretation keys for land degradation has been included as table 4.3. However, for delineation of severity, the interpretation cues vary with the season of data available and local processes. Using these cues the satellite data are visually interpreted either on the screen or using image prints. After preliminary interpretation of satellite data sample areas are identified for ground truth collection.

Ground truth Collection

Ground truth/ field verification is an important component in mapping and subsequent validation exercise. Utmost care and planning is required for collecting ground data and verification. To facilitate a good ground

Table 4.3: Visual interpretation cues for land degradation.

Land degradation process	Land degradation type	Colour / Tone (On standard FCC)	Texture (on LISS-III data)	Pattern	Size	Shape	Association	Remarks
Water erosion (W)	Sheet erosion (sh)	Slightly brighter than surrounding land of its class	Smooth to medium	Contiguous patches	Small to large	Irregular	Sloping cultivated / lands with poor vegetal cover during rainy season	Information need to be deduced from available soil information slope and satellite data in conjunction RUSLE can be used to quantify soil loss
	Rills (ri)	Brighter than surrounding land of its class	Medium	Discrete to contiguous patches	Small to medium	Irregular	Sloping cultivated lands	Mostly seen on ploughed land after first rains
	Gullies (gu)	Brighter than surrounding land / gray in color depending on soil colour.	Medium to slightly coarse	Discrete to contiguous patches	Small to medium	Irregular	First order streams	–
	Ravines (rs / rm)	Medium gray to dark gray	Slightly coarse for shallow ravines and coarse for deep ravines	Contiguous patches	Large to very large	Irregular	Stream / river banks	Image texture and association are to be given attention
Wind erosion (E)	Sheet erosion (sh)	Various shades of yellow and light gray combination	Smooth to medium	Contiguous / mottling (in cultivated areas)	Large to very large	Regular / Irregular	Desertic plain areas with of active sand movement	In deserted areas; with little or no vegetal protection
	Partially stabilized dunes (dp)	Light grey to medium grey with light yellowish tones	Medium	Contiguous / discrete patches	Small to medium	Regular/ irregular	Desert sandy dunal area	Sand dunes in desert areas with slight to moderate vegetal /grass cover

	Stabilized dunes (ds)	Medium grey with light yellowish tones during dry season. Pink mottles during rainy season	Medium to coarse	Discrete patches	Small to medium	Regular / Irregular	Desert sandy dunal area	Sand dunes in desert areas with good vegetal / grass cover
	Un-stabilized dunes (du)	Various shades of yellow and very light gray combination	Smooth to medium	Contiguous / discrete	Medium to large	Irregular	Desert sandy dunal area	Sand dunes in desert areas with no vegetal / grass cover
Water logging (L)	Surface ponding (sp)	Light blue to Very dark blue	Smooth	Discrete patches	Small to large	Regular / Irregular	Depressions in inland plains / coastal plains	
	Sub-surface water logging (sw)	Medium to dark gray on normal FCC; on FCC with SWIR band (R:G:B=SWIR: NIR:Red) various shades of blue	Smooth	Discrete/ contiguous patches	Medium to large	Irregular	In irrigated areas / plains with high water table	
Salinisation / Alkalisation (S)	Saline (sa)	Light gray to white	Smooth	Discrete patches	Small to medium	Irregular	Coastal plains / young alluvial plains / stream courses / irrigated canal commands	Needs very careful delineation delineation in black soils and sandy regions
	Sodic (so)	Grayish white / dull white	Smooth	Discrete patches	Small to medium	Irregular	Older alluvial plains / stream courses / irrigated canal commands.	Needs very careful delineation in black soils and sandy regions
	Saline – Sodic (ss)	Grayish white to White	Smooth	Discrete patches	Small to medium	Irregular	Young to older alluvial / stream courses / irrigated canal commands	Needs very careful delineation in black soils and sandy regions
Acidification (A)	Acidic (ac)	Various shades of green/ black	Smooth to medium	Mottled / parceling, contiguous / discrete	Small to large	Irregular	Lateritic /high rainfall regions, cultivated peats / marshes	Soil pH data is essential

Glacial (G)	Frost heaving (fh)	Light pink to grey	Smooth	Discrete / contiguous patches	Medium	Regular / Irregular	Cultivated / fallow valley areas of glacial region	Look for valleys adjacent to snow covered peaks
Anthropogenic (H)	Industrial – effluent affected areas (ie)	Various shades of blue, if ponded with water. Light grey to white patches when dries	Smooth	Discrete / contiguous	Small to medium	Irregular / regular	Adjacent to industries and its effluent discharge pathways	Association is very important
	Mining and dump areas (md)	Shades of White, yellow, red, black	Smooth to medium	Discrete	Small to medium	Irregular / regular	Hilly / plain areas	Colour varies depending on the mining stage and type of mineral explored
	Brick kiln (bk)	Dull white to light yellow	Smooth	Isolated patches giving rise to mottling pattern on its background.	Very small	Irregular / regular	Associated with urban areas and its surroundings; located along trafficable road network	Requires careful logical deduction
Others (T)	Mass movement / mass wastage (mm)	Yellowish white to very light cyan	Smooth	Discrete	Very small to small	Irregular / regular	Foot of steep sloping hilly regions	–
	Barren rocky / Stony waste (bs)	Light to medium grey / yellowish white	Smooth	Discrete / Contiguous	Medium to large	Irregular	Hilly or pediment regions	–
	Snow covered areas (sc)	Bright white to dull white; bright blue on SWIR band FCC (R:G:B=SWIR: NIR:Red)	Smooth	Contiguous patches	Large to extensive	Irregular	Very high altitude peaks & glaciers.	Use SWIR band FCC for their separation from clouds
	Miscellaneous (Riverine sands / Sea ingress areas, etc) (ms)	Generally white. Light cyan when associated with moisture	Smooth	Discrete / Contiguous	Medium to large	Irregular	River banks / old river course/coastal beach/dune sands and river bed/ natural levees	Sandy areas other than desert sands

truthing exercise identify and list all the doubtful areas for the ground verification and refer all such areas with respect to the toposheet to know their geographical location and accessibility on the ground. Then prepare field traverse plan to cover maximum doubtful areas in the field. Ensure that each traverse covers, as many land degradation classes as possible, apart from the doubtful areas. Soil samples are collected from representative areas and are analysed for chemical & physico-chemical properties.

Soil Sample Analysis

The soil samples are to be analysed for pH, EC, texture (sand, silt, clay), CEC, exchangeable cations, calcium carbonate %, organic carbon % using standard analytical procedures. These observations are required for signature extrapolation during interpretation.

Final Map Generation

The land degradation map needs to be finalized in light of the ground observations, visual interpretation keys, available ancillary and legacy data sets. Once map is finalized they need to be checked for topological and labelling errors. For mapping units having more than one problem, the associated problem need to given the mapping symbol in a separate attribute column. Map is composed using the major land degradation problem. Edge matching of the features are carried out to maintain the continuity of classes between adjoining sheets. Final map is tested for thematic accuracy. Base map features are overlaid and then map is generated on the layout consisting of theme map, legend, scale bar, north arrow, sources of data, index map, agencies involved, project name and year of publication.

Validation

Information collected during the field visit is utilised in checking the final maps for which purpose a representative samples are collected on ground covering all the thematic classes. In extreme cases, the finalised thematic maps are also be validated by verifying the mapping units in the field. A salt – affected soil map prepared using the above approach has been appended as figure 4.5.

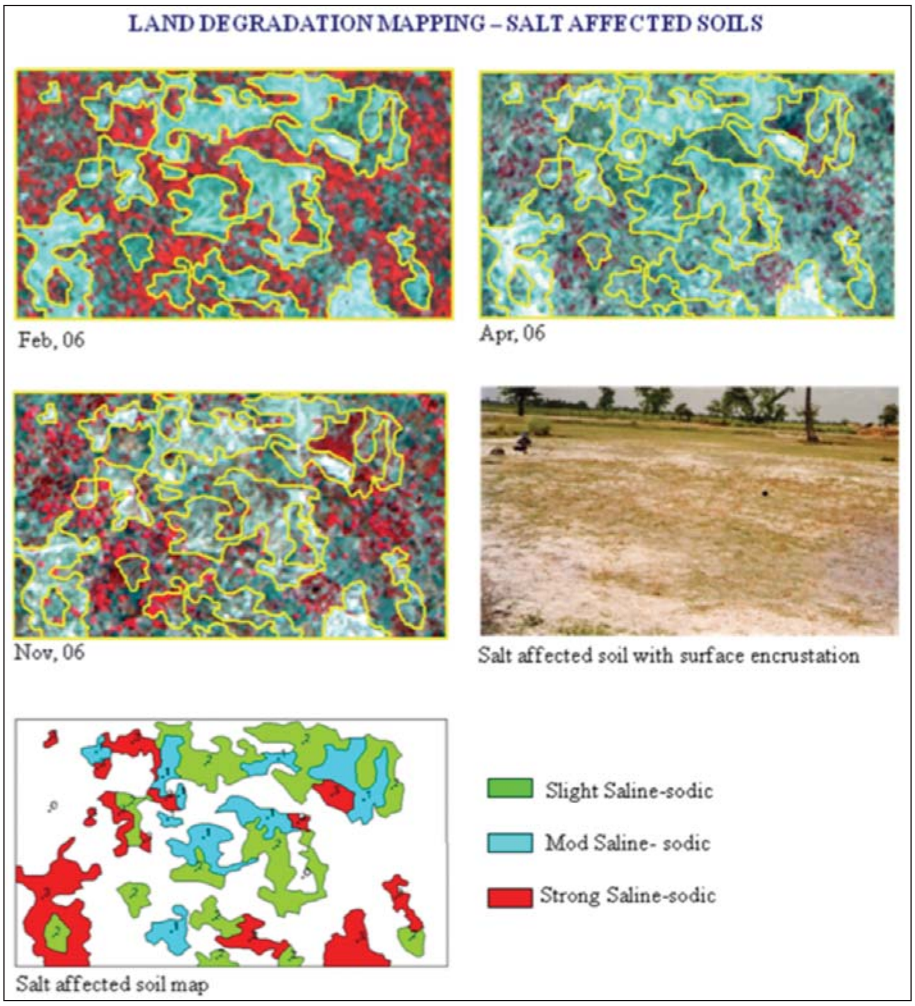


Figure 4.5: Salt-affected soil map prepared from multi-season temporal LISS-III satellite data

4.5.5. Monitoring of land degradation

Repeatitive nature of satellite data enables to monitor land degradation process over a period of time in any geographical location (figure 4.6) The methodology consists of the geometric correction of multi date satellite data. Then the satellite data is corrected for Sun elevation angle effects and atmospheric influences. Subsequently the data is normalized for their radiometric differences. Once the data set is ready, the ground truth is collected with respect to current season data by means of studying soil profiles and surface observations. The soil samples are analysed for various chemical and physical properties. Based on the ground truth and ancillary information, the signatures are established for various land degradation classes. Using the other ancillary information and ground truth information, the signatures are extrapolated to other dates. The changes that have been observed in the satellite data are verified again on the ground. NRSC had carried out monitoring of waterlogging and salinity/alkalinity in the major command areas in various states in India like UP - Sharada Sahayak, Maharastra – Upper Tapi, Purna, Krishna, Bhima, Girna, Jayakwadi, AP – NSP Command, Karnataka – Krishnarajasagar command and Rajasthan – Chambal command at the request of Central Water Commission, New Delhi. In this project using pre-monsoon, monsoon and post-monsoon season satellite data salinity and water logging were identified with field investigations. Sample areas portraying significant changes in land degradation status has been appended as Figure 4.6.

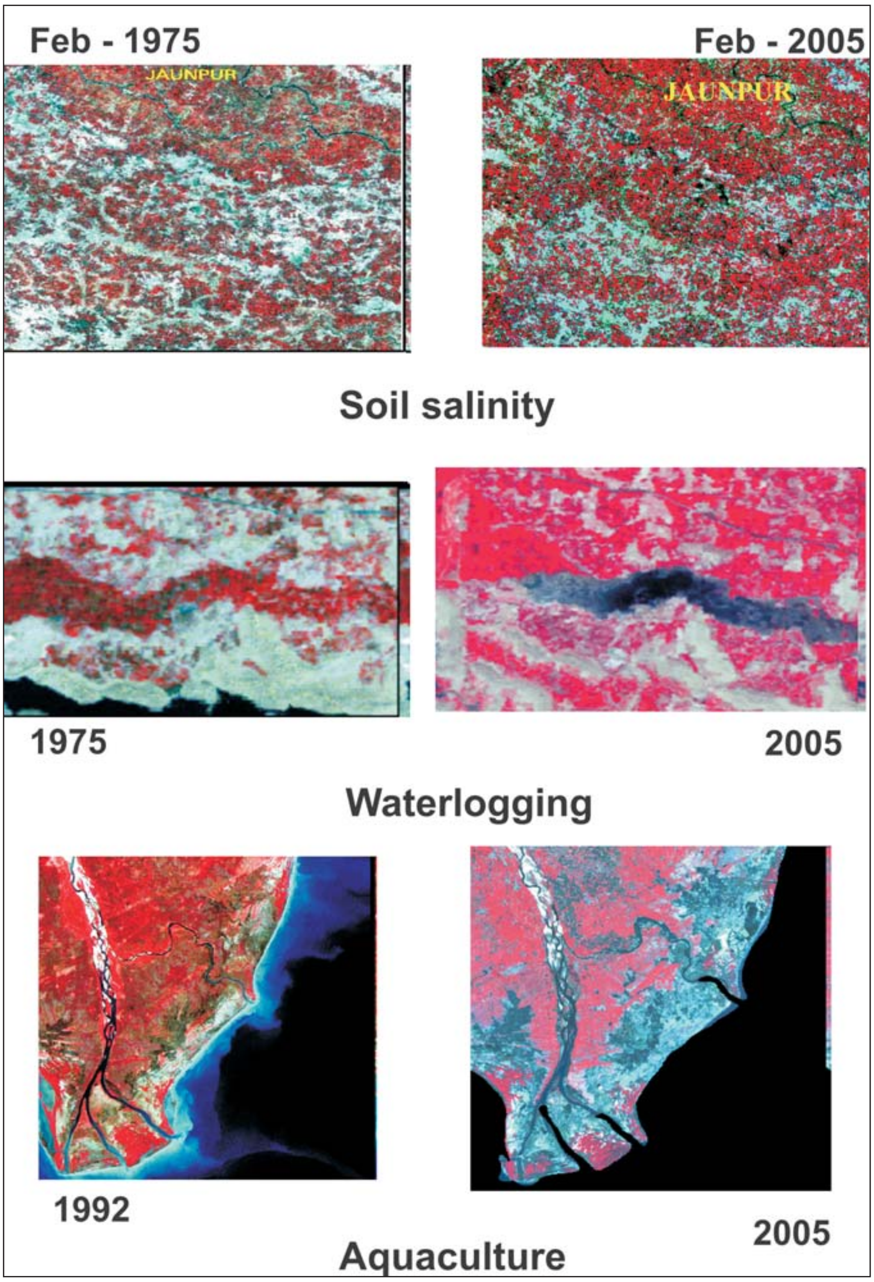


Figure 4.6: Monitoring land degradation

4.6. Soil Moisture Studies

Soil moisture is an important input parameter in number of land surface and atmospheric processes in view of its ubiquitous nature and unique thermal and electrical properties. In addition, its role in agriculture and hydrology needs no emphasis. Remote sensing techniques, by virtue of their large area coverage, frequent revisit capability enabling repeated estimates on regular basis are highly suitable for soil moisture estimation. The assessment of soil moisture was done by studying the changes in soil colour (Musick and Pelletier, 1986; Kijowski, 1988), by estimating the thermal inertia (Evans and Catt, 1987; Berge and Stroosnijder, 1987) and microwave radiometry (Schmugge and O'neill, 1986).

Moisture also greatly influences the reflection of shortwave radiation from soil surfaces in the VNIR (400–1100 nm) and SWIR (1100–2500 nm) regions of the spectrum (Bowers and Hanks, 1965; Skidmore *et al.*, 1975). In a study Lobell and Asner (2002) concluded that the SWIR region is more suitable to pickup soil moisture differences than optical wavelengths. The effect of soil type difference on soil moisture could be reduced by expressing the moisture as degree of saturation rather than volumetric soil moisture content. More pronounced decrease in reflectance was noticed at 2.2 µm irrespective of soil type. Reflected radiation in visible and Near IR regions, though sensitive to soil moisture, is not applicable due to its higher sensitivity to soil chemical composition, colour and organic carbon and its inability to provide remote sensing data during inclement weather conditions. Thermal radiation emitted in the 8-14 µm range is highly sensitive to soil moisture variations as soil moisture content determines the thermal inertia of soils. Higher the soil moisture content higher the thermal inertia leading to smaller change in physical temperature of the soil with time. Attempts using thermal remote sensing techniques are successful to the extent of determining soil moisture qualitatively due to influence of intervening atmosphere and any ground cover.

Microwave remote sensing techniques (passive and active) are by far the most successful and widely investigated since early 70s in view of all weather capability of emitted or scattered microwave radiation and its strong sensitivity to soil moisture variations and penetration through crop cover and surface soil layers. Microwave backscattered radiation increases with increasing soil moisture content at low look angles i.e., 10 to 20 degrees. Under similar surface conditions, soil textural variations, which in turn govern the quantum of bound water fraction, modify this relationship (Schmugge, 1983; Ulaby *et al.*, 1983).

Active microwave sensors operate on the principle of radar. Magnitude of radar backscatter coefficient (a measure of reflected microwave radiation) depends on soil moisture, surface roughness and crop cover on one hand and on microwave frequency, polarization and look angle at which the terrain is viewed on the other. Though observation made at C-band (5.3GHz), HH or VV polarization and near nadir look angles of 10^o to 15^o is considered to be the ideal sensor configuration for soil moisture estimation using radar, it is proved inadequate in terms of accuracy of soil moisture retrieval due to the effects of other terrain parameters.

Passive microwave radiometers are best suitable for large area soil moisture estimation from space borne platforms such as NIMBUS, Oceansat-1 and DMSP satellites due to their coarse spatial resolution and high revisit capability of 2 days or higher. Microwave radiometers record the emitted microwave radiation in terms of brightness temperature, which is the product of emissivity and physical temperature of the target and is highly sensitive to soil moisture variations. Thus passive microwave radiometry at L-band in dual polarization mode caters to the needs of meteorologists in global circulation models. In view of its potential, ESA is planning to Soil Moisture and Ocean Salinity (SMOS) Mission in 2009 to provide soil moisture on operational mode at regular intervals with a spatial resolution of 50 km.

At NRSA, experiments with SAR data from ERS-1/2 satellites have been attempted for estimation of soil moisture under different soil and moisture conditions (NRSA, 1995). The studies enabled to understand the relation between soil moisture and back scattering coefficient of SAR data; and also the influence of surface roughness on soil moisture estimation. A study on soil moisture with IRS-P4 MSMR data was also attempted for regional level study. Efforts in the direction of root zone soil moisture modeling with remotely derived surface soil moisture content and soil profile characteristics are in progress. Subsequently experiments are also conducted with SAR data from RADARSAT.

Soil moisture estimated from remote sensing platforms would enable retrieving moisture in surface layers of the soil only. Adequate modeling techniques need to be developed using soil profile information on soil characteristics and satellite derived surface soil moisture for estimating the profile soil moisture for a wide range of applications in agriculture. The various efforts made in retrieval of soil moisture are (i) regression modeling with moisture vs. soil roughness and soil texture; and (ii) inversion of physical or quasi-physical models. Most of the inversion techniques developed includes inversion of forward physical or quasi-physical radar backscattering models which are a function of dielectric constant and surface roughness.

Assured availability of multi-dimensional SAR data with dual or quad polarizations from such future satellites as Indian Radar Imaging Satellite (RISAT), Canadian RADARSAT-2 and Japanese PALSAR in the current decade may lead to operational soil moisture estimation.

4.7. Remote Sensing of Soil Fertility

The main components of soil fertility addressed with remote sensing include organic carbon, soil nitrate levels, soil clay content and thickness, etc. Amongst plant nutrients, nitrogen is one of the most important factors in maximizing the crop yields and economic returns to farmers. The spatial variation in nitrogen content has been addressed using crop vigor as a proxy indicator, in-field referencing of point in question with a point of known nitrogen status, spatial interpolation of soil analytical data using remote sensing data as guiding force for interpolation.

In general, Nitrogen deficiency causes a decrease in leaf chlorophylls concentration, leading to an increase in leaf reflectance in the visible spectral region (400-700 nm). However, several other stresses (pest and diseases) may also result in increased plant reflectance due to reduced amount of chlorophyll (Carter and Knapp, 2001). Diagnosing a specific nutrient deficiency with remote sensing data can be difficult when plants are subjected to deficiencies of multiple elements. Hyperspectral remote sensing was found to be an important tool for the diagnosis of plant nutrient stress which is an indicator of soil fertility as well. Osborne *et al.* (2002) showed the utility of hyperspectral data in distinguishing differences in nitrogen and phosphorus at the leaf and canopy level, but the relationships were not consistent over all plant growth stages. Spectral reflectance peaks resulted from derivative analysis of spectral reflectance spectra found to be a good technique for stress detection. The position of the inflection point in the red edge region (680 to 780 nm) of the spectral signature, termed as red edge position (REP), is affected by biochemical and biophysical parameters. Shifts in the REP to longer or shorter wavelengths has been used as a means to estimate changes in foliar chlorophyll or nitrogen content and also as an indicator of vegetation stress. Cho and Skidmore (2006) have used linear extrapolation method for extracting REP that has shown high correlations with a wide range of foliar nitrogen concentrations for both narrow and wide bandwidth spectra.

Another area of research that is fast growing is fluorescence spectrometry which was found to be good for detecting plant nutrition status. Plants contain pigments which absorb photons from sunlight that are involved in photosynthesis and other photochemical processes. The leaf pigment absorbs the photons of certain wavelengths and can emit partially or fully of this absorbed energy as fluorescence at longer wavelengths. The magnitude of the fluorescence emission is inversely related to relative efficiency of plant photosynthesis and other biochemical systems. Fluorescence can also be an indicator of the relative concentration of certain plant constituents. This technique was successfully used in corn and soybean (*Glycine max*.Mirr.) and differences between the fluorescence of healthy plants and plants deficient in the major plant nutrients N, P and K, and the minor plant nutrients Ca, Mg, S, Fe, and B have been detected (Chappelle *et al.*, 1984). Using laser-induced fluorescence (LIF) and passive reflectance measurements in the laboratory McMurtrey *et al.*, (1994) observed differences in maximum intensity of fluorescence at 440nm, 680nm, and 780nm which were found related to different levels of N fertilization in corn (*Zea mays* L.).

4.8. Application of GIS techniques in Soil Resources study

Development of computer technology, especially Geographical Information System (GIS), provides valuable support to handle voluminous data being generated through conventional and remote sensing techniques both in spatial and non-spatial format. Further, GIS also allows the integration of these data sets for deriving meaningful information and outputs in map or tabular formats. The integrated analysis of resources data at different scales, enables to study the potentials and limitations of natural resources and to generate optimal utilisation plans for land and water resources.

In recent years the applications of GIS has increased many folds in various fields. It is used widely as a standard tool in agriculture, environmental management, forestry, hazard monitoring, hydrology, watershed management, land analysis, etc. The introduction of GIS promoted interdisciplinary studies, both within the natural, environmental, social and economic sciences. GIS technology and applications have expanded rapidly in parallel with advances in remote sensing and computer technology and increasing demand for environmental information. It provides an infrastructure for the examination of complex spatial problems in new and exciting ways. The technology has developed rapidly, and has quickly been taken up by a diverse user community with very difficult and often demanding applications.

Besides digital cartography, major applications of GIS in the field of soil survey and land evaluation are land capability classification (LCC), land irrigability assessment, land suitability for different purposes, watershed management and generation of optimal land use maps.

Land evaluation provides a rational basis to analyse various soil, climate and land parameters to arrive at optimum solution to various problems of natural resources. In the land evaluation process GIS has become an important tool because it enables to integrate the complex decisions to be taken under multi-variant situations of the resource base and their dynamics. Land evaluation principle is based on matching the requirements of a land for specific use with the characteristics of inherent soil, climatic, topographic and other natural resources and is concerned with the assessment of land performance when used for a specific use.

Major GIS applications relevant to soils are:

- land capability assessment

- land irrigability assessment
- land productivity assessment
- irrigation water management in command areas
- prioritization of sub-watersheds / micro-watersheds in a given watershed
- soil suitability assessment for various purposes like specific crops, industries, forestry, etc.
- to identify critical areas in watershed / micro-watershed
- to generate optimal land use plans etc
- quantification of soil loss
- planning the urban development
- reclamation planning of degraded lands

… and so on.

4.8.1. Crop Suitability Studies

The sustainable crop production in any area depends on its climate, soil and site characteristics of the area. This can be achieved through evaluation of soils of a given area for their suitability to different crops considering the inherent soil properties, topographical features and climatic parameters independently as well as in combination. A study had been carried out at NRSA (1998b) with the objective of assessing soil suitability to groundnut crop through GIS approach. The test site for the study was Tettavai vagu watershed in Tungaturthi mandal of Nalgonda district of AP. The soil maps for the study area was prepared using IRS-1B LISS-II data at 1:50,000 scale. Suitability criteria for groundnut crop in terms of climate, soil and site parameters were developed following FAO approach and incorporated as decision rules in GIS environment. The study revealed that in the test area about 69% of the total geographical area is highly suitable for groundnut crop. Similarly studies were carried out using remote sensing and GIS for sugarcane crop suitability in Puddukottai district, Tamilnadu and upland rice in Koraput district., Orissa. Similarly larger scale soil maps of Mohammadabad village, Nalgonda (Figure 4.3) were used in similar lines as mentioned above to assess the suitability of the village for various crops (Figure 4.7).

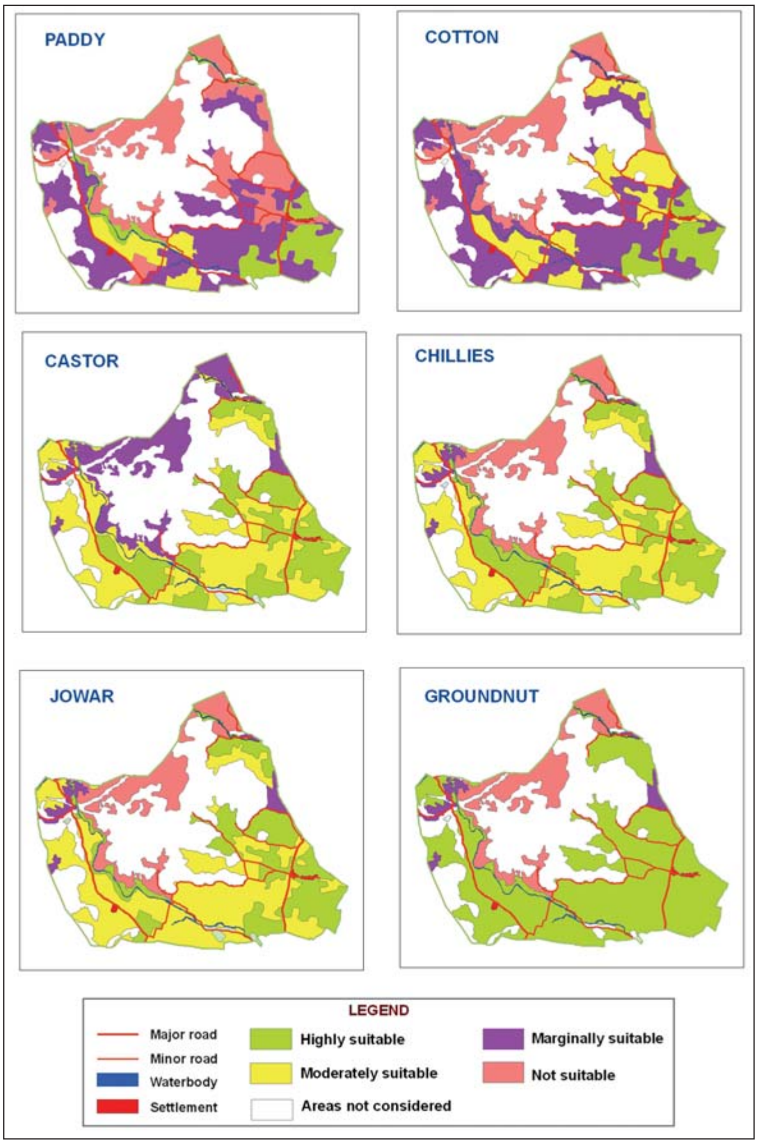


Figure 4.7: Land suitability of soils of Mohammadabad village for various crops

4.8.2. Land Irrigability Assessment

Land irrigability assessment is another important derivative map from soil map. It gives an assessment whether or not an area is suitable for irrigation. The soil depth, slope, salt problem, stoniness, waterlogging, etc are the some of the criteria used for irrigability assessment. It is more relevant before introduction of irrigation in any proposed command areas. The soil maps were overlaid on slope maps and various criteria were given as weightages to derive mapping units in an GIS environment. Then based in irrigability criteria, the assessment of the area is made for their suitability for irrigation. This enables to prevent salinity or water logging and maximize the crop production by efficient utilization of irrigation water. An irrigability assessment made on similar lines for the Mohammadabad village has been appended as Figure 4.8. Similar exercises were carried out for various canal irrigated command areas like Sri Ram Sagar Project (SRSP) Phase-II (NRSA, 1997a) and Krishna-Pennar link canal command area.

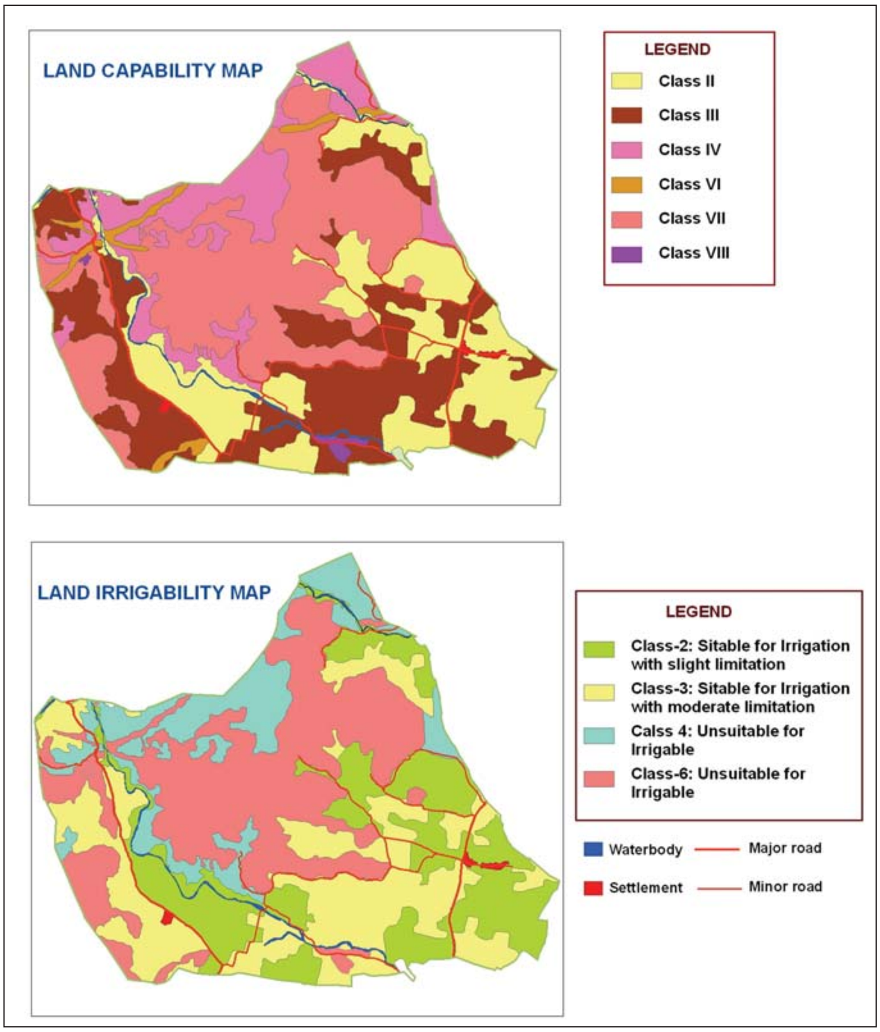


Figure 4.8: Land Capability and Land Irrigability map of village Mohammadabad

4.8.3. Land Productivity Assessment

The soil / land productivity assessment is one of the several soil survey interpretations which plays a critical role in the generation action plan for sustainable development of soil and water resources. An experiment has been carried out with the objective of assessing the land productivity using remote sensing and GIS techniques (Ravisankar, 2001). To assess the land productivity, initially soil map of the study areas are prepared at suitable scale. The land productivity index (LPI) of the area are assessed with respect to crops, pasture and forest / trees, following parametric approach of Riquire et al (1970). GIS tools were used for calculating LPI values for soil types and for deriving area weighted LPI values for soil mapping units and in the generation of Land Productivity map for the study area . The LPI varied from 8 – 65 for crops and forest / tree species and 8 – 58 for pasture for different soil mapping units. The study revealed that in the test site all soil mapping units have better coefficient of improvement with respect to crops (0.7 to 2.6) and minimum for forest / tree species (1.0 to 2.0).

4.8.4. Soil Erosion Modelling

Quantification of soil loss is an important application that several researchers attempted using GIS. The general approaches include a rule based approach where several parameters that influence the soil loss are weighted and summed to assess the final index to rate whether or not a particular area is eroded. In another approach, the absolute values of the model are derived from the maps and the soil loss is calculated using a physical or an empirical model. Unlike rating method, this method gives the physical quantity of soil loss. The important parameters that influence the soil loss are slope, cover, soil erodibility, rainfall quantity and intensity and the soil conservation or management factor that are practiced on a parcel.

4.8.5. Prioritization of Watersheds

In recent years, resources developmental planning has taken a shift towards watershed-based approach. In order to plan and manage the watersheds efficiently and use the available monitory resources judiciously, prioritization of watersheds becomes very crucial. Remotely sensed data provides a valuable spatial information on natural resources and the information thus generated can be used in integrated analysis in Geographical Information System (GIS) to arrive at suitable solutions for complex resource problems in watersheds. The potential of these two technologies have been demonstrated in DOS projects like IMSD, IRIS-DA, Sujala, NATP etc., at watershed level to micro-watershed level. Presently a number of developmental projects are being implemented based on the watershed approach. However, when we have several such watersheds all cannot be developed at a time due to paucity of funds. Such a situation calls for prioritization of watersheds. A variety of approaches are in vogue for their prioritization. They include, resource based, economy based and socio-economic based approaches. Thus, the problem of prioritization of watershed is objective oriented and efforts are being made in the direction of development of methodologies that have more scientific rationale for development of watersheds and monitoring them in future.

NRSA (2007) had carried out a project for Ministry of Rural Development with the objective of prioritization of micro-watersheds based on wasteland information (NRSA- wasteland project), percent ST/SC population, acute shortage of drinking water, and development of knowledge base to combine the theme-wise priority maps and to ascertain the priority of sanctioned watersheds of MoRD. The study was taken up in Chhattisgarh, Maharashtra and Orissa states . The methodology of the project was established by considering the percentage distribution of waste land categories in each village, village wise drinking water status such as NC, PC, FC etc., and socio-economic data like SC/ST percentage etc. Initially individual theme-wise priority maps namely drinking water status, waste lands, and % SC/ST population were generated. The final integrated priority maps were generated based on these thematic maps on to which village boundaries were superimposed. In Orissa state it was found that 5200 (9.9%) villages fall under high integrated priority class while 9,872 (18.8 %) villages under medium priority and 30,400 (57.8%) villages under low priority. Analysis of the sanctioned watersheds / villages by MoRD revealed that out of the 601 watersheds only 79 villages were found to occur in high, 138 villages under medium and 380 watersheds under low priority integrated classes.

Issues and prospects

Even though remote sensing techniques are in vogue over a period of nearly three decades in the study of various aspects of soils, there are certain issues still to be resolved for efficient utilization of satellite data. The various issues and future prospects are discussed below:

- Soil reflectance is modified to a great extent due to the presence of vegetation cover. If the vegetation cover is sparse, a mixed response from soil and vegetation may be observed. If the density of vegetation is high, the reflected energy received at the sensor is mostly from the vegetation. Even though the soils are intimately related to the natural vegetation cover, presence of crops / plantations modifies this relationship. Consequently, the inherent and natural relationship of soils with the vegetation is disturbed
- In satellite imagery one can observe similarities in spectral reflectance of two different soil types. Example - Mollisols and Vertisols, which exhibit same spectral reflectance pattern, as both of these are darker in colour. Similarly, Vertisols and deltaic alluvium, Red and lateritic soils, as well as highly calcareous alluvial soils and salt affected soils
- Even though, the remote sensing data enables better delineation of soil mapping units, there are certain gray areas like areas covered with crops or forest vegetation where the accuracy of soil maps could be relatively less, without extensive ground truth
- Another issue is keeping of contrasting soils in the same mapping unit which diminishes the prediction of soil potentials for practical uses. For example, Lithic Ustorhents and Typic Haplustepts may be placed in the same mapping unit. To some extent scale of mapping and type of sensing spatial resolution do contribute to such situation. At times some soil properties needed for specific uses may be missing from mapping legend or soil report because most of the soil surveys are conducted for general land use planning and not for locale specific applications
- Soil maps are available at 1:250,000 scale for the whole country (NBSS & LUP) which serve the requirement of broad land use planning at regional / state level. In recent years for many of the projects concerned with conservation of natural resources or for planning the strategies to combat land degradation or to develop action plans to improve land productivity, the emphasis is on soil information at 1:50,000 scale especially for district level planning

- The existing soil maps at 1:50,000 scale with various organizations need to be checked for quality by an expert committee before using them to create database. This would also enable to identify the areas where soil surveys need to be repeated or partial surveys to be conducted to get data. Guidelines for quality auditing of soils maps should be formulated in consultation with various state / central government organizations. Even for the mapping to be done in future, quality of delineation, interpretation of remote sensing data, ground truth collection and soil chemical / physical analysis etc., has to be thoroughly standardized
- Design of a sound soil database using Geographical information System (GIS) for storage, updation, retrieval, analysis, modeling and generation of outputs is very essential. Though various soils survey organizations have developed their own data base, a national level expert committee should be formed to standardize the various aspects of creating digital base such as design, coding, GIS package to be used etc

4.9. Conclusions

The application of remotely sensed data from space borne sensors for study of soil resources is almost three decades old and its usage is increasing at a rapid pace. This potential of the remote sensing technology need to be exploited / employed on regular basis for mapping and monitoring soils / degraded lands at different scales. GIS based models for automatic land evaluation need to be developed for operational use. The utility of stereoscopic satellite data in soil mapping has not been fully exploited and greater scope is seen in this aspect. Soil informatics is still in R&D stage and high priority should be accorded for better utilization of soil information towards soil data handling and establishment of digital soil database. Ground Penetrating Radars for soil survey investigations was successfully demonstrated in various studies conducted in France and USA and used to study the presence, depth and lateral extent of soil horizons. These properties are useful for classifying the soils and estimate the taxonomic composition of soil map units. These techniques are needed to be explored. Polarimetric SAR data need to be explored for studying the spatial-temporal variations in soil moisture. The hyper spectral remote sensing data need to be explored to establish quantitative relationship between spectral reflectance and soil properties. The scope of data from remote sensing satellites with very high spatial, spectral and radiometric resolutions need to be made operational usage for micro-level (1:4000 to 1: 8000 scales) management of soil resources for sustained agricultural production.

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