

Chapter 15

Land Resource Inventory and Mapping: Tools and Techniques



S. K. Gangopadhyay, G. P. Obi Reddy, D. C. Nayak, and S. K. Singh

Abstract Nature, extent, and reliability of spatial data on land resources become the imperative need of the present day for scientific utilization of land resources and sustainable management. In land resource inventory and mapping, the applications of remotely sensed data and geographic information system (GIS) are found to be not only timesaving but also economic in generation of base maps and conducting of soil survey. Further, high-resolution remote sensing and applications of GIS have made the task of land resource inventory and mapping cost effective and time efficient. Depending upon the objective, method and intensity of land resource surveys and scale, the type of satellite data to be selected to generate the base maps in order to show the details of survey information. A detailed soil survey provides sufficient information about various kinds of soils, including problematic or degraded soils, and is immensely useful for resource appraisal and development of alternative strategies for land use and site-specific agricultural development. As a case study, a detailed land resource survey was conducted in Piprakothi Block under Purba Champaran district of Bihar, and it shows that soils are very deep, well to somewhat poorly drained, and highly calcareous. Soils suffer from waterlogging, frequent flooding, drainage congestion, calcareousness, salinity, and multi-nutrient deficiency, affecting the crop yield. Soil-site suitability evaluation of sugarcane in the soils of the block indicates that 31.7% of the area is moderately suitable for the cultivation of sugarcane due to moderate limitation of soil fertility and 53.0% of the area is marginally suitable due to relatively low water availability and severe soil fertility limitations.

Keywords Detailed soil survey · Exploratory soil survey · Geographic information system · Land resource inventory · Reconnaissance survey · Remote sensing

S. K. Gangopadhyay (✉) · D. C. Nayak
ICAR-National Bureau of Soil Survey & Land Use Planning, Regional Centre, Kolkata, India

G. P. O. Reddy · S. K. Singh
ICAR-National Bureau of Soil Survey & Land Use Planning, Nagpur, India

15.1 Introduction

Soil is one of the most valuable, life-supporting natural resources and an important component of a geosphere-biosphere system, which directly provides food, fuel, fiber, and fodder for a variety of human and livestock needs and indirectly contributes to regulations of water and nutrient supply to plants (FAO and ITPS 2015). The ever-burgeoning human and animal population coupled with the ever-shrinking per capita availability of land and water resources has resulted into a serious threat to the land resources in terms of quantity and quality resulting in poor agricultural productivity and ecological sustainability. Therefore, basic and reliable data on soil resources have become an imperative need of the present day for scientific utilization of land resources for the posterity (Reddy et al. 2017). The optimal management of land resources with minimal adverse environmental impact is essential not only for sustainable development but also for human survival. A knowledge of soil in respect to their extent, distribution, characteristics, use potential, and limitation is, therefore, extremely important for optimizing land use. Soil resource inventory provides an insight into the potentialities and limitations of the mapped area for its optimum utilization.

The study and assessment of soil properties and their response to management is important in agriculture and forestry for decision-making in agricultural land use planning and various land development projects. Soil survey information is a prerequisite to map the soils into relatively homogeneous units (Deshpande and Sarkar 2009; Sarkar 2003). Soil survey depicts ideal combination of changes of soil properties occurring in the landscape. The usefulness of soil survey depends on two things: the accuracy with which soil properties are mapped and the relevance to the purpose in hand. The information collected from a soil survey helps in the development of land-use plans and evaluates the effect of land use on the environment (Deshpande and Sarkar 2009).

Soil survey is essentially a systematic study, description, classification, and mapping of soils of an area in their natural environment. Soil survey comprises a group of interlinked operations involving fieldwork to study the important characteristics of soils and the associated external land features, such as landform, natural vegetations, slope, etc., and laboratory analysis to support and supplement the field observations, correlations, and classification of soils into delineated taxonomic units (Deshpande and Sarkar 2009). Mapping of soils is establishing and drawing of soil boundaries of different kinds of soils on a standard base map. Soil survey interpretations consist of making predictions about the potential of soils for alternative uses, like agricultural crops, grasses, fruit, and forestry or plantation crops, and ascertaining their management requirements for sustained production (Sehgal 1996). Transfer of agro-technology from research stations to farmer's fields based on precise soil information will be of more effective and sustainable. Various authors have reported the applications of remote sensing and GIS in soil resource inventory (Dobos et al. 2000; Dwivedi 2001; Srivastava and Saxena 2004; Reddy et al. 2013a, b; Gangopadhyay et al. 2014, 2015), land capability classification (Rosser et al.

1974; Panhalkar 2011), soil suitability assessment (Velmurugan and Carlos 2009; Boonyanuphap et al. 2004; Gangopadhyay et al. 2010), land productivity assessment (Patil et al. 2010), quantification of soil loss (Lal et al. 1998; Karale et al. 1988; Olson et al. 1998; Singh and Dwivedi 1989; Reddy et al. 2004, 2016), and assessment of biophysical resources (Reddy et al. 2013a, b).

15.2 Purpose and Objectives of Soil Survey

Modern soil surveys basically aimed at providing comprehensive information about soils and an inventory of the soil resources of the area. They consist of studying and recording important characteristics of soils in field and in laboratory, classifying them into well-defined units, and demarcating their extent on a map. The broad general objectives of soil survey are both fundamental and applied in nature. Fundamentally, soil surveys help in expanding our knowledge and understanding of different soils, as regards to their genesis, development, classification, and nomenclature. The applied part of soil surveys includes interpretation of soil data for use in agriculture, pasture development, forestry, engineering, urban development, recreation, and others. It gives information needed for development of land-use plans under irrigated and rainfed conditions. Further, it helps in correlating with characteristics of soils of known behavior and predicting their adaptability to various uses and also their behavior and productivity under defined sets of management practices. It thus forms the very basis for land-use planning as per the potential and limitations of soils. In addition, soil map helps in determining the degraded soils (Karale et al. 1988) such as saline, alkaline, waterlogged, water and wind eroded, and so-called wastelands and suggesting soil and water conservation measures to ameliorate these degraded soils. Furthermore, soil surveys are useful for land settlement, rehabilitation, tax appraisal, and locating and designing highways, airports, and other engineering structures and in public sanitation works.

15.3 Development of Soil Survey Program in India

Soil surveys were conducted earlier for developing irrigated agriculture for promoting sugarcane cultivation in the then Madras Presidency and also for understanding the causes of soil salinity in Bombay Deccan area. At the same time, surveys were undertaken in Uttar Pradesh, and a linkage between genetic soil types and specific management practices for the major crops was suggested (GOI 1984). Based on the report of the Royal Commission on Agriculture in India (1928), it was reported that the large-scale soil surveys in India may be taken up for specific purposes in specific areas. A wider range of investigations including soil characteristics like drainage, soil reaction, exchangeable bases and location, or concentration of clay and salts in the profile were considered. These studies mark the recognition of the importance of

profile characteristics, physical and chemical properties of the soil, as against the purely chemical studies of plant nutrients carried out earlier. Almost with similar objective but in a more comprehensive manner, soil surveys were carried out during 1953–1955 under Technical Cooperation Mission (TCM) project on “Determination of Soil Fertility and Fertilizer Use.” The Stewart Report in 1947 recommended soil surveys and fertilizer trials with a view to correlate fertilizer responses to different soil types. However, soil surveys carried out under this scheme were preliminary and broad types and yield only some general information.

Systematic studies on soils based on genetic factors have been initiated by Raychoudhury during the 1950s. Raychoudhury and Mathur (1954) divided India into 16 major soil regions with 108 minor basic soil regions by integrating the effects of climate, vegetation, and topography on soil formation. Further, Raychoudhury (1964) and Raychoudhury and Govindarajan (1971) have subdivided soils of India into 27 major groups. In the year 1954, the government of India invited Dr. F.F. Reickens, a soil specialist of the USA, to advise on soil survey work to be taken up in India. Following his recommendations, the All India Soil Survey Scheme was initiated in 1956 at Indian Agricultural Research Institute (IARI), New Delhi, with four regional centers, to carry out reconnaissance soil survey, correlate and classify soils, and prepare a small-scale soil map of India. In 1958, the scheme was integrated with the “Land Use Survey Scheme” of the central soil conservation board and redesignated as the All India Soil and Land Use Survey (AIS&LUS) presently renamed as Soil and Land Use Survey of India (SLUSI). The scope and activities of the enlarged scheme were expanded to cover detailed soil and land-use surveys in the catchments of major river valley projects (RVPS). In 1969, AIS&LUS was bifurcated, and the portion remaining with the Department of Agriculture was entrusted with responsibilities of soil surveys for soil conservation and other developmental activities. The research aspects of soil survey, classification, and correlation including countrywide reconnaissance surveys and training were taken over by the Indian Council of Agricultural Research (ICAR), which was known as All India Soil Survey Unit of ICAR. Based on the presidential notification in 1973, this unit was converted into a directorate and was given the status of national bureau and renamed as National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) in the year 1976 with its headquarters at Nagpur. As per the recommendations made by the task force in 1972 on land and soil resources for soil correlation, uniform nomenclature, and proper soil mapping and also following the presidential notification on December 15, 1973, the duties with respect to research, training, correlation, mapping, and interpretation were entrusted with the NBSS&LUP.

15.4 Basic Understanding from Soil Surveys

Unlike in other types of surveys, soil survey is not aimed to identify soils per se or delineate areas having absolutely same soil, but to separate areas having almost similar soils requiring similar management needs (Sehgal 1992). This means that

within a certain range of soil properties, the management needs would not vary and there is likely to be similar response by plants of same species. There are thus ranges in soil properties, which can be standardized for a particular area and scale of mapping. This concept of identifying soils in the field based on their range in characteristics has shifted the earlier focus of studying soils in the field from pedon to pedon. Thus, polypedon has become the unit of soil, but locating the boundary of the polypedons in the field is a challenge for soil scientists. There is a close relationship existing between the various landforms and types of soils present in an area. Since, the properties of a soil change gradually from one place to another and governed by various factors and processes of soil formation, the change observed at the surface if any one of these features (like changes in slope, erosion, wetness, land use, etc.) can be used to identify the boundary of the soil (polypedon) in the field.

The concept of polypedon as a unit of soil with their range in characteristics and linking their boundary with changes observed in the landforms has helped the soil surveyors in identifying the soil and their boundaries in the field easily. Further, this concept serves the purpose of the land user better, because this approach divides the landform into more homogenous units suitable for better management of the land resources based not only on soil but also by all the site characteristics.

15.5 Types of Soil Surveys

Depending upon the objective, method and intensity of surveys, scale and type of base map used, and resulting detail and precision of mapping, the following types of soil surveys are recognized.

15.5.1 Exploratory Soil Survey

Surveys at 1:1,000,000 and 1:2,50,000 scale can be employed for large areas as general inventory maps of soils as a natural resource. At these small scales, surveys rely heavily upon satellite or extensive air photo interpretation as most boundaries are drawn in the laboratory on the evidence of interpretative methods. Ground inspection of soils is limited to approximately one per km² and takes the form of checking areas defined upon air photographs to see if the boundaries are valid and that the soils belong to particular great soil groups or orders. In addition to the general inventory purpose, these maps may be used for large-scale comparative exercises and for identifying sites for future work and macro-level planning for various agro-based developmental programs.

15.5.2 Reconnaissance Survey

The reconnaissance survey is undertaken to prepare resource inventory of large areas. Their major purpose is to identify possible areas for further intensive soil survey works which might be done before locating a new irrigation scheme. Reconnaissance survey enables to access broad potentialities of soils and recognition of areas that are suitable for intensive agriculture and helps in recognizing areas which require amelioration due to their suffering from erosion, acidity, salinity, and sodicity, which affect soil fertility and capacity for crop production. In reconnaissance soil survey, only few or part of the soil boundaries is actually checked in the field, and the remaining are extrapolated from the available information.

In reconnaissance survey, toposheets and satellite images, either alone or in conjunction, are used as a base for mapping soils. The scale of mapping can vary from 1:50,000 to 1: 500,000, but normally 1:50,000 or 1:100,000 scale is preferred. First the satellite images (1:50,000 scale) are interpreted, either visually or digitally, in conjunction with the available collateral data from toposheets and geological and land-use/land cover maps to identify the various landforms occurring in the area. Then based on slope, elevation, and image characteristics, the landforms are delineated into physiographic/photomorphic units. The delineated boundaries are transferred to 1:50,000 scale Topobase and used as a base map for field survey and mapping. Many authors conducted reconnaissance survey at district level (1:50,000 scale) for optimum land-use planning (Gangopadhyay et al. 2013; Nayak et al. 2014; Verma et al. 2015). The type of soil survey and potential satellite sensor data for the use at different scales is shown in Table 15.1.

For the survey, a base map of 1:100,000 or (smaller) (1:2,50,000) is used. Aerial photo or interpretation of remotely sensed data is the basis for physiographic boundary location. The land type, land use, texture, and tone of images are used as a basis for boundary delineation. These are checked in the field by a few random checks to develop and confirm correlation between soils and land types. The soils are identified by traversing represented areas to determine soil patterns and composition of map units. The boundaries plotted by interpretation of remote sensing data are confirmed by ground truth checks. The fieldwork will involve studies of profiles at an interval of 2–3 km or shorter depending upon the soil heterogeneity. Auger

Table 15.1 Type of soil survey and potential satellite sensor data

Type of survey	Scale of survey	Mapping unit	Sensor data used
Reconnaissance	1:2,50,000	Subgroup association	Landsat MSS LISS-I, IRS LISS-I
Semi-detailed reconnaissance	1:50,000	Families/series association	Landsat TM-2,3, IRS-1A, 1D-LISS-III, IRS IC LISS-III, Spot
Detailed	1:25000	Phases of soil series	IRS IC, LISS-III and PAN data, IRS P6 LISS-IV

sampling for every 1/4 to 1 km is carried out to study the variation in profile characters.

After rapid traverse of all the physiographic/photomorphic units, representative areas are selected for transect study and soil profile examination. In the selected transect or sample area, soil profiles are studied at close intervals based on the difference observed in slope, erosion, moisture content, presence of gravels, land use, etc. The soil profiles from transect study are grouped into soil series and preliminary legend with association of soil series as mapping unit is determined by translating each image interpretation-cum-physiographic unit in terms of soils. The preliminary physiographic soil legend forms the base for further survey and mapping. Any further investigation done in the field is only for the confirmation of this preliminary legend.

To test the validity of the preliminary legend, minipits, auger borings, road cuts, well cuts or gully cuts, and soil profiles are examined in the entire survey area. In the course of the survey, if any variations are observed, then the preliminary legend and whatever necessary the delineation is modified accordingly. This way, the legend is progressively modified and refined as the survey progresses and soil map is finalized for the area with associations, complexes, and undifferentiated groups as soil mapping units. The draft physiography-cum-soil map thus prepared for the area can be subjected to test its validity. Soil samples from typifying pedons are collected for laboratory characterization as per the guidelines. The field map in different sheets can be scanned and digitized, and final soil map can be generated using the GIS software.

The reconnaissance soil survey is being carried out following a three-tier approach comprising image interpretation, field survey and soil analysis, and cartography and printing.

The different steps involved in this type of survey are:

- Collection of available soil survey information
- Image interpretation, field survey, and mapping
- Laboratory analysis of soil
- Cartography/GIS and printing
- Interpretation for land-use planning

15.5.3 Detailed Reconnaissance Survey

This kind of survey combines both the detailed and reconnaissance surveys and is undertaken for understanding distribution of basic soil classes of series/families and their phases. The selected areas that have development potentials are surveyed in detail and the others at reconnaissance level.

15.5.3.1 Image Interpretation

The soil survey is carried out on 1: 50,000 scale by using the Survey of India toposheet and satellite imagery (FCC) as base maps. The geocoded IRS-ID LISS-III false-color composite (1:50,000) was visually interpreted for landform analysis based on the color, tone, texture, and pattern of false-color composite (FCC) and field visit. The information thus generated is being transferred to the toposheet on the same 1:50,000 scale, and the Topobase was prepared for undertaking the soil survey following the procedure as outlined in the *Soil Survey Manual* (Soil Survey Staff 1995). Out of the area surveyed at reconnaissance level, the selected areas that have development potentials are surveyed in detail. For this purpose, a cadastral map on 1:12500/1:10,000/1:4000 scale is usually employed. Interpretation of IRS-ID LISS-III fused with PAN/IRS-P6 LISS-IV false-color composite and its superimposition on the cadastral map helps in the delineation of landforms, which are further confirmed by traversing and ground truth checking. The Topobase thus prepared is being used for detailed soil survey of the selected area.

15.5.3.2 Soil Sampling/Fieldwork

Field surveys include the study of soil profiles in all the landform units to represent the soil-physiography relationship. The morphological features of representative pedons were studied up to a depth of 150 cm or more/lithic contact (for shallow soils), and the soil samples were collected from different horizons for laboratory analysis. Soil-physiography relationship was established, and a random study of soil profiles at different landform units was also carried out to confirm the soil-landform relationship. During soil survey, field reviews were conducted to correlate and classify the soils up to the soil series level (Soil Survey Staff 1999). The surface soil samples (0–25 cm) were also collected at an interval of 100 meter for preparing the soil fertility maps of the study area.

For a detailed survey of the selected portion of the study area, soil profiles are exposed to a depth of 150 cm in each and every landform, and the morphological properties are being studied in all the horizons. The representative soil samples from each and every horizon were collected and analyzed in the laboratory as per the standard procedure. For soil fertility mapping, the surface soil samples (0–25 cm) were also collected at an interval of 10 m from the selected area and analyzed to determine various soil macro- and micronutrients.

15.5.3.3 Soil Analysis

The soil samples collected from different genetic horizons were air-dried and analyzed for the physical and chemical properties, viz., particle size class, pH, organic carbon, cation exchange capacity, exchangeable bases and exchangeable

acidity (H^+ and Al^{3+}), available macro- and micronutrients, etc., following standard procedures (Black 1965). Of the two series, the dominant one occupies 60% or more of the area; the subdominant series covers 30% or more of the area of the mapping units. Soils have been mapped in relation to landform units. The soil map shows the soil association numbers (polygon nos.) such as 1, 2, 3. . . . Each polygon number specifies a map unit representing the association of two soil series (dominant and subdominant).

15.5.3.4 Generation of Thematic Maps and Analysis Through GIS

For preparing the various thematic maps, viz., district boundary, drainage and water bodies, road network, contours and heights, soil map, etc., the satellite data and SOI toposheets are used as inputs to Geo-Media Professional GIS (Ver. 3.0) system. The maps are subsequently transformed to vector layers. These covers are projected and transformed to real-world coordinates, edited, and assigned polygon IDs, and topopolygon is built for areas and polygons. Using the available profile-wise soil information (soil morphological and physicochemical properties), attribute/nonspatial data could be compiled at mapping unit level. This attribute data is then linked to the spatial data. These are subsequently made into individual covers of soils by adding items in the polygon attribute table (PAT) of soil coverage following map generalization procedures. These are subsequently made into individual covers using “dissolve operation” thus forming different derivative thematic maps. Thus, various thematic maps could be prepared in GIS based on dominant soils of the mapped unit.

15.5.4 Semi-detailed Survey

This survey comprises very detailed study of some selected strips cutting across many physiographic units for developing correlation between physiographic units and soils. Once the correlation is developed and is found to be valid by random checking, the rest of the area is checked at random, and soil boundaries based on physiographic units are delineated. The base maps commonly used for detailed soil surveys are cadastral maps of about 1:5000–1:8000 scale, topographical maps of 1:25000–1:2,50,000 scale, aerial photographs of 1:10,000–1:50,000 scale, or Indian remote sensing data on 1:25000–1:2,50,000 scale. Aerial photo interpretation may have its part to play in boundary location at these scales, but ground observation becomes increasingly important as the scale becomes larger. Thus maps compiled at 1:1,00,000 would have soil associations as their mapping units, but maps at scales larger than 1:50,000 would have soil series as the major mapping unit. A detailed soil survey provides sufficient information about various kinds of soils, including problematic or degraded soils – soil surveys published at scales between 1:1,00,000 and 1:50,000 scale are used for general resource appraisal purposes at regional level and to establish areas for detailed investigations. The semi-detailed surveys provide a

basis for developing alternative strategies for land use, settlement, or agricultural development. The relationship between the scale of soil mapping and frequency of field observations is shown in Table 15.2. The scale, minimum area covered, and minimum number of observations to be studied at different scales are shown in Table 15.3.

15.5.5 Grid Soil Survey

Grid survey is generally employed where a survey of detailed or very detailed nature is required in difficult terrain. It is most suitable for scales of soil mapping greater than 1:10,000 and is used for all intensive soil surveys. If the area is a plain (like in a delta or alluvial plain or if the slope gradient is negligible), then locating of soil profiles in transects is not possible. In such situations, either freestyle survey or grid type of survey is recommended to locate the profiles. In a grid survey, soil profiles are located at a predetermined interval irrespective of variations encountered in the field. Though the number of profiles studied will be more in a grid type of survey, it is the easiest method to follow by the surveyor. However, one major disadvantage of the method is that it can be inflexible in areas where the soil pattern is simple and it can lead to wastage of time and resources. It can also result in inspection taking place too close to roads or the rivers. The grid survey is also adopted for mapping small areas, such as micro-watershed or an agricultural research station. With the use of global positioning system (GPS) and computers, grid survey at geo-referenced points (with latitude and longitude) has been found to be of great value in digitization of database and generating several thematic maps of practical value.

15.5.6 Free Soil Survey

At semi-detailed and reconnaissance scale of soil mapping, the most economical method of producing a soil map is by “free survey.” As the surveyor walks across the field, he positions his soil observations according to his interpretation of the landscape and soil boundaries according to morphological breaks and changes of slope. The selection of observation points depends on the assumption that change in physiography (as observed by aerial photographs) and other surface features such as soil color, vegetation, and land use are indicative of differences in soil characteristics. The density of observations can be varied as the mapper concentrates on confirming the inferred boundaries and checking the uniformity of the soil within each boundary. On large scales, the inferred boundaries are often accepted as soil boundaries, and very little efforts are made to find soils within the physiographic

Table 15.2 Relationship of the scale of soil map and frequency of field observations

Kind of survey	Scale of base map	Area represented by 1 cm ² on map (ha)	Distance between field observations	Frequency of observation	Mapping unit	Accuracy of soil boundaries
Reconnaissance	1:2,50,000	625	2.5 km	1 in 625 ha	Association of soil groups or soil families	Almost all boundaries are inferred
	1:1,00,000	100	1.0 km	1 in 100 ha		
Semi-detailed	1:50,000	25	500 m	1 in 25 ha	Soil series or association of soil series	Some boundaries are checked (sample areas); most inferred
Detailed low intensity	1:10,000	1	100 m	1 per ha	Phases of soil series	Almost all boundaries are checked through the course of traversing
High intensity	1:5000	0.25	50 m	4 per ha	Phases of soil series	All boundaries are checked through the course of traversing

Table 15.3 Scale, area of 1 cm² on the map, and minimum number of observations per km²

Scale of map	Size of 1 cm ² area	Minimum number of observations per km ²
1:2500	0.000625 km ²	8000
1:10,000	0.01 km ² (1 ha)	400
1:25,000	0.0625 km ²	64
1:50,000	0.25 km ²	16
1:1,00,000	1 km ²	4
1:2,50,000	6.25 km ²	0.7
1:5,00,000	25 km ²	0.15
1:10,00,000	100 km ²	0.05

boundaries. On large scale, however, several new boundaries within physiographic boundaries are recognized depending upon the scale of mapping. Based on the differences in physiography, parent materials, drainage class, and profile development, surveyors group soils of an area into defined soil map units, the limits of which are rigidly defined as per criteria used. For general purpose, each soil map unit is built around a central concept covering a limited range in the values of several soil parameters. Sometimes, the soils are grouped at soil series level.

The great advantage of this method is that the surveyor is free to vary the intensity of his observation according to the intricacy of the soil pattern. This results in great accuracy when soil parameters are complex and does not waste time and energy when conditions are uniform. The use of free survey method necessitates a good base map or aerial photograph upon which the surveyor can work without any problem of location so that observations and boundaries are correctly placed. Experience has shown that free survey is best adopted for the production of maps between the scales of 1:1,00,000 and 1: 25,000.

15.5.7 Detailed Soil Survey

This type of survey is undertaken in priority areas such as pilot projects, agricultural stations/farms, micro-watershed, and areas for urban development. For this kind of soil survey, cadastral maps on 1:4000–1:8000 or aerial photos of 1:10,000 scale are used depending upon the intensity of survey and developmental need of the areas. The purpose of detailed soil survey is to delineate similar areas, which respond or expected to respond similarly to a given level of management. This is achieved by studying all the site (such as slope, erosion, drainage, salinity, occurrence of rock fragments) and soil characteristics (such as depth, texture, color, and soil reaction) in detail and delineating/grouping areas based on their similarity or differentiating characteristics into various management units.

15.5.7.1 Pre-field Activities

The scale and type of base map required for survey is very important because that will decide the amount of information that can be depicted on the map. The larger the scale used, the more will be the information available and vice versa. For detailed soil survey, cadastral maps showing field boundaries and survey numbers are the most suitable maps. High-resolution large-scale satellite images available from Indian remote sensing satellite (IRS)-1D or Resourcesat at 1:12,500 scale can be used as a base in conjunction with the cadastral maps for field survey. In addition to the base maps, 1:25,000 or 1: 50,000 scale toposheets and geological and landform maps available for the survey area can be used for traversing the area for preparing preliminary legend. At 1:25,000 scale, the smallest area, which can be conveniently shown true to scale, is 0.25 ha, and a soil boundary line on the map represents a zone of 5 m wide on the ground. When the scale is increased to 1:10,000 scale, the smallest area, which can be conveniently shown, is 0.625 ha, and at this scale a boundary line on the map represents a zone only 2 m wide on the ground.

Before starting fieldwork in the selected village/block, preliminary traverse of the surrounding areas is to be carried out with the help of the cadastral map, toposheets, or satellite images of the same scale. During the traverse, based on geology and landform position, the major landform divisions occurring in the block are to be delineated first. This is followed by the identification of various landforms occurring within each physiographic division based on shape, slope, and position in toposequence.

15.5.7.2 Field Activities

Soil boundaries are demarcated by actual traverse throughout the course. After careful delineation of the various landforms, updating the cadastral sheets with new permanent features, and familiarization of the area with survey numbers and field boundaries, intensive traversing of each landform (like ridges, uplands, lowlands/valleys, etc.) is undertaken to select representative areas for transect study. Transects are located across the slope and cover most of the variations or changes observed in a landform. In the selected transect, soil profiles are located at closely spaced intervals to take care of any change in the land features like break in slope, erosion, gravels, stones, etc. In the selected sites, soil profiles were to be opened up to 150 cm or hard substratum or rock, whichever comes earlier, and studied in detail for all their morphological properties. Detailed soil and site characteristics are to be recorded in the standard proforma for all the profile sites as per the guidelines given in the *Soil Survey Manual* (IARI 1971; Soil Survey Staff 1951, 1993). Apart from the transect study, if the distance between two transects are more, then few more soil profiles can be studied in between the transects, and in areas not covered by the

transects, additional profiles at random can be studied to bring out all the possible variability of the survey area. Auguring can also be carried out to study soil properties whichever possible in the field.

The soil mapping can be done by intensive traversing covering all plots and survey numbers after grouping the soils into different soil series within each landform. During the traverse, starting from one transect area, boundary between two series can be established by checking for the differentiating characteristics of one series from the other through minipit, auger, road cut, well cut, or any other information available from the area. The exercise is continued and boundaries established for all the series identified in the area. During this exercise itself, within the delineated area of a soil series, based on variations in the surface texture, slope, erosion, presence of gravels, salinity, etc., phases of soil series can be separated, and their boundaries can be delineated on the cadastral map. The survey enables identification of soil units up to phases of soil series for planning development of individual parcels of land. Soils in detailed survey are examined in details and closer intervals so as to detect differences that can be significant in their use and management. A detailed soil survey furnishes detailed information required for proper assessment of soil properties, terrain features, erosional aspect, and related factors, which help to work out the details about use capability and management practices that would be needed for conservation and crop production.

15.5.7.3 Laboratory Analysis

Soil samples collected from different genetic horizons have to be analyzed for the physical and chemical properties, viz., particle size class, pH, organic carbon, cation exchange capacity, exchangeable bases and exchangeable acidity (H^+ and Al^{3+}), available macro- and micronutrients, etc., following standard procedures (Black 1965). Based on the morphological, physical, and chemical characteristics, soils can be grouped into a series depending upon similarities in soil characteristics, and the extension of the soil and the name of the series is given in the name of the area, i.e., name of the village or adding numbers with the name of the village (Piprakothe-1, Piprakothe-2. . ., if the Piprakothe village has got two soil series) or the name of the river, etc. Again, the mapping units are prepared based on the different phases of soil series like slope, soil depth, surface texture, erosion, salinity/sodicity, gravelliness, etc. For example, the mapping unit Pip-sic-d5/A-e1 indicates that Pip represents the name of the soil series Piprakothe; sic, surface texture, silty clay; d5, very deep; A, nearly level; and e1, slight erosion. In detailed soil survey, the mapping units are phases of soil series.

15.5.7.4 Post-field Activities

The scale and type of base map required for survey is very important because that will decide the amount of information that can be depicted on the map. The larger the scale used, the more will be the information available and vice versa. For detailed soil survey, cadastral maps showing field boundaries and survey numbers are the most suitable maps. High-resolution large-scale satellite images available from IRS (IRS-1D fused with PAN or Resourcesat (IRS-P6 LISS-IV) at 1:10,000 scale can be used as a base in conjunction with the cadastral maps for field survey. In addition to the base maps, 1:25,000 or 1:50,000 scale toposheets, geological and landform maps available for the survey area can be used for traversing the area for preparing preliminary legend. At 1:25,000 scale, the smallest area, which can be conveniently shown true to scale, is 0.25 ha, and a soil boundary line on the map represents a zone of 5 m wide on the ground. When the scale is increased to 1:10,000 scale, the smallest area, which can be conveniently shown, is 0.625 ha, and at this scale, a boundary line on the map represents a zone only 2 m wide on the ground.

Before proceeding for soil survey work, the available secondary information pertaining to the area, viz., geology, geomorphology, groundwater depth, rainfall, and temperature, are collected. After procuring the remote sensing data, it is interpreted visually/digitally, and the information generated based on remote sensing data were superimposed on the cadastral map of the area, and thus the base map is produced for soil survey work. With the base map thus prepared, the surveyor has to go to the field and performs extensive traversing of the area to find out the different features observed on the ground, i.e., the changes in slope, direction of slope, surface stoniness, erosion status, and other morphological features like waterlogging, surface cracks, salinity/sodicity, wasteland areas, etc. During field traverse, the features observed in the field were compared with the base map prepared from the interpretation of satellite image, and if anything is found not matching with the map information, the ground truth was recorded, and finally the base map is modified, and thus the final base map is used for soil resource inventory.

Based on the soil-site characteristics, the soils were grouped into different soil series (soil series is the most homogeneous unit having similar horizons and soil properties and behaves uniformly for a given level of management). The important characteristics used to group the pedons into different soil series are soil depth, texture, color, amount and nature of coarse fragments present, calcareousness, presence of calcium carbonates, mottles, coats, stress features, nature of the substratum, horizon sequences, etc.; a significant difference in any one of these characteristics can be the basis for recognizing a different soil series. For the soil series identified in the study area, the characteristics that differentiate one series from another are listed in the form of a table. In any survey area, the differentiating characteristics between one soil to another will be only few in number, and this table helps the surveyor to identify and remember them easily.

15.6 Soil Mapping

Soil mapping is done by intensive traversing covering all plots and survey numbers after grouping the soils into different soil series within each landform. During the traverse, a boundary between two series is established by checking for the differentiating characteristics of one series from the other through a minipit, auger, road cut, well cut, or any other information available from the area.

15.7 Detailed Land Resource Survey: A Case Study

15.7.1 Study Area

The detailed land resource survey was conducted in Piprakothi Block under Purba Champaran district of Bihar which is located between $26^{\circ}31'40''$ to $26^{\circ}36'20''$ N latitude and $84^{\circ}51'49''$ to $85^{\circ}02'07''$ E and consists of 20 villages covering 6613 ha area representing nearly level to very gently sloping alluvial plain (AESR – 13.1) developed from the deposition of alluvium from the Nepal Himalayas and also from the Ganga river (Fig. 15.1). The mean maximum temperature of the area is 46°C , and the mean minimum temperature is 05°C , and the average rainfall is 1242 mm. Geology of the area is depositional landforms of recent origin and developed from the alluvium deposited by the Ganga river and its tributaries and also from Nepal Himalayas. The major landforms are young alluvial plain and active alluvial plain (meander plain, point bar, and oxbow lakes) with a flat topography sloping toward east. The major crops cultivated in this area are *kharif* paddy, wheat, sugarcane, maize, vegetables, and horticultural crops, viz., mango and litchi. The soils are very deep, well to somewhat poorly drained, and highly calcareous. The soils suffer from waterlogging, frequent flooding, drainage congestion, calcareousness, salinity, and multi-nutrient deficiency, affecting the crop yield.

15.7.2 Image Interpretation

IRS Resourcesat-II (IRS-P6) LISS-IV image of March 13, 2015 (Fig. 15.2), was interpreted based on the tone, texture, size, shape, and pattern for the delineation of landforms, which were confirmed by intensive traversing of the area. The image of the block was superimposed on the cadastral map of the block to prepare the base map for undertaking the soil survey following the procedure as outlined in the *Soil Survey Manual* (Soil Survey Staff 1995).

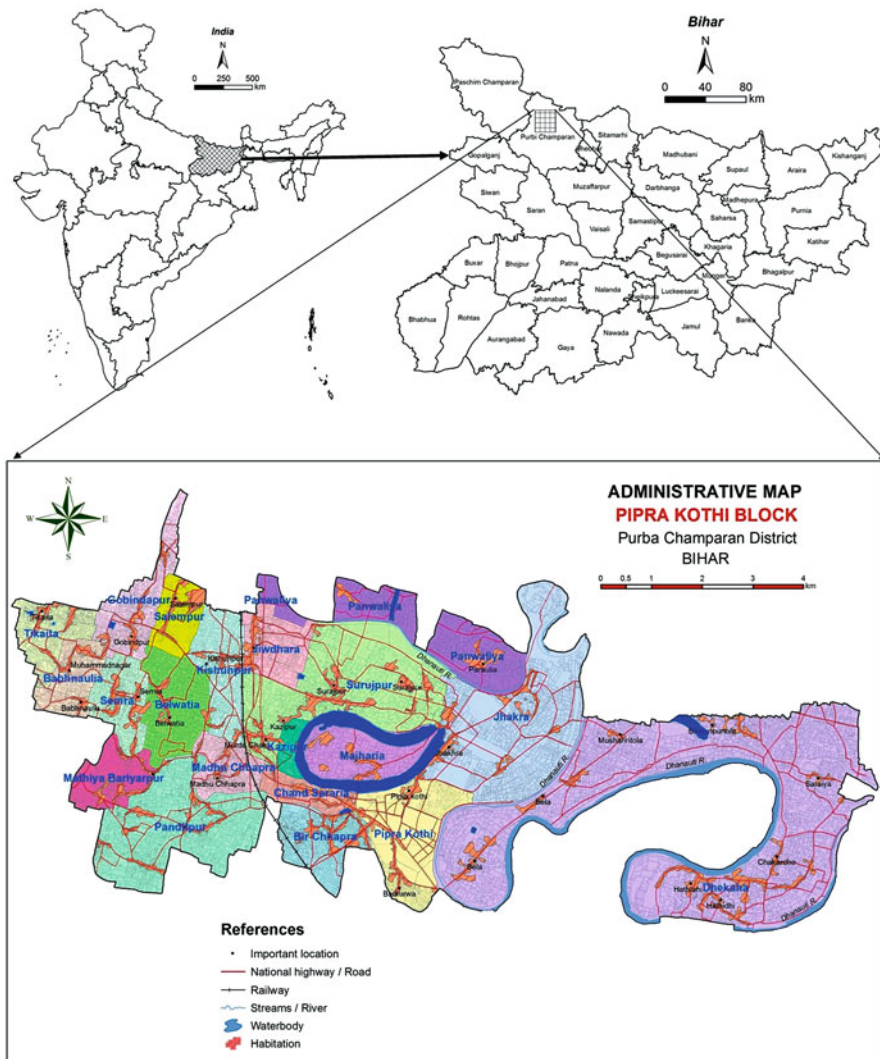


Fig. 15.1 Location map of Piprakothi Block, Purba Champaran district, Bihar

15.7.3 Soil Sampling/Fieldwork

Field surveys include the study of soil profiles in all the landform units. The morphological features of representative pedons were studied up to a depth of 150 cm or more/lithic contact (for shallow soils), and the soil samples were collected from different horizons for laboratory analysis. Soil physiographic relationship was established and random study of soil profiles at different landform units was also

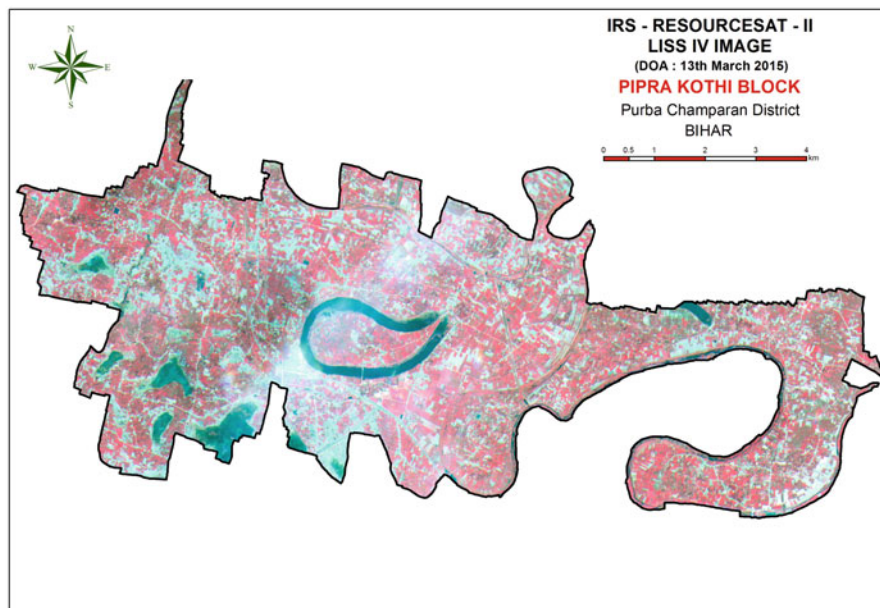


Fig. 15.2 IRS-P6 LISS-IV image (March 13, 2015) of Piprakothi Block, Purba Champaran district, Bihar

carried out to confirm the soil landform relationship. During soil survey, field reviews were conducted to correlate and classify the soils up to the soil series level (Soil Survey Staff 1999). The surface soil samples (0–25 cm) were also collected at an interval of 2.5 ha in the block for preparing the soil fertility maps of the block. Methodology adopted in land resource mapping is shown in Fig. 15.3.

The soil mapping is done by intensive traversing covering all plots and survey numbers after grouping the soils into different soil series within each landform. During the traverse, boundary between two series is established by checking for the differentiating characteristics of one series from the other through minipit, auger, road cut, well cut or any other information available from the area. The exercise is continued and boundaries established for all the series identified in the area. During this exercise itself, within the delineated area of a soil series, based on variations in the surface texture, slope, erosion, presence of gravels, salinity, etc., phases of soil series are separated and their boundaries delineated on the cadastral map.

15.7.4 Soil Analysis

The soil samples collected from different genetic horizons were air-dried and analyzed for the physical and chemical properties, viz., particle size class, pH, organic carbon, cation exchange capacity, exchangeable bases and exchangeable

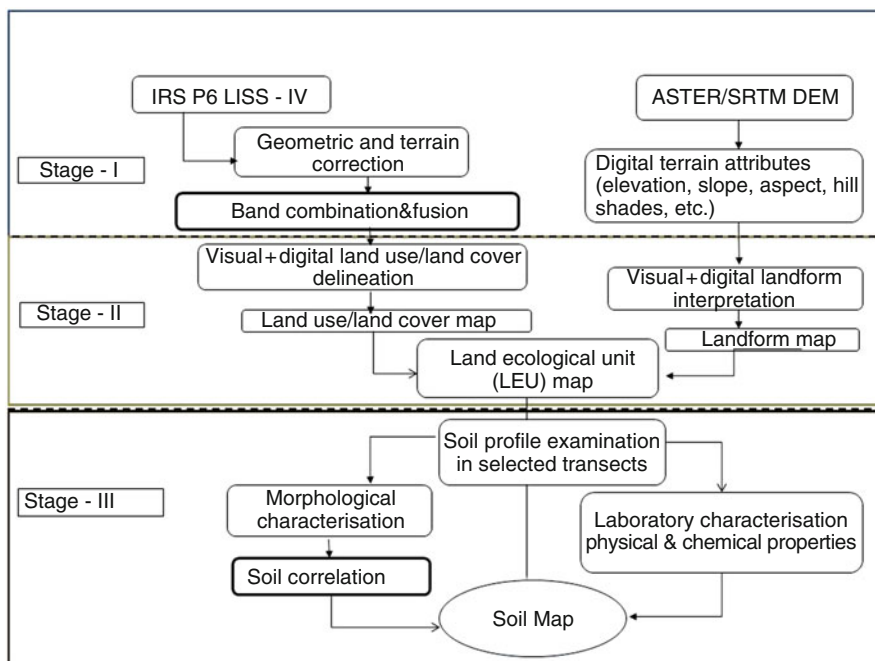


Fig. 15.3 Methodology adopted in land resource mapping

acidity (H^+ and Al^{3+}), available macro- and micronutrients, etc., following standard procedures (Black 1965). The soil map of Piprakothi Block was prepared on 1:10,000 scale with phases of soil series as mapping unit. A total of 7 soil series were identified and mapped into 13 mapping units (Fig. 15.4).

15.7.5 Soil Physical Characteristics

Soils of Piprakothi Block are very deep, moderately well to imperfectly drained, developed from alluvium of Ganga river as well as from the Nepal Himalayas, grayish brown to dark yellowish brown in color, and mostly silt loam to silty clay loam in texture. The particle size distribution of these soils indicates that these soils are dominant in silt and are mostly in the form of fine silt which restricts the infiltration and reduces the permeability of soils. The soils are very prone to flooding, and in *kharif* season, the low-lying areas are flooded extensively, and crops cannot be grown in these areas. The presence of redoximorphic features, viz., mottles in subsurface horizons, indicates fluctuation of groundwater in these soils. Paddy, wheat, maize, pulses, oilseeds, and sugarcane are mostly grown in this area.

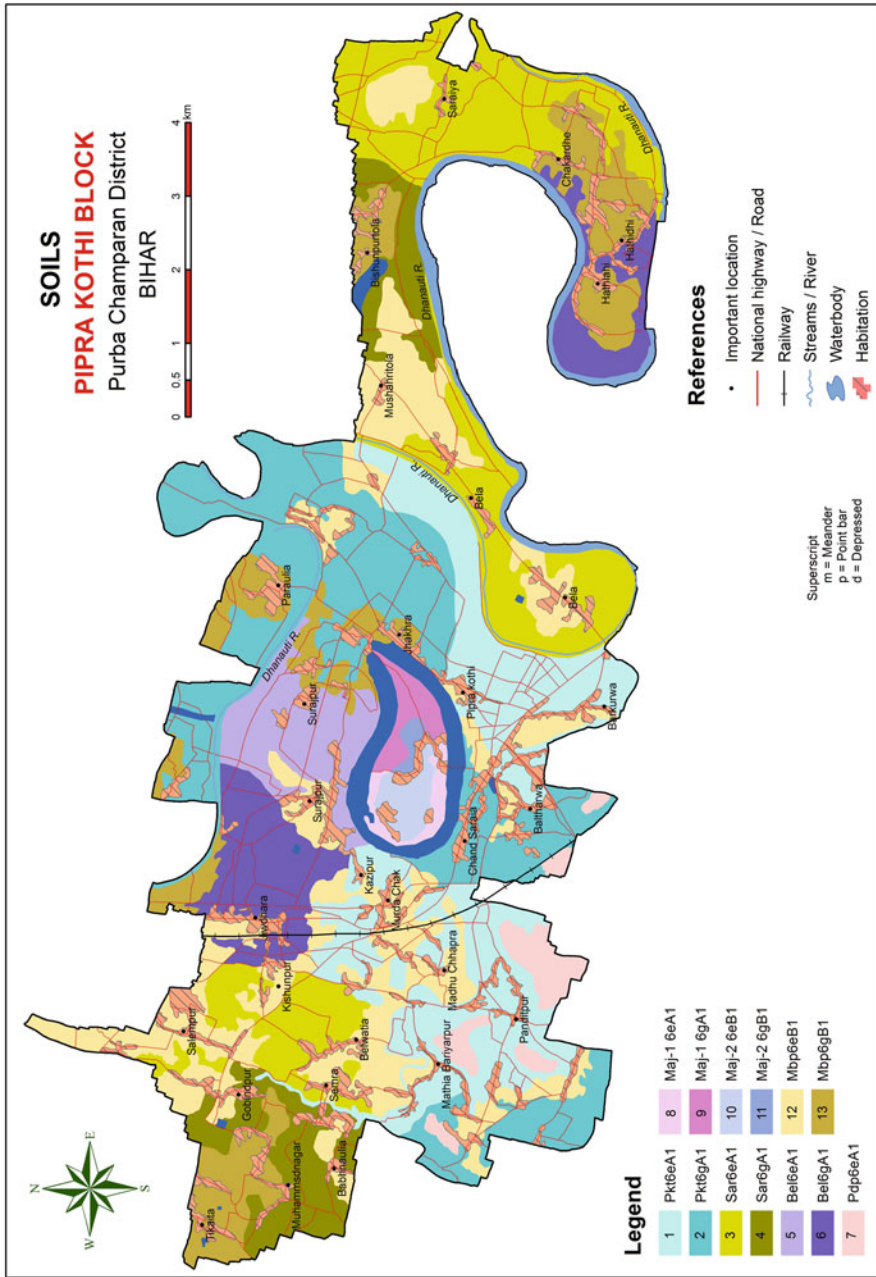


Fig. 15.4 Soil map of Pipra Kothi Block, Purba Champaran district, Bihar

15.7.6 Soil Chemical Characteristics

Soils are mostly alkaline, and the pH of the soils ranges from 7.0 to 9.9. However, the electrical conductance (EC) of the soils is low (0.1–0.97 dS m⁻¹), and also the EC_e (electrical conductance of the saturated paste of the soil) ranges from 1.4 to 5.8 dS m⁻¹. Soils are rich in silt (more than 65%), and the clay content varies from 13 to 37%. Soils are low to high in organic carbon (1.0–14.0 g kg⁻¹) and are low in CEC (2.0–9.9 cmol (p⁺) kg⁻¹) with high base status (80–90%). Soils are highly calcareous, and the CaCO₃ content varies from 40 to 50%.

15.7.7 Land Capability Classification

Land capability classification is an interpretative grouping of soils mainly based on (i) the inherent soil characteristics, (ii) external land features, and (iii) environmental factors that limit the use of land (Dent and Young 1981). Information on the first two items is provided by a standard detailed soil survey. Scientific survey and classification of soils are the primary requirements for grouping soils according to their capability for use of varying intensity. Capability grouping is thus another aspect of soil survey work and is closely related to soil correlation. The taxonomic soil units established after field and laboratory studies and correlation are the ultimate management units, which afford specific information about the ability of the soil to respond to use, management, and plant growth.

The basic USDA land capability classification allocates land suited to cultivation to classes I to IV followed by land suited to grazing to classes V to VII and forestry to class VII, leaving class VIII for wildlife and recreation (Dent and Young 1981). In Piprakothi Block, soils are suffering from drainage congestion, calcareousness, and salinity and hence mostly grouped under the land capability subclasses IIws and IIIws indicating the limitations of drainage and soil.

15.7.8 Land Irrigability Classification

The interpretation of soil and land conditions for irrigation is concerned primarily with predicting the behavior of soils under the greatly altered water regime brought about by introduction of irrigation. For irrigation projects, interpretations are required to indicate the areas suitable for irrigation, crops that may be grown, yields that may be expected, water delivery requirements, land development needs, problem in drainage, and special reclamation practices. The soils are first grouped into soil irrigability classes according to their limitations for sustained use under irrigation, regardless of their location. Soil irrigability classes are useful to make groupings of soils according to their suitability for sustained use under irrigation. The

classes are defined in terms of the degree of soil limitations. Soil irrigability classification is made on the basis of important soil characteristics, viz., soil texture, depth, available water-holding capacity, infiltration, and permeability. Soil irrigability classification of the soils of Piprakothi Block grouped them into two soil irrigability subclasses, viz., 2ds and 3ds indicating the major limitations of drainage and soil.

15.7.9 Soil-Site Suitability Evaluation

Each plant requires definite soil and climatic conditions for optimum growth. Since the availability of both water and plant nutrients is largely controlled by the physical and chemical properties and microenvironments of soils, the success and failure of any species in a particular area is, therefore, governed by the soil characteristics. The soil-site suitability studies for different plant species illustrate how soil depth, subsoil texture, salinity, and drainage conditions are related to the site quality. The objectives of various site evaluation studies are to predict and classify land for growth. Since such evaluation of land has gained high popularity in almost every land development program, the objective of this study is to develop criteria for soil-site suitability evaluation on the basis of the available soil and site characteristics, so that the soil maps can be interpreted in terms of suitability for agricultural crops and/or forest plantations.

The FAO panel for land evaluation suggested the classification of land for specific use (FAO 1976). The classification itself is presented in different categories or orders (S for suitable and N for unsuitable land). There are three classes (S1 to S3) under the orders S and two classes (N1 to N2) under the order N. The appraisal of the classes within an order is done according to the evaluation of land limitations or the main kinds of improvement measures required within classes. The limitations are climate (c), topography (t), wetness (w), salinity (n), soil fertility (f), and physical soil limitations (s). They are indicated by the symbol, for example, S2w, where w indicates wetness limitation (subclass). The limitation approach has successfully been used to provide a qualitative land evaluation based on general characteristics which are made available after a quality soil survey and a general study of other resources. Sys et al. (1993) proposed a scheme for evaluating the degree of limitation rating with the following general observations.

0 (No limitation)	Optimum crop growth
1 (Slight limitation)	Nearly optimum for crop growth
2 (Moderate limitation)	Moderate influence on crop growth decline
3 (Severe limitation)	Uneconomical for the suggested land use
4 (Very severe limitation)	Yield below profitable level not fit for suggested land use

The soil-site parameters considered for the purpose of evaluating land for general agricultural crops, horticultural crops, other plantation crops, and forestry are as follows. These are considered for defining suitable classes.

Soil-site characteristics	Related land, soil, and crop quality
Climate (c)	Available moisture
Rainfall	
Temperature	
Topography and landscape (t)	Resistance to erosion
Slope	Landscape position
Wetness (w)	Available moisture/soil aeration
Drainage	Landscape position
Flooding	Deficiency/toxicity of nutrients
Physical condition (s) of soil	Water availability/soil aeration/soil structure
Texture	Available space for root development
Depth	Landscape position
Groundwater table	Available moisture/soil aeration
Soil fertility (f)	
pH (soil reaction)	Availability of plant nutrients
Silt and clay content	Availability of moisture nutrients
Cation exchange capacity and base saturation	Availability of plant nutrients
Organic matter	Soil structure/availability of plant nutrients

Source: Sys et al. (1993)

The soils of Piprakothi Block, Purba Champaran district, Bihar, have been evaluated for soil-site suitability for sugarcane (Fig. 15.5). The analysis indicates that 31.7% of the area of the block is moderately suitable for the cultivation of sugarcane due to moderate limitation of soil fertility. About 53.0% of the area is marginally suitable due to relatively low water availability, which is a prime requirement for the crop, and severe soil fertility limitations. Only 2.0% of the area representing nearly depressed meander plain is not suitable for the crop as the area remains under deep water throughout the year.

15.8 Conclusions

Soil resource mapping through soil survey involves manpower to accomplish the job in a given time following the traditional methods of soil survey and mapping. During the soil resource mapping program, the introduction of remotely sensed data and their interpretation to generate the base maps for ground truth was found to be not only timesaving but also economic. With the advent of the modern tools of remote sensing and GIS, the task of completing of soil resource mapping has become very easy and fast. Besides this, the remotely sensed data with 5.8 m resolution has made resource mapping easy with less time. It is now high time that such remotely sensed data with even higher resolution and at a very large scale should be complemented

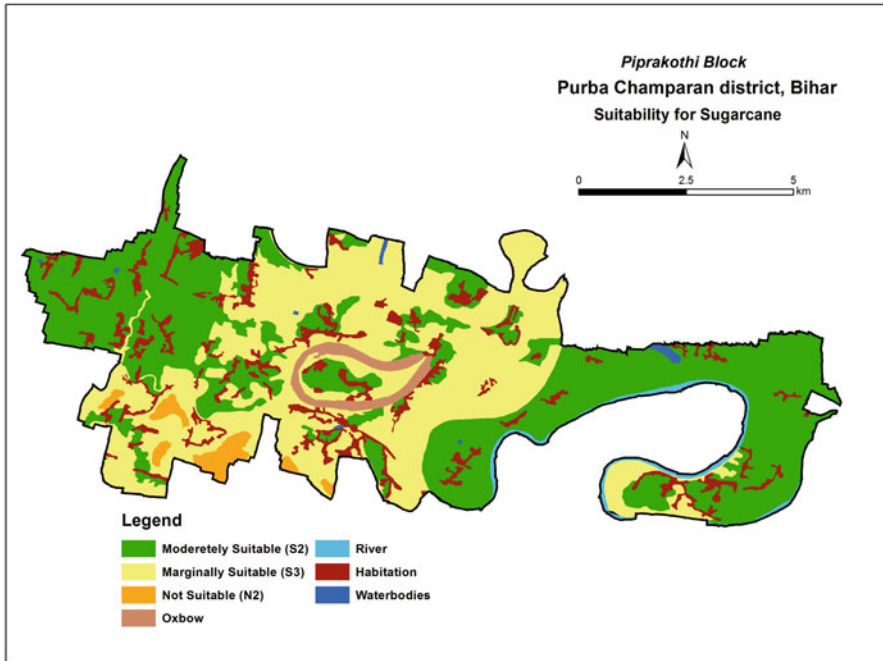


Fig. 15.5 Soil-site suitability for sugarcane in Piprakothi Block, Purba Champaran district, Bihar

with ground truth. With increasing GPS capability and its integration with GIS, the ability to collect accurate spatial data for soil survey field data collection becomes easy. Considerable production time is saved on the digital version of the soil map rather than on a hard copy map. Real-time mapping enables the creation or modification of digital product on site by a surveyor. With the integration of remote sensing data, GIS, and GPS, the surveyor is no longer constantly burdened to move place to place, and it saves time and labor and brings more accuracy in collecting the field data. Detailed land resource survey conducted in Piprakothi Block under Purba Champaran district of Bihar shows that soils are very deep, well to somewhat poorly drained, and highly calcareous. Soil-site suitability evaluation of sugarcane in the soils of block indicates that 31.7% of the area is moderately suitable, 53.0% of the area is marginally suitable, and 2.0% of the area is not suitable for sugarcane.

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