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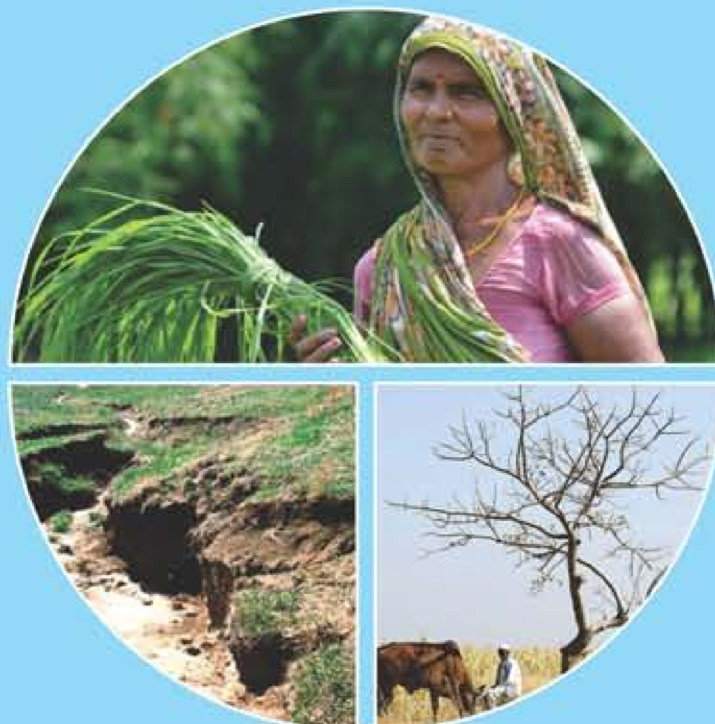
Land Use Planning for Arresting Land Degradation, Combating Climate Change and Ensuring Food Security

- A Training Manual

ICAR-National Bureau of Soil Survey and Land Use Planning
(Indian Council of Agricultural Research)
Amravati Road, Nagpur - 440033, Maharashtra



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About the ICAR-NBSS&LUP

The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, a premier Institute of the Indian Council of Agricultural Research (ICAR), was set up in the year 1976. The mandate of the institute is to prepare soil resource maps at state and district levels and to provide research inputs in soil resources mapping, soil correlation and classification, soil genesis including soil mineralogy and soil micromorphology, remote sensing applications, land evaluation for land use planning, land resource management and database management using GIS for optimising land use on different kinds of soils in the country. The Bureau has been engaged in carrying out agro-ecological and soil degradation mapping at the country, state and district levels for assessing and monitoring soil health. The research activities have resulted in identifying the soil potentials and problems and found various applications towards sustainable agricultural development. The Institute is also imparting training to the staff of soil survey agencies in the area of soil survey, land evaluation, and land use planning. The Bureau in collaboration with Dr. Panjabrao Deshmukh Krishi Vidhyapeeth, Akola, is conducting post-graduate teaching and research programme in land resource management under which M.Sc. and Ph.D. degrees are awarded.

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For further information or
To obtain copies of this bulletin, please write to :

Director,
ICAR-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP)
Amravati Road, NAGPUR - 440 033, Maharashtra, India
Phone : (0712) 2500386, 2500664, 2500545, 2500226
Telefax : +91(0)712- 2500534
Email : director@nbsslup.ernet.in

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Content

FOREWORD

Land is a vital natural resource, both for the survival and prosperity of humanity and maintenance of all terrestrial ecosystems. The limits of land resources are finite whereas human demands on them are ever increasing. Fertile land in rural areas becomes scarcer due to population growth, pollution, erosion and desertification, effects of climate change, urbanization, etc. The increasing demands put pressure on land resources leading to decline in crop production and degradation in land quality. Arresting land degradation, mitigating and adapting to climate change, protecting biodiversity, that aim at ensuring food security are just a few of the many challenges developing countries are currently facing. Land use planning is one of the tools that can help to meet them as it focuses on negotiating future land and resource uses by stakeholders.

In view of this, it becomes highly desirable to equip land use planning researches with the required knowledge and skills to develop sustainable land use plans. Besides providing them with subject knowledge of detailed land resource appraisal data base and site specific requirements of land use, integrating the same with stakeholders' needs and requirements is essential while formulating land use plans.

A 8-day Model Training Course (MTC) on **Land Use Planning for Arresting Land Degradation, Combating Climate Change and Ensuring Food Security** was organized by ICAR-National Bureau of Soil Survey and Land Use Planning at its HQrs., Nagpur during 19-26 November 2015. The participants, 17 in number, were officials of ICAR (7 nos.), SAUs (5 nos.) and KVKs (5 nos.) working in the field of agriculture. The present manual was developed as a reference material for the trainee officers. The manual would also be useful for trainee officers undergoing training on the above mentioned topic in future.

It discusses 15 topics, that are, minimum required to address the core issues related to the topic of the training. The lectures have been composed by eminent researchers and teachers with long and rich experience in the relevant fields.

The first four lectures focus on concept, need, methods of land resource inventory at different scales including use of geospatial tools and techniques (Remote Sensing and GIS) in Soil Resource Mapping and Database Management in GIS environment. Land resource inventory forms the basic pre-requisite for any land use planning. One needs site-specific land resource data for identifying potentials and constraints of land. With the continued advent of geospatial techniques, land resource inventory is becoming cost effective and time efficient, and at the same time ensures accuracy.

Water resources constitute, one of the important components of land and its harvesting potential, form an important input in land use planning programmes. The fifth lecture discusses the concept and applications of Digital Elevation Models. Soil Geoportal Development and some of its applications are discussed in lecture 6. Other different aspects covered towards land use planning include, concepts and approaches, combating land degradation and mitigating changing climate, role of non-edaphic factors, participatory land use planning approach, database development in SOTER, socio-economic assessment, land degradation – causes, assessment and control, soil nutrient mapping in West Bengal (as a selected study), management of salt affected soils and the highly important topic of contemporary and future relevance namely, land and land use policy issues in India. I sincerely hope the training manual will be of much use to the trainee officers in enhancing their skills for addressing the challenges of land degradation and changing climate posing severe threat to agricultural production through effective and efficient land use planning.

I acknowledge the contribution of authors of different lectures in the manual. I am extremely thankful to Dr. R.K. Batta, Ex-Director, ICAR Complex for Eastern Region, Patna and Ex-Principal Scientist, NBSS&LUP for adding valuable inputs by editing the document and giving proper shape to the manual. I thank Dr. T.K. Sen, Pr. Scientist & Incharge Training and Dr. S. Chatterji, Pr. Scientist & Incharge, PME Cell for compiling and editing the material. I am also thankful to the staff of PME Cell for word-processing of the document, administration and accounts section for giving administrative support to bring out the publication.

(S.K. Singh)
Director
ICAR-NBSS&LUP

Land Resource Inventory (LRI) of India for Development of Sustainable Agricultural Land Use Plans using Geospatial Techniques

S.K. Singh, Director

ICAR-National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur-440033

ABSTRACT

LRI is being executed by ICAR-NBSS&LUP in a consortia mode involving State Governments / State Departments of Agriculture, State Agricultural Universities, National Remote Sensing Centre, Hyderabad, India, State Remote Sensing Applications Centres and Soil and Land Use Survey of India.

The need and relevance of undertaking Land Resource Inventory of the country on 1:10000 scale to generate resource base information required for situation-specific agricultural land use planning and management of land resources is discussed. A conceptual model for LRI including preparation of base map using remote sensing and GIS, generation of soil map (on 1:10000 scale) and investment expected to be made therein are discussed. Utility of geo-portal in synthesizing database and mining the information from the database for their use towards ultimate goal of sustainable agricultural production is also highlighted. Case studies dealing with the use of LRI-generated database for land use planning are presented. LRI envisages to develop NBSS-Geoportal, a web based platform towards Web Map Server (WMS) and web Future Server (WFS). On country level the investment is extended to be Rs. 1,20,000M which comes out to be Rs. 120/ha. A priority programme of the ICAR-NBSS&LUP and investments thereon are expected to generate rich dividends for land use planning programme in the country.

Key words: *GIS, Investment, Land Resource Inventory, Land Use Planning.*

1. Introduction

Consequent upon the advent of green revolution in India, a significant good investment has been made in agricultural research and development both in public and private sectors which is growing @ 9 % per annum. As a result, food grain production has increased by five fold times from 50 MT in since 1950-51 to 250 MT in 2011-12 (Vision 2050, NBSS&LUP, 2015). During the period, production of horticultural and fish farm produce have increased 6 and 9 times respectively. Considering the base year of 1950-51, milk and egg production have increased 6 and 27 times, respectively. From 1950 to 2014, horizontal expansion of agriculture has been one of the objectives and investment was made on land reforms, land acquisition, resettlement and rehabilitation, watershed management and modernization of land records. Area under agriculture has expanded from 95 to 126 Mha. During the period, unplanned and haphazard increase in area under different land uses was prominent. In West Bengal, area under rice has gone from 3.9 Mha to 5.63 Mha and the area under potato and jute increased six times whereas the area under different alternate land uses have decreased. In the journey of seven decades of green revolution, about 121 Mha area suffered from various kinds and degrees of degradation (Maji *et al.*, 2010). Recent data indicated that 64 out of 142 Mha of net sown area are affected with one or other kind of degradation (NBSS&LUP, 2015). Inspite of exponential increase in fertilizer consumption, productivity of food grains showed linear grains only.

It is attributed to inappropriate land use planning of growing crops and soils beyond their capability/ suitability domain in an attempt to produce maximum. Intensive agriculture with total disregard to adequate conservation measures was practiced. Its harmful effect affected all lands, the hills, plateau and desert. Erosion on Darjeeling hills and Chotanagpur plateau intensified the problem of increasing acidity in the flood plains of Bengal (NBSS&LUP, 2012). Erosion and subsequent transportation of sediment from the Eastern Himalayas was the cause of Arsenic contamination in the flood plains of the Bengal basin. Rising pH in the desert resulted in development of Aerosols due to the faulty management practices on dunes (Singh and Singh, 2011). Aerosols arising from on the dunes also affected the good adjoining agricultural land in the desert of Rajasthan (Pratap Narain and Singh, 2006).

The sustainable food production is further constrained by ill effects of projected climate change. In 2050, it is estimated that maximum and minimum temperature will go up by 2.4^0C and 4^0C, respectively. Southern peninsula, northwest India and the southern parts of Punjab, Haryana and Bihar will be the severely affected due to the rise of minimum temperature. Apart from this, large shift in monsoon months, reduction in number of rainy days, increase in rain intensity and high frequency of cyclone would further aggravate the problems of agrarians (IPCC, 2007). In view of above, therefore, there is need of fresh investment in the application of agro-technologies, which may be path breaking for vertical expansion/ intensification of agriculture. An interdisciplinary approach linking environment, ecology, agriculture, geology and natural resources is necessary. Over the last few decades, there has been growing interest in interdisciplinary resources, watershed management, integrated agriculture, precision farming, sustainable land use planning, non-point source pollution ecosystem restoration, arresting degradation towards ensuring food security (Lin *et al.*, 2006). For executing such programs, site-specific land resources information and situation specific recommendations are a pre-requisite.

Under such grim situation, targeted food production of 455 MT from the present level of about 257 MT (Kathpalia and Kapoor, 2010) is an arduous task to nourish the rising population estimated to be 1.6 billion in 2050 from the current level of 1.2 billion. Moreover, by 2050, per capita land holding will go down to an abysmally low to 0.087 ha, posing a serious concern (Sharma, 2006). Stagnant net sown area from 1980 onwards suggests little possibility of horizontal expansion of agriculture. It is projected that land available for cultivation may be reduced by 20 per cent in 2050 due to land degradation, urban expansion and conversion of crop land to non-agricultural land uses. The problem is expected to be compounded further due to growing scarcity of water. At present water availability for the country as a whole is around 2000 BCM which will go down to 1500 BCM by 2050 thus downscaling India from a status of water sufficiency to water scarcity (Singh and Singh, 2013).

NBSS&LUP has mapped soils of India on 1:1 M scale and of states on 1:250,000 scale. It has also prepared district level maps on 1:50,000 scale like Sri-Ganganagar (CAZRI, 2003), Ajmer (NBSS&LUP Staff, 2001), Aurangabad and Rohtas (Bihar), (NBSS&LUP, 2011), Bolangir (Odisha) (NBSS&LUP, 2011). However, these maps have limited application at the farm level due to scale limitations. Hence, the NBSS&LUP has undertaken a gigantic task of mapping of soils on 1:10,000 scale under its Land Resource Inventory (LRI) project.

Land resource inventory (LRI) on 1:10000 scale provides such site specific information needed for farm/ village level planning. LRI involves systematic survey of soils (agricultural land) on 1:10000 scale and collection of other collateral data needed for scientific land use planning in GIS environment. The detailed database generated at farm level and its subsequent abstraction to village, mandal, taluk, district, state and country will form the basis needed for prioritizing, initiating and executing any land-based developmental programmes. In LRI, use of high resolution remote sensing data and digital elevation model (DEM)/ digital terrain model (DTM) using Geographic Information System (GIS) provides new dimensions to the soil survey programme. A DEM can provide data that can assist the surveyor in mapping and deriving quantitative attributes of landform (Ardak *et al.*, 2010, Sankar *et al.*, 2010). DEM (NBSS&LUP, 2015) is capable of providing very precise and quantified information on degree, length and curvature of slope, which are much needed information for execution of soil conservation programme, irrigation planning and precision agriculture. Data on degree of slope, length of slope and curvature of slope together with contours and drainage are very important to quantify the water harvesting potentials (Lin *et al.*, 2006) under rainfed agriculture. Thus detailed characterisation of soils together with added site specific information for DEM forms the basis of all land based planning programmes.

Under LRI, land use planning consisting of suggesting right land use, right technology on well-defined soil and site characteristics will be facilitated and disseminated in the farthest and remotest village of the country through web geo-portal, where stakeholders could interact with the system and extract the desired information (Singh *et al.*, 2013). Execution of such programme in the country, however, attracts huge investment. However, considering the expected returns, the programme assumes priority.

The Land Resource Inventory (LRI) on 1:10000 Scale

The ICAR–National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, Maharashtra, India has taken initiatives through its Land Resource Inventory (LRI) at country level programme on 1:10000 scale to fill the vital gap by generating data on site-specific soil and land resources. It involves systematic surveys of soils (cultivable land) on 1:10000 scale and collection of other collateral data needed for scientific land use planning in GIS environment. The NBSS&LUP has responsibility to provide required scientific/technical back-up and facilitate establishment of the National Portal on soil and other land resources for effective dissemination of information. The said programme utilises the latest time efficient and cost effective geospatial technologies.

The nationwide survey will categorize the agricultural and non-agricultural areas in terms of their strengths, limitations and opportunities for appropriate use and threats from misuse/ abuse. This will help in developing perspective land use plans and monitoring their impact at macro (district/state) and micro level (village level). Special Agricultural zones (present and potential) are planned to be delineated for giving focused support and services for major agricultural and horticultural production systems across the country and simultaneously delineating non-arable areas for other land uses. The importance of such land use planning is further enhanced if it is communicated / disseminated through well designed Geo-portal. LRI envisages to develop a NBSS Geo-portal, a Web based platform deployed in a simple architecture with database server and application server to manage the database. Depending on the authorizations, the user is able to visualize, analyze and download the soil information, upload maps, create new maps and merge them with other maps. Besides the legacy datasets, the land resources database developed under LRI project will be integrated with agro-technologies developed by other institutions in the Geo-portal. The so developed web based NBSS Geo-portal will help to acquire, process, store, distribute and improve the utilization and dissemination of geospatial data through Web Map Services (WMS) and Web Future Services (WFS).

In LRI, data on climate, vegetation, crops, land-use pattern, socio-economic conditions, existing infrastructure and marketing facilities are collected through various agencies, whereas data on soils will be collected through systematic survey. At present, the soils information available in the country is of general nature (1:250000 scale soil maps for the entire country and few district maps at 1: 50000 scale) and is suitable up to district or taluk level planning only. Few pilot studies on 1:10000 carried out in various parts of the country have proved conclusively the importance of such site-specific database. Land resource inventory (LRI) on 1:10000 scale is expected to provides site-specific information needed for farm/ village level planning. The detailed database generated at village level and its subsequent abstraction to mandal, taluk, district, state and country level will formulate the basis and provide the required information needed for prioritizing, initiating and executing any land-based developmental programmes.

Advent of high resolution remote sensing data and digital terrain model (DTM) has added new dimensions to LRI. DTM can provide very precise and quantified information on degree, length and curvature of slope, which are much needed information for execution of soil conservation measures, irrigation planning and precision agriculture. Data on degree of slope, length of slope and curvature of slope together with contours and drainage are very important to quantify the water harvesting potential. This is much needed information required to develop rainfed agriculture in the country. Thus detailed characterization of soils together with added site specific information has the potential to become the basis of any land based planning programme. Data analysis and mining, using Geographical information system (GIS) further enhances the capability of data to fulfill the requirement of research and development in the years to come.

Value of the information is further widened, if it is disseminated in the farthest and remotest village of the country through web geo-portal, where stakeholders interact with the system and carve out the information for their own use. The expected output from LRI project will have great practical significance, specifically useful for site-specific farm and village level planning, soil-based watershed development and wasteland development, strategic planning for land use, efficient cropping zones, kisan soil-health card, fertilizer recommendation, proactive advice to farmers, and for monitoring the state of health of the natural resources through a continuing watch at benchmark sites and hot spots.

2.1 Conceptual Model for LRI

Soils are formed on different landforms as per soil-physiographic relationships. Soils are mapped at different levels and a soil mapping unit represents the soil properties acquired over time. The mapping unit in itselt is of limited use. It does not represent dynamics of variation in soil properties in response to present climatic conditions and prevailing soil forming processes and land use. Land Resource Inventory (LRI) envisages to replace traditional Soil Mapping Unit (SMU) with Land Ecological Unit (LEU) by inclusion of dynamics of climate change and land use. LEU is the assemblage of landform, slope and land use. The conceptual model for LRI programme is presented in (Fig.1). It assumes that if landform, slope and land use are identical, there is high possibility of getting similar kind of soils.

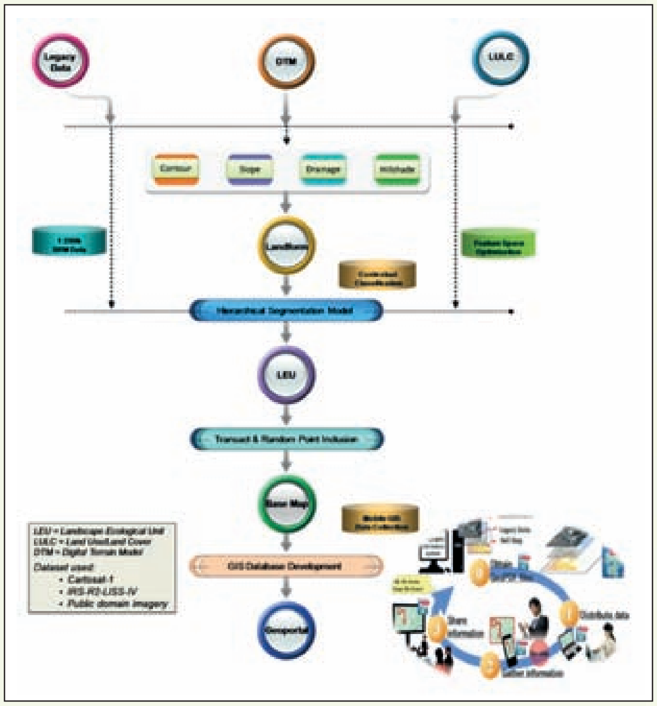


Fig. 1. Conceptual model for LRI

2.2 Methodology

In LRI, different kinds of remote sensing data such as Digital Terrain Model (DTM), IRS LISS IV P6 data on 5.8 M resolution and other data available in public domain are used. In the undulating terrain, Digital Terrain Model (DTM), which is the integral part of LRI, is prepared using Cartosat-1 data of 1 M resolution. Sahu *et al.* (2014) also used cartosat-1 DTM and IRS LISS IV P6 data of 5.8 M resolution data for characterization of landforms and; land use and land cover (LULC) mapping in the basaltic terrain of Nagpur. Also in the flat terrain like Indo-Gangetic plains, Thar Desert of Rajasthan and coastal region of West Bengal, IRS-LISS IV P6 data of 5.8 M resolution is used. Recently methodology was fine-tuned for the part of lower Gangetic plains using IRS LISS IV data of 5.8 M resolution (NBSS&LUP, 2012). Stepwise methodology is explained in the subsequent paragraphs for the undulating terrain of southern Deccan plateau with an example of Indervelle Mandal, Adilabad district of Telangana state.

Digital Terrain Model (DTM)

Cartosat-1 stereo pair data of 1M resolution are processed to generate DTM at 10 M spatial resolution. Steps include projection setup, sensor data reading, collection of GCPs and tie points, block adjustment, model computation (Satellite Math Model) and epipolar image generation. These are followed by using Toutin's Model, a rigorous math model before developing Digital Surface Model (DSM) in Ortho Engine of Geomatica version 14.0. Further Balancing algorithm and filters are applied to obtain the seamless mosaic and to convert bare earth model DSM to DTM, respectively. Editing is done to smoother out irregularities and to create a quality output (Fig. 2).

Slope Map

The object-based modeling using the spectral and spatial/contextual properties of pixels and segmentation process with interactive learning algorithm are used in the process. For extracting slope and the raster slope layer, the output of DTM is taken as input layer. The slope layer is classified in nine classes following the USDA-NRCS slope class threshold criteria. The criteria was fitted as fuzzy instead of hard rule using the less than and greater than "s-curve" membership function. Contextual filters are applied to generate smooth slope class zones (Fig. 3).

Contour and Drainage

DTM is subjected to a series of hydro-enforcement process including reconditioning, sinks and pit removal, flat and level water bodies, flat and level bank to bank and gradient smoothening by DAT/EM and Arc Hydro tool, etc for enriching the quality of the hydrological output such as slope, contour and drainage (Fig.4).

Landforms

Finally the terrain attributes like contours, drainage, slope and hill shade are treated as input layer for landform delineation. The landform classification process is hastened taking into consideration the slope class zone, hill shade, contour and auto-drainage pattern along with legacy mapping unit of 1:250000. Table 1 illustrates an example of logical rule set used for delineating different landform units (Fig.5).

Table 1. An example of logical ruleset used for landform units in Indervalle Mandal of Telangana state

Landform	Logical Ruleset Condition
Un-dissected Plateau	Slope Range: 0 to 5% Relative boarder to escarpment: >80% Existence of drainage = False Relative Topographic Position = Upper
Pediment	Side slope of Plateau/Upland Slope Range: >1 to <15% Profile Curvature = Convex Presence of erosive features
Valley	Existence of drainage = True V-shaped contour with decreasing elevation gradient Profile Curvature = Concave Relative Topographic Position = Lower

Land Use and Land Cover Map (LULC)

LULC map is developed using current *rabi* season data of Cartosat-1 merged LISS-IV (2.5M) as well as high resolution (0.5M) public domain imagery at the backend. The delineation of subclasses viz. single and double cropped areas within the agriculture zone are done using novel LULC subclass classification algorithm (Fig.6). The merged data was segmented into spectrally homogeneous region using multi-resolution segmentation algorithm. The optimum scale parameter for segmentation of the layer is achieved through estimation of scale parameter (ESP) analysis tool. The point of interest lies where the local variance and rate of change are minimum in the graphical output. Feature space optimization as a data mining tool is applied to extract the double cropped area based on certain number of layer variables and the vegetation indices combination as obtained through the maximum separation distance (Fig.7).

Integration of Landforms, Slope and LULC for Landscape Ecological Unit delineation

The integration of three secondary layers i.e. landform, slope and land use are achieved through the hierarchical object based segmentation algorithm taking into consideration the area, morphology of the landform units and its relation with the neighbor objects to develop Landscape Ecological Unit (LEU) map. The segmentation was accomplished in three levels:

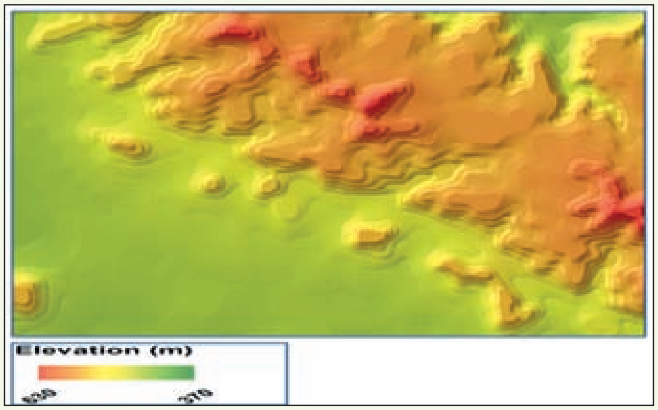


Fig. 2. Digital terrain model

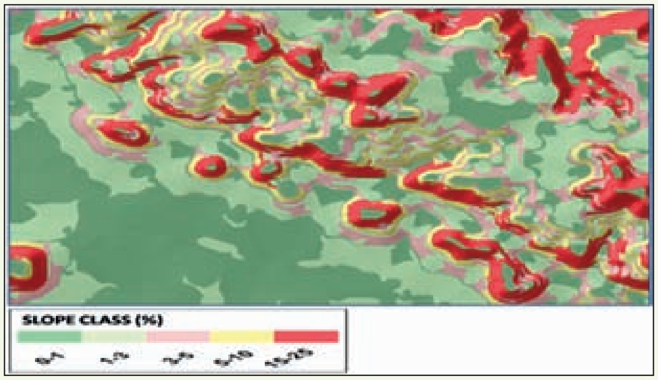


Fig. 3. slope map

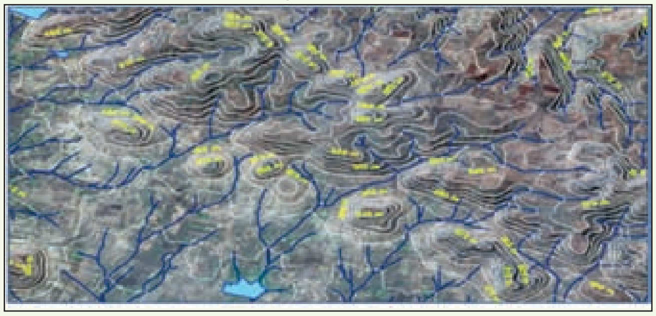


Fig. 4. Contour and drainage

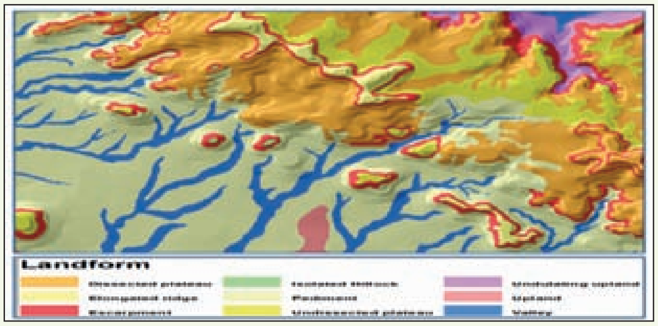


Fig. 5. landform map

Fig.6. Automation of land use land cover mapping

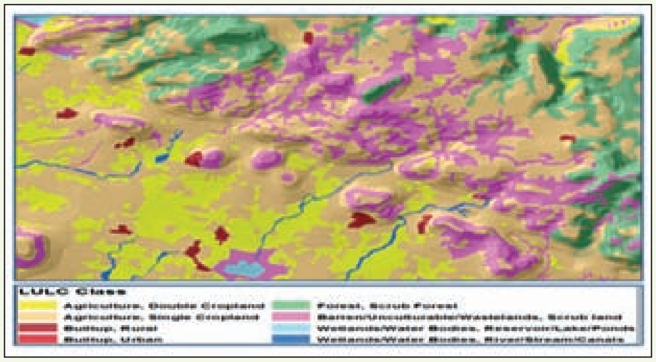


Fig 7. LULC map

Level-I: First level segmentation is done based on the landform layer.

Level-II: This segmentation runs within each of the 1st level segment based on fuzzy threshold based slope class. Second level intermediate outputs give rise to landform-slope unit.

Level-III: The landform-slope segments of 2nd level are further subdivided into landform-slope-land use unit i.e. LEU by incorporating the land use factor. The logical condition used to incorporate the land use factor is that the minimum overlap with the thematic polygon i.e. level-II segment is more than or equal to 60 per cent. The criteria ensures the continuity of LEU zone vis-à-vis soil boundary by ignoring negligible change in land use. (Fig.8) explains the steps involved in the delineation of LEU.

Interpretation of LEUs map

A scheme (Fig.9) has been developed for delineating Land Ecological Units. The interpretative unit consists of letters and numeral. Letters are designed for

Fig.8. Hierarchical object based segmentation algorithm process for generating LEU maps.

landforms; numeral represents slope class, followed by the letters for land use and land cover. In some places for segmenting the uniform pattern of landscape, image characteristics are also used for delineating LEUs particularly in Indo-Gangetic plains. The interpretative units are preceded with text and symbols to have linkage with physiographic, sub-physiographic (Table 2) and broad landform, defined during soil resource mapping of the country on 1:250000 scale.

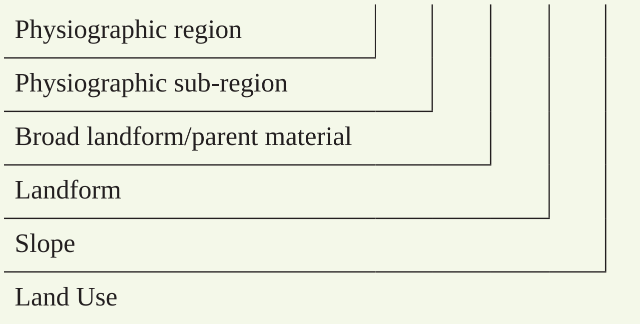


Fig.9. Scheme for the interpretation of Land ecological units

Table 2. LEU interpretation (South Deccan Plateau: Gajwel Mandal, Medak District, Telangana state

Physiography	Physiography Sub region	Board Landscape	Landform	LEU unit	Descriptions
Deccan Plateau (D)	South Deccan Plateau (Ds)	Granite and Gneissic Complex (Gn)	Hillock (H)	DsGnH4r	Isolated Hillock with pediment
			Pediment (D)	DsGnD3s	Gently sloping pediment (Single crop)
				DsGnD3d	Gently sloping pediment (Double crop)
				DsGnD2s	Very gently sloping pediment (Single crop)
				DsGnD2w1	Very gently sloping pediment (Wasteland / Open scrub)
				DsGnD1s	Nearly level pediment (Single crop)
				DsGnD2d	Very gently sloping pediment (Double crop)
			Upland (U)	DsGnU2s	Very gently sloping upland (Single crop)

Physiography	Physiography Sub region	Board Landscape	Landform	LEU unit	Descriptions
				DsGnU2w1	Very gently sloping upland (Wasteland / Open scrub)
				DsGnU2d	Very gently sloping upland (Double crop)
				DsGnU1s	Nearly level upland (Single crop)
				DsGnU1d	Nearly level upland (Double crop)
				DsGnU1w1	Nearly level upland (Wasteland /Open scrub)
		Basaltic (Ba)	Upper alluvial plains (A_u)	$D_sB_aA_u$1s	Nearly level upper alluvial plain (Single crop)
				$D_sB_aA_u$2w1	Nearly level upper alluvial plain (Wasteland / Open scrub)
				DsB_aA_u1d	Nearly level upper alluvial plain (Double crop)
				DsB_aA_u1w1	Nearly level upper alluvial plain (Wasteland / Open scrub)
				DsB_aA_u 2d	Nearly level upper alluvial plain (Double crop)
			Lower alluvial plains (A_l)	DsB_aA_l 1d	Nearly level lower alluvial plain (Double crop)
				DsB_aA_l 1s	Nearly level lower alluvial plain (Single crop)

Establishing Soil-Landscape Ecological Unit Relationship

Field studies are conducted to establish Soil-LEU relationship by studying profiles, minipits and auger observation in well-defined strips. Numbers of strips are marked for covering entire units of LEU. Relationship between soil and LEU (Fig.10) is described for Gajwel Mandal of Medak district in the state of Telangana (Table 3). For describing the relationship the properties which have significant bearing on management are chosen. During the traverse of the area, most of delineated boundaries are checked and confirmed.

Table 3. Soil-LEU Relationship of Gajwel Mandal, Medak District, Telangana state

LEU	Soil Series	Phases	Soil landform relationship
DsGnH4r	Muddapur	Mud1hC3st1	Shallow, well drained, dark yellowish brown, sandy clay soils on gently sloping is land with sandy loam surface, severe erosion and slight stoniness.
DsGnD3s		Mud1bC3	Very shallow, well drained, brown, loamy sand soils on gently sloping pediments, severe erosion.
DsGnD3d		Mud1cC2	Very shallow, well drained, brown, sandy loam soils on gently sloping pediments, moderate erosion.
DsGnD2s	Ananthraopalli	Anp2hB2	Shallow, well drained, dark yellowish brown, sandy clay soils on very gently sloping pediments with sandy clay loam surface and moderate erosion.
DsGnD2w1		Anp2cB2	Shallow, well drained, dark yellowish brown, sandy clay soils on very gently sloping pediments with sandy loam surface and moderate erosion.

DsGnD1s	Jaligaon	Jlg3hB2	Moderately deep to deep, well drained, strong brown, sandy clay soils on very gently sloping pediments with sandy clay loam surface and moderate erosion.
DsGnD2d		Jlg3cB2	Moderately deep to deep, well drained, strong brown, sandy clay soils on very gently sloping pediments with sandy loam surface and moderate erosion.
DsGnU2s		Jlg3dB2	Moderately deep to deep, well drained, strong brown, sandy clay soils on very gently sloping uplands with loam surface and moderate erosion.
DsGnU2s		Jlg3bB2	Moderately deep to deep, well drained, brown, sandy clay on very gently sloping uplands with loamy sand surface and moderate erosion.
DsGnU2w1		Jlg3cB2	Moderately deep to deep, well drained, strong brown, sandy clay soils on very gently sloping uplands with sandy loam surface and moderate erosion.
DsGnU2d	Madhepur	Mdp4iB2	Deep to very deep, well drained, brown, sandy clay soils on very gently sloping uplands with sandy clay surface and moderate erosion.
DsGnU1s		Mdp4bA1	Deep to very deep, well drained, brown, sandy clay soils on nearly level to level uplands with loamy sand surface and slight erosion.
DsGnU1d		Mdp4cA1	Deep to very deep, well drained, brown, sandy clay soils on nearly level to level uplands with sandy loam surface and slight erosion.
DsGnU1w1		Mdp4bB1	Deep to very deep, well drained, brown, sandy clay on very gently sloping uplands with loamy sand surface and slight erosion.
DsBaAu1s	Singatam	Sgt3hA1	Moderately deep to deep, moderately well drained, very dark gray, clayey soils on nearly level to level upper alluvial plain with sandy clay loam surface and slight erosion.
DsBaAu2w1		Sgt3hA2	Moderately deep to deep, moderately well drained, very dark gray, clayey soils on nearly level to level upper alluvial plain with sandy clay loam surface and moderate erosion.
DsBaAu1d	Sangampalli	Sgp4iA1	Deep to very deep, moderately well drained, dark gray, clayey soils on nearly level to level upper alluvial plain with sandy clay surface and slight erosion.
DsBaAu1w1		Sgp4fA1	Deep to very deep, moderately well to imperfect drained, dark gray, clayey soils on nearly level to level upper alluvial plain with clay loam surface and slight erosion.
DsBaAu1d		Sgp4mA1	Deep to very deep, moderately well drained, dark gray, clayey soils on nearly level to level upper alluvial plains with clay surface and slight erosion.
DsBaAu 2d		Sgp4fA2	Deep to very deep, moderately well drained, dark gray, clayey soils on nearly level to level upper alluvial plains with clay loam surface and moderate erosion.
DsBaAl 1d		Sgp4mA1	Deep to very deep, moderately well drained, dark gray, clayey soils on nearly level to level lower alluvial plains with clay surface and slight erosion.
DsBaAl 1s		Sgp4iA1	Deep to very deep, moderately well drained, dark gray, clayey soils on nearly level to level lower alluvial plains with sandy clay surface and slight erosion.

Soil Maps

After extensive field work and soil correlation, soil series is established; phases of each soil series are defined. Phases of series include soil depth, surface texture, slope, erosion, gravelliness, salinity/sodicity and any other feature influencing management. The soil map consisting of series and phase for Gajwel Mandal, Medak district, Telangana state is given in the text for example (Fig.10). For collecting very precise and quantified information in the field and their subsequent transmission to the data centre for processing, android based mobile can be used. ICAR- NBSS&LUP Nagpur has developed such application for use (Fig.11).

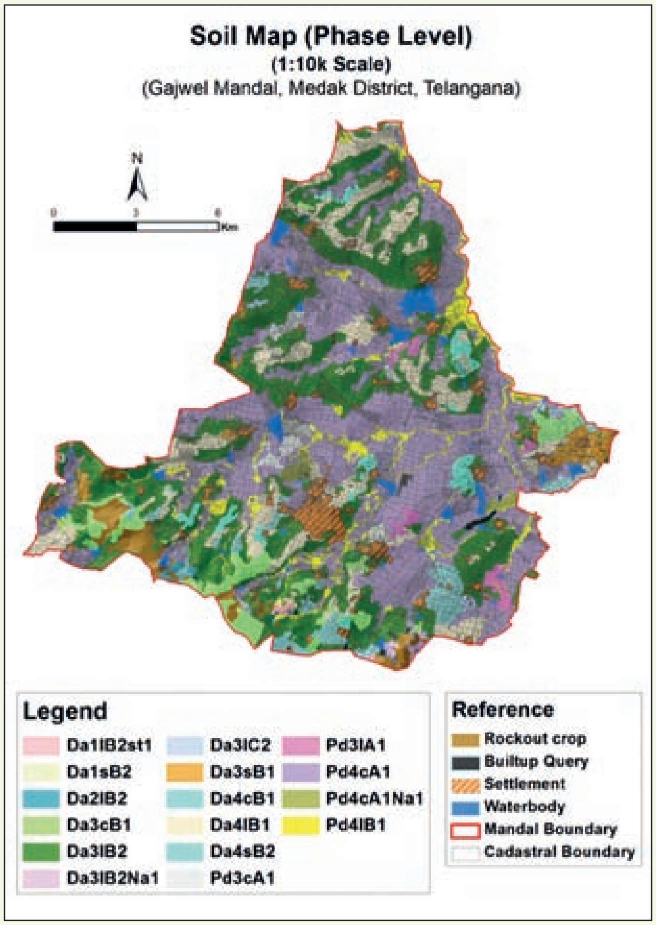


Fig. 10. Soil map of Gajwel Mandal

Fig. 11. Android based mobile for collecting and transmitting the information

Fig.12. Selected blocks under LRI programme

2.3 Status of LRI

Land resource inventory programme has been taken in the country in phased manner. In the first phase sixty blocks (Fig.12) belonging to the different agro-ecological regions and sub-regions have been taken, targeting to 3.3 million hectare land in a four years period. During the year 2014-15, mapping was taken up in 34 blocks of the country. Apart from this, Government of Karnataka and the state Government of Goa initiated the programme with their own budget. NBSS&LUP Nagpur coordinates the programme. National Remote Sensing Centre Hyderabad and Bhaskra Institute of Remote Sensing and Geo-informatics are also participating in the programme.

Database in National Soil Geo-portal

NBSS&LUP initiated another programme on developing and deploying geo-portal for synthesizing present dataset of LRI, the legacy dataset of bureau and other organizations. It is a web-based platform deployed in a simple architecture with database server and application server to manage land resource database. Geo-portal contains the information in four modules (Table 4) viz. polygon, point, raster and other non-spatial format (Singh and Singh 2013) for soils, climate, water resources, area-specific agro-techniques, and socio-economic conditions of the farmers. Phases of soil series are re-designated as land management unit (LMU), which is linked with the cadastral map for giving farmerwise and plotwise information on soils and land (Fig.13). Depending on the authorization, the user is able to visualize and download the soil information, upload maps, create new maps and merge them with other maps. The so developed web based NBSS Geo-portal will help to acquire process, store, distribute and improve the utilization and dissemination of geospatial data through Web Map Services (WMS) and Web Future Services (WFS). National co-operative soil survey programme in the U.S. also maintains soil survey information of 100 years including soil series description, soil characterization covering physical and chemical properties for over 20000 samples (www.nrcs.usda.gov/wps/...NRCSConsumption/download).

Module 1
Polygon based module • Administration • Soil resource map on 1:250, 000 scale • Soil resource map on 1:50,000 scale • Soil resource map on 1:4 to 10,000 scale • Geology of the state/region • Physiography

Module 2
Point data based module • Grid points collected during SRM • Typifying pedons • Grids and typifying pedons of subsequent surveys • Climatic variant • Ground water status and quality from prominent locations • Land use and yield data • Agro-technology - management and yield of demonstration plots and research farms

Module 3
Raster based module • Ground and surface water prospects and irrigation potentials • Climatic history punctuated with rainfall pattern and drought frequency • Land use dynamics • Periodic RS data

Module 4
Other data • Human and livestock profile • Land use requirement • Market demand and trends Non-spatial data based module

Fig.4. Database Modules in Geo-portal

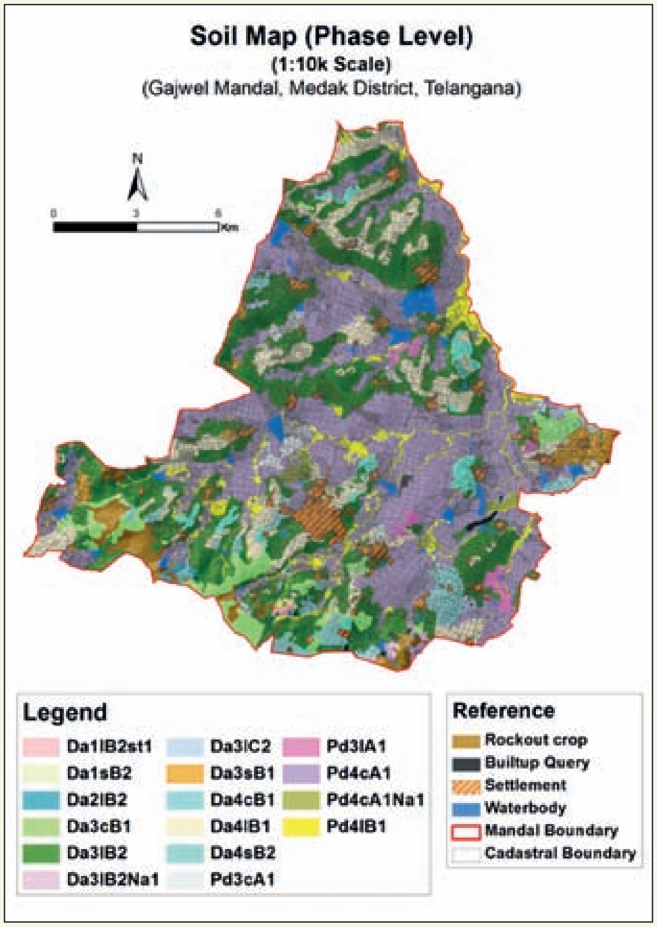


Fig.13. Land Management Unit (LMU) of Gajwel Mandal, Medak district, Telangana

LRI Database for Agricultural Land Use Planning

An interface is designed in the geo-portal, which integrates land resource information and agro-techniques and thus helps in identifying the best land use options for well-defined land management units. The land use option based on benefit:cost ratio for three well-defined land management units of Gajwel Mandal is given in Table 4 as an example. In LMU 1 characterized with gravelly soils, sorghum is one of the most profitable options, whereas in LMU2 grouped with deep black soils, cotton is the most preferred land use. In LMU 3 defined for moderately dark brown soils, maize is one of the most promising options. On medium and long term basis agriculture is intensified with woody trees in LMU1, fruit trees in LMU2 and the mixture of both wood and fruit trees are advised for planting in LMU3.

Table 4. Land use options based on the benefit: cost ratio in three LMUs of Gajwel, Mandal, Medak district, Telangana state, India

LMU	Short Term Planning	Medium and long term planning
LMU1 (Shallow gravelly soils)	Jowar, small millets, horse gram, green gram, black gram, and cotton, maize	Agri-horti system comprising custered apple, amla, jamun and ber; Boundary plantation with Gliricidia; water harvesting farm ponds.
LMU2 (Deep black soils)	Cotton, maize, paddy, sunflower, red gram, jowar, Maize/sunflower (short duration)-gram; Cotton+red gram, millets, cowpea, green gram, black gram - vegetables like coriander, cluster bean, Pumpkin, tomato, chillies,	Agri-Horti System (Banana, mango, guava with drip); Agri-horti-pasture system (*C.ciliaris*, Stylo, Bracharia;Water harvesting farm ponds
LMU3 (Moderately shallow brown soils)	Maize, cotton, sunflower, red gram, jowar, Maize/ sunflower (short duration)-gram, millets, paddy as aerobic rice cultivation, cowpea, green gram, black gram and vegetables like coriander, cluster bean, Pumpkin	Agri-horti-pasture system (*C.ciliaris*, Stylo, Bracharia on bunds; Mango, guava, custard apple, amla, jamun, ber and suitable MPTs; SWC measures and water harvesting farm ponds needs to be created

The information on land use options could be further linked with the socio-economic conditions of the farmers by using software Automated Land Evaluation System (ALES) with Geo-portal. ALES is specially designed to link bio-physical features with the social economic profiles of the farmers (Fig.14). Table 5 illustrates the links between the socio-economic conditions of the farmers and the land use options.

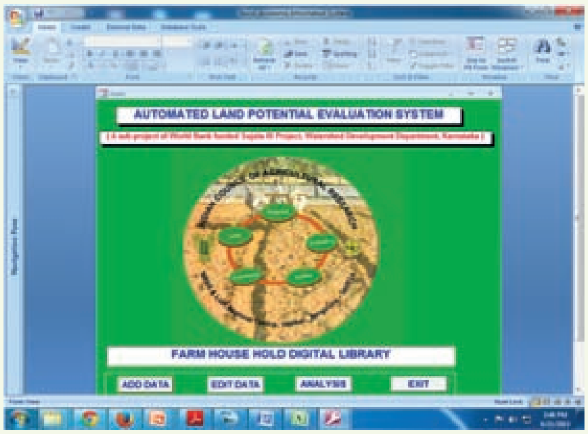


Fig.14. Automated land evaluation system

Table 5. Linking bio-physical and socio-economic information

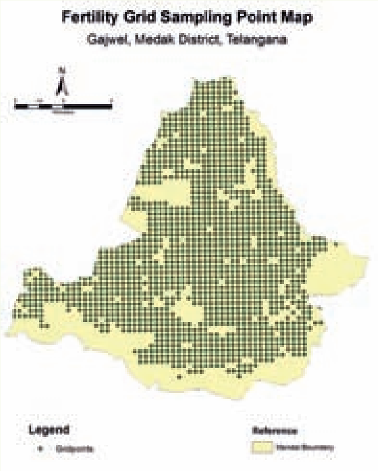
Suggested land use options based on B:C ratio					
LMUs	**Marginal**	**Small**	**Semi-medium**	**Medium**	**Large**
LMU1	Horse gram (2.13), Sorghum (0.9), Coconut (0.65)	Coconut (2.18), Horse gram (1.72), Sorghum (1.34), Horse gram (2.47), Sorghum (1.17), Cotton (0.45)	Horse gram (3.66), Mulberry (3.51), Banana (1.34), Sorghum (1.26), Coconut (1.07), Tomato (1.07)	Banana (4.6), Beans (3.03), Tomato (1.79), Watermelon (1.65), Horse gram (1.42), Sorghum (1.03), Cotton (0.9), Coconut (0.31)	
LMU2	Mulberry (2.71), Tomato (2.0), Horse gram (1.98), Chilli (1.63), Sorghum (0.63), Coconut (0.6)		Chilli (4.17), Tomato (3.35), Horse gram (0.86), Cotton (0.44), Sorghum (0.33)	Coconut (1.46), Sorghum (0.85)	Coconut (4.92), Tomato (2.13), Watermelon (1.75)
LMU3	Cotton (0.83)	Horse gram (1.09), Castor (0.65), Sorghum (0.63)	Sorghum (1.04)		

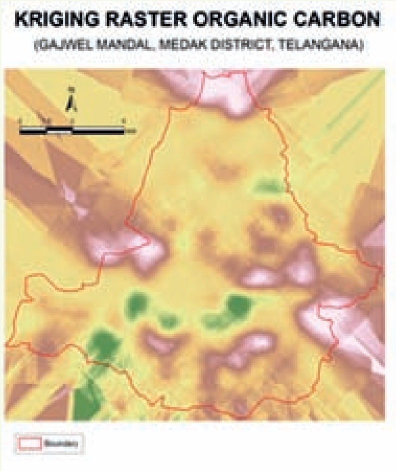
Suggested land use options based on B:C ratio					
LMUs	**Marginal**	**Small**	**Semi-medium**	**Medium**	**Large**
LMU4	Coconut (3.09), Tomato (1.8)	Sorghum (1.54), Chilli (1.5), Horse gram (1.45), Tomato (0.83)	Horse gram (2.15), Sorghum (0.95), Coconut (0.32)	Horse gram (1.81), Cotton (1.27), Sorghum (0.75)	Coconut (3.09), Tomato (1.8)
LMU5	Coconut (2.25)		Coconut (0.93)		
LMU6		Mulberry (3.35), Tomato (2.74), Chilli (2.0), Sorghum (1.73), Horse gram (1.71), Coconut (1.47)	Sorghum (1.36), Coconut (0.99)		

The figures in parantheses indicate B:C ratio

2.4 Soil Health Cards- A Product of LRI

In response to Govt. of India initiating to promote Soil Health Cards for farmers, NBSS&LUP endeavours to develop Soil Health Cards as a byproduct of LRI. Developing soil health cards includes designing sampling scheme, soil sample collection, lab analysis, developing surface of different parameters, using GIS technique, attaching the surface layer with the cadastral information (Figs.15,16, & 17). Finally, it develops farmer/plot wise information on soil health parameters (NBSS&LUP 2015). In the present programme of LRI, samples have been collected at 325x325 M grid interval for this purpose and one lakh fifty thousand farmers are provided with Soil Health Cards (Table 6). Following such scheme, part of soil health cards for the farmers of Gajwel Mandal, Medak district in the state of Telangana has been shown as an example.





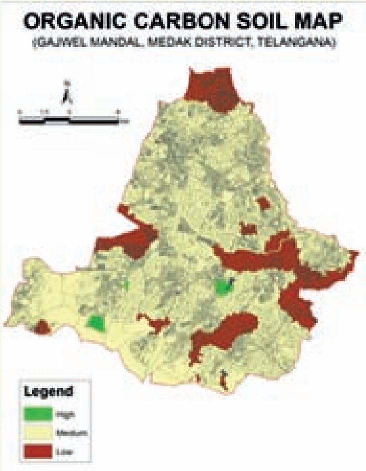


Table 6. Farmers wise/plot wise soil health parameters

Parcel no.	Village	Depth	Tex-ture	pH	EC	Organic carbon	Nitrogen	Phos-phorus	Pota-ssium	Sulfur	Iron	Manga-nese
/1	Ahmadipur	Medium	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	Medium	High	Suffice	Suffice
/2	Ahmadipur	Medium	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	Medium	High	Suffice	Suffice
/3	Ahmadipur	Medium	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	High	High	Suffice	Suffice

/4	Ahmadipur	Deep	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	High	High	Suffice	Suffice
1	Ahmadipur	Medium	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	Medium	High	Suffice	Suffice
10	Ahmadipur	Medium	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	Medium	High	Suffice	Suffice
100	Ahmadipur	Deep	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	High	High	Suffice	Suffice
101	Ahmadipur	Deep	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	High	High	Suffice	Suffice
102	Ahmadipur	Deep	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	High	High	Suffice	Suffice
103	Ahmadipur	Deep	Loamy	Slightly Alkaline	Non Saline	Medium	Medium	HIgh	High	High	Suffice	Suffice

2.5 Expected Investment

Execution of LRI in the country involves an investment of Rs. 120000 M. It involves investment on strengthening soil testing laboratories using geospatial techniques, undertaking field work and development of geo-portal (Table 7). The per hectare cost comes out to be Rs. 120/- The amount is very meager as compared to other agriculture related programmes running in the country. For example, watershed development programme under IWMP merged with Pradhanmantri Krishi Yojna where the per unit cost is Rs. 12000 to 15000 per hectare. However, considering the deliverables products it would generate in form of soil maps and land use plans, undertaking the programme is expected to be viable.

Table 7. Land Resource Inventory (LRI Project)

S.No.	Description of the items	Cost (Rs. in lakhs)
1.	Laboratory/ field equipments and lab facilities	9204.59
2.	Geographical Information System	4586.25
3.	Contingencies for Field Work	86741.99
4.	Others	15725.00
5.	Development of Geo-portal on soils	5000.00
	Total – (A)	121257.03
6.	Unforeseen expenses @ 5% of the cost **(B)**	6062.85
	Total (A + B)	127319.88

2.6 Summary

With hardly any scope of horizontal expansion of land area, effective land resource conservation and proper land use planning become indispensable. This necessitates generation of information on nature and extent of soils. LRI, using high resolution remote sensing data provides such information. In the absence of site-specific land resource data and situation-specific recommendations, the ICAR-National Bureau of Soil Survey and Land Use Planning has undertaken a project on Land Resources Inventory of the country on 1:10000 scale. The project plans to fill this vital information gap. Execution of this project on such a large scale would need huge investments but considering the expected returns, in the form of judicious land use plans, the project seems viable.

References

Ardak, A.S., Nagaraju, M.S.S., Prasad, J., Srivastava, R. and Barthwal, A.K. (2010). Characterization and evaluation of land resources in Khapri village of Nagpur district, Maharashtra using high resolution satellite data and GIS. *Agropedology* **20**:7-18.

CAZRI (2003). *Integrated natural resources and environmental impact assessment for sustainable development of Sri Ganganagar district of Rajasthan*. Division of Natural Resources and Environment, Central Arid Zone Research Institute, Jodhpur, India.

IPCC (2007). *Fourth Assessment Report: Climate Change- A Synthesis Report*. An Assessment of the Intergovernmental Panel on Climate Change at Valencia, Spain, 12-17 November 2007.

Kathpalia, G.N. and Kapoor, Rakesh (2010). *Management of land and other resources for inclusive growth*: India 2050.

Lin, H., Bouma, J., Pachepsky, Y., Western, A., Thompson, J., Genuchten, R. Van, Vogel, H.J., and Lilly, A. (2006). Hydropedology: Synergistic integration of pedology and hydrology. *Water Resource Research*, doi:10.1029/2005WR004085.

Maji, A., Reddy, Obi G.P. and Sarkar, D. (2010). Degraded and Wasteland of India. Prasad, R. and Pathak, P.S. (Eds), Indian Council of Agricultural Research, New Delhi, India.

NBSS&LUP (2011). *Annual Report 2010-11*. National Bureau of Soil Survey and Land Use Planning, Nagpur, India.

NBSS&LUP (2012). *Annual Report 2011-12*. National Bureau of Soil Survey and Land Use Planning, Nagpur, India.

NBSS&LUP (2015). *Annual Report 2014-15*. National Bureau of Soil Survey and Land Use Planning, Nagpur, India.

Pratap, Narain and Singh, S.K. (2006). *Drought management in India*. Indian Society of Soil Science Bulletin No. 24. New Delhi.

Sahu, Nisha, Obireddy, G.P., Nirmal Kumar, Nagaraju, M.S.S., Srivastava, Rajeev and Singh, S.K. (2014). Characterization of landforms and land use/land Cover in basaltic terrain using IRS-P6 LISS-IV and Cartosat-1 DEM data: A case study. *Agropedology* **24**:166-178.

Sankar, M., Sivasamy, R. and Dadhwal, K.S. (2010). Land resource data and its evaluation for village level land use planning. *Agropedology* **20**:1-6.

Sharma, N. (2006). Population and economic growth as drivers of future land use in India. (In): Browser, F. and McCarl, B.A. (Eds). *Agriculture and Climate Beyond 2015.*Volume 46 of the series Environment and policy, Springer Publication, P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Singh, A.K. and Singh, S.K. (2011). Strategies for Arresting Land Degradation in South Asian Countries.In:Sarkar, D., Azad, A.K., Singh, S.K., and Akter, N. (Eds) *Strategies for Arresting Land Degradation in South Asian Countries*. SAARC Agricultural Centre, BARC Complex, Farmgate, Dhaka -1215, Bangladesh.

Singh, S.K., Patil, N.G., Tiwari, P., Chatterji, S. (2013). Issue and strategies of natural resource management and land use planning in semi arid regions of India. *Annals of Arid Zone* **52**:1-13.

Land Resource Inventory at Different Levels-Need and Methods

Jagdish Prasad, Pr. Scientist
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

The role of Land Resource Inventory for land use planning at different levels is highlighted. Soil survey methodology and kinds of soil surveys are explained. Case studies of soil resource mapping at different scales are presented and steps in land use planning are explained.

1. Introduction

A soil survey describes the characteristics of the soils (such as depth, colour, texture, structure, internal drainage, parent material, depth to groundwater, topography, degree of erosion, stoniness, and salinity etc.) and their spatial distribution over a landscape in a given area. Soils are grouped into similar types and their boundaries are delineated on map. Each soil type has a unique set of physical, chemical and mineralogical characteristics and has similar response to use and management.

The information collected in a soil survey helps in the development of land use plans and evaluates and predicts the effect of land use on the environment. Soil survey also provides insight into the kind of land management measures that will be needed. The database generated through soil surveys at different scales provide opportunity to policy makers, planners and researchers and other stake-holders to develop land use plan for sustainable utilization and management of land resources at local, regional or national level.

Soil Variability

The properties of soil vary from place to place, but this variation is not random (Wilding, and Dress, 1983). Natural soil bodies are the result of *climate*, and *vegetation including living organisms* acting on *parent material*, with *topography* or local relief exerting a modifying influence and with *time* required for soil forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same.

The effects of topography or local relief, parent material, and time on soil become apparent when soils are studied in small areas. In the humid region, for example, the soil properties associated with wetness are common in low lying areas; better drained soils form in most instances in higher lying area. In arid regions, the differences associated with relief may be salinity or sodicity. This indicates that topography or local relief is important for variation in soil properties within a climatic region. In a local environment, the variation in soil properties is essentially governed by the nature of underlying parent rock (parent material) upon which the soil formation takes place. For example, in an area of mainly sandstone, the soil formed due to the weathering of the rock is likely to be well-drained, coarse and sandy; whereas, the soils formed from weathering of basalt are relatively poor-drained, fine and clayey. Soils on a flood plain differ from soils on higher and older terraces with no longer deposition of parent material on surface. This indicate that time is important for soil development. Local differences in vegetation are closely associated with differences in relief, parent material, or time. The effects of microclimate on vegetation may be reflected in the soil, but such effects are likely associated with difference in local relief. In addition, there is substantial human influence on the land which itself can also lead to the development of distinctive soils.

2. SOIL SURVEYS

Soil survey is a technique that provides information on the spatial distribution of soils and their variations. Soil survey of an area is expected to provide answer to general questions such as, (i) What types of soils are present and in what proportions? (ii) What is the soil type at any site of interest? (iii) Where can soil of a particular type or particular range of soil properties be found?

Questions of the first type can be answered most efficiently by identifying the soil. However, most soil surveys also aim to answer questions of the second and third types by the production of a soil map showing how and where the soil varies (Beckett and Burrough, 1971).

Although soil survey plays an essential role in increasing knowledge and understanding soil variability, they are most commonly made for more practical purposes (such as, adopting soil conservation measures, land reclamations, designing irrigation scheme) and can be categorized accordingly as general purpose or special purpose. A general purpose survey is intended to serve as a systematic inventory of the soil resources of an area, providing information that can be used or interpreted for a wide range of purposes. Special purpose surveys are those made to meet specific objectives, such as designing an irrigation or land reclamation scheme or assessing the suitability of land for growing a particular crop. Attention is focused in each case on a limited number of soil properties or attributes that are considered to be relevant for the objective.

The soil survey provides basic information about soil resources needed for planning development of new lands or conversion of land to new uses and information on soil quality that bear directly on land value for different purposes. Actual and potential users of soil survey information include farmers, agricultural advisory staff and researchers, foresters, planning agencies, development organizations, engineers and private investors.

"Soil surveys are expensive to make and publish"

2.1 Orders of Soil Surveys

Soil survey provides the most useful product for the intended purposes. Different intensities of field study, different degrees of detail in mapping, different phases or levels of abstraction in defining and naming map units and different map unit designs produce a wide range of soil surveys (Table 1). Recognition of these different levels of detail is helpful for communicating about soil surveys and maps. The orders are intended to aid in the identification of the operational procedures used to conduct a soil survey.

Table 1. Key for identifying kinds of soil surveys

Level of data needed	Field procedures	Minimum-size delineation (hectares)	Typical components of map units	Kinds of map units	Appropriate scales for field mapping and publications
1st order – very intensive (i.e., experimental plots, individual building sites)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Remotely sensed data are used as an aid in boundary delineation.	1 or less	Phases of soil series, miscellaneous areas.	Mostly consociations, some complexes, miscellaneous areas.	1:15,840 or larger
2nd order – Intensive (i.e. general agriculture, urban planning)	The soils in each delineation are identified by field observations and by remotely sensed data. Boundaries are verified at closely spaced intervals.	0.6 to 4	Phases of soil series, miscellaneous areas, few named at a level above the series.	Consociations, complexes; few associations and undifferentiated groups.	1:12,000 to 1:31,680

Level of data needed	Field procedures	Minimum-size delineation (hectares)	Typical components of map units	Kinds of map units	Appropriate scales for field mapping and publications
3rd order – Extensive (i.e. range, community planning)	Soil boundaries plotted by observation and interpretation of remotely sensed data. Soil boundaries are verified by traversing representative areas and by some transects	1.6 to 16	Phases of soil series or taxa above the series; or miscellaneous areas.	Mostly associations or complexes, some consociations and undifferentiated groups.	1:20,000 to 1:63,360
4th order – Extensive (general soil information for broad statements concerning land-use potential and general land management)	Soil boundaries plotted by interpretation of remotely sensed data. Boundaries are verified by traversing representative areas and by some transects.	16 to 252	Phases of soil series of taxa above the series or miscellaneous areas.	Mostly associations; some complexes, consociations, and undifferentiated groups.	1:63,360 or 1:250,00
5th order – Very extensive (i.e. regional planning, selections intensive study)	The Soil patterns and composition of map units are determined by mapping representative ideas and like areas by interpretation of remotely sensed data. Soils verified by occasional onsite investigation or by traversing.	252 to 4,000	Phases of levels above the series, miscellaneous areas.	Associations; some consociations and undifferentiated groups.	1:250,000 to 1:1,000,000 or smaller

Source: Soil Survey Division Staff (2000)

2.2 Soil Survey Methodology

Soil surveyors consider the physiographic variation (keeping other soil forming factors constant) as a base for depicting the soil variability on a map. The general methodology of soil survey comprises pre-field interpretation using cadastral map, Survey of India toposheets, aerial photograph and satellite data (depending upon their availability) for delineation of various physiographic units, ground truthing for verification of physiogphic units, soil profile study, developing physiography- soil relationship and extrapolation of this relationship to other similar areas. Topographical maps are generally published on the scale of 1: 25,000, 1: 50,000 and 1: 250,000. These map show not only physical features but also contain topographical details in the form of contours and elevation. Black and white or pan-chromatic aerial photographs contain 50-65 per cent over lap for a stereoscopic viewing. The flow chart showing the general methodology used for soil mapping using remote sensing data is shown in Fig. 1.

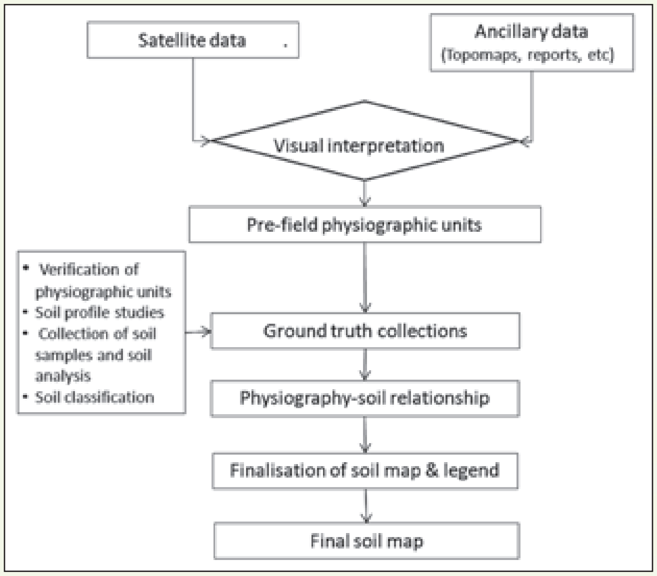


Fig.1. Flow chart depicting the general methodology for soil mapping

Among the two methods of remote sensing data interpretation viz. visual and digital, the former approach is pre-dominantly used in soil mapping. Visual interpretation of satellite imagery is done based on shape, size, tone, shadow, texture, pattern, site and association. This has the advantage of being relatively simple and inexpensive. In digital interpretation, the computer aided techniques utilize the spectral variations for classification. The pattern recognition in remote sensing assists in identification of homogeneous areas, which can be used as a base for carrying out detailed field investigations.

Spatial and spectral resolution of remote sensing data plays an important role in determining the scale of mapping. The coarse resolution data from IRS LISS-I, WiFS, AWiFs and LANDST-MSS sensors have been used by NBSS&LUP, Nagpur to prepare soil maps on 1:250,000 scale or smaller. To map soils on 1:50,000 scale, medium resolution remote sensing data from LANDSAT-TM, IRS LISS-II/LISS-III and SPOT-MLA are mostly employed. Satellite data from IRS-P6 (LISS-IV sensor), Cartosat-1 and Cartosat-2 and IKONOS are now being employed for detailed characterization of soils on 1:10,000 scale and larger

2.2.1 Field Work

Field work is the most important component in soil survey. Valuable information about soils and its behaviour can be obtained from observations made in the field while surveying. Intensive field traversing is done to check and verify the pre-field landform or physiographic boundaries delineated in the laboratory through interpretation of satellite image. Based on soil-site variations (for example, landform, slope, aspect, geology, vegetation/land use, etc.), profiles/ mini-pits are excavated and examined for the detailed morphological properties. Horizon-wise soil samples are collected for detailed soil analysis (physical and chemical properties) in the laboratory. Depending on the similarity of the pedons in the surveyed area, soil series are tentatively

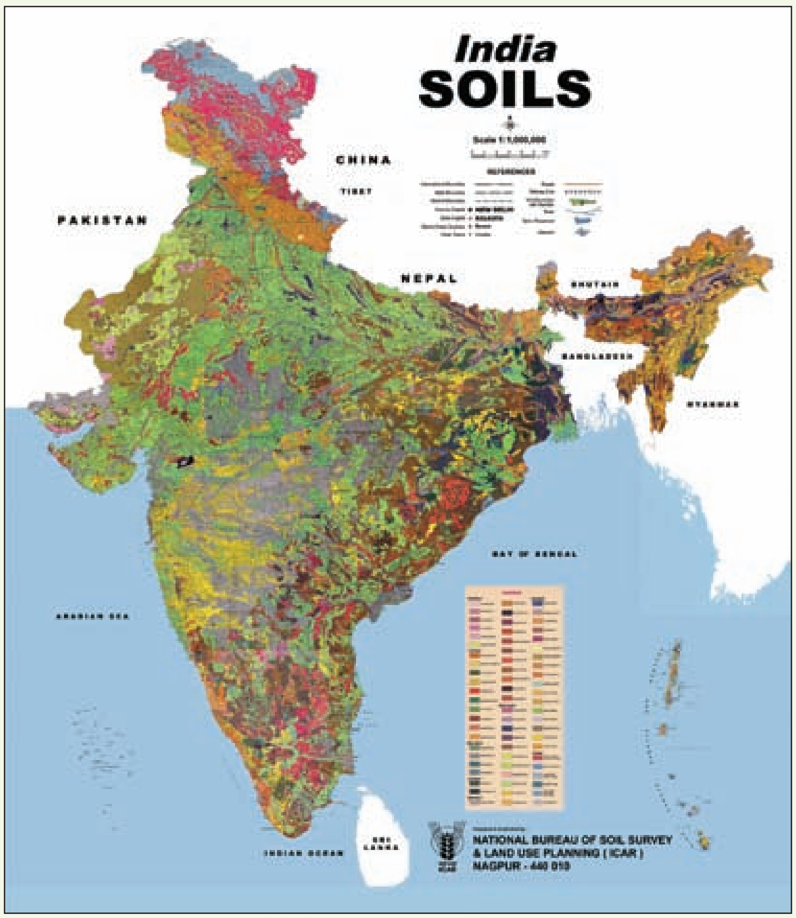


Fig.2. Soil Map of India at 1:1 Million scale

established. The soil surveyor, then attempts to establish the relationships between the landforms and the soils so that it can be depicted on the map.

Field work has been undertaken in national level under Soil Resource Mapping project by NBSS&LUP and a Soil Map of India on 1:1 M scale (Fig.2) has been prepared. The map contains 1649 polygon occurring on different physiographic units composed of subgroup association (two soils). These units are arranged as per physiographic regions (Sehgal *et al.,*1987). Besides taxonomic classification, these mapping units are also described in terms of depth, drainage, texture, calcareous, topography of landforms and phases like slope, erosion, stoniness, rockiness, salinity, sodicity, flooding, etc. The colour of mapping units has been assigned as per great group of dominant soils as :

Soils of Himalayan Mountains and Siwalik

Soils of Western Himalayas

[1] Deep, excessively drained, calcareous sandy soils on moderate erosion and slight stoniness; associated with : Deep, excessively drained, calcareous sandy-skeletal soils with moderate erosion and moderate stoniness	Typic Cryorthents Typic Cryopsamments

Along with Soil Map of India (1:1 M), soil maps of different states have also been prepared at 1:250,000 scale. A part of Soil Map of Maharashtra is presented in Fig.3.

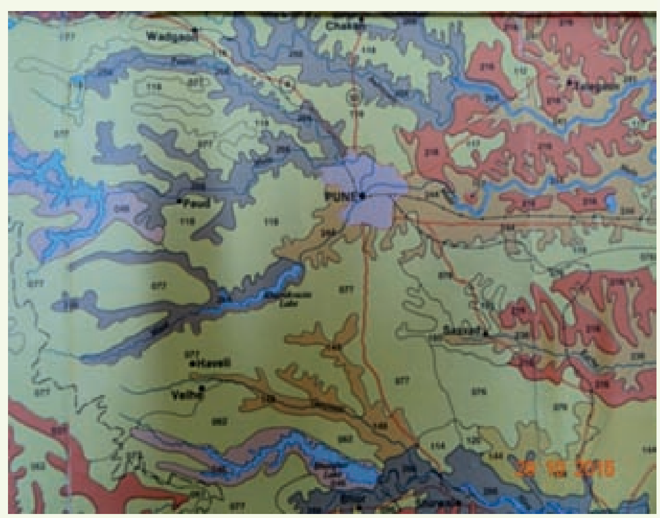
Soils of State (example Maharashtra)

The soils of Maharashtra were mapped on 1:250,000 scale and got printed on 1:500,000 scale. There are 355 polygon (family associations of two soils) depicting the depth, drainage, particle-size class, slope, erosion, stoniness. For example :

Soils of Konkan Coast

Soils of Coastal lands with residual hills

001	Extremely shallow, somewhat excessively drained, loamy soils on moderately sloping lands with residual hills with severe erosion and strong stoniness; associated with extremely shallow, somewhat excessively drained, loamy soils on gently sloping lands with severe erosion and strong stoniness	Loamy-skeletal, mixed, isohyperthermic, Lithic Ustorthents Loamy, mixed, isohyperthermic, Lithic Ustorthents



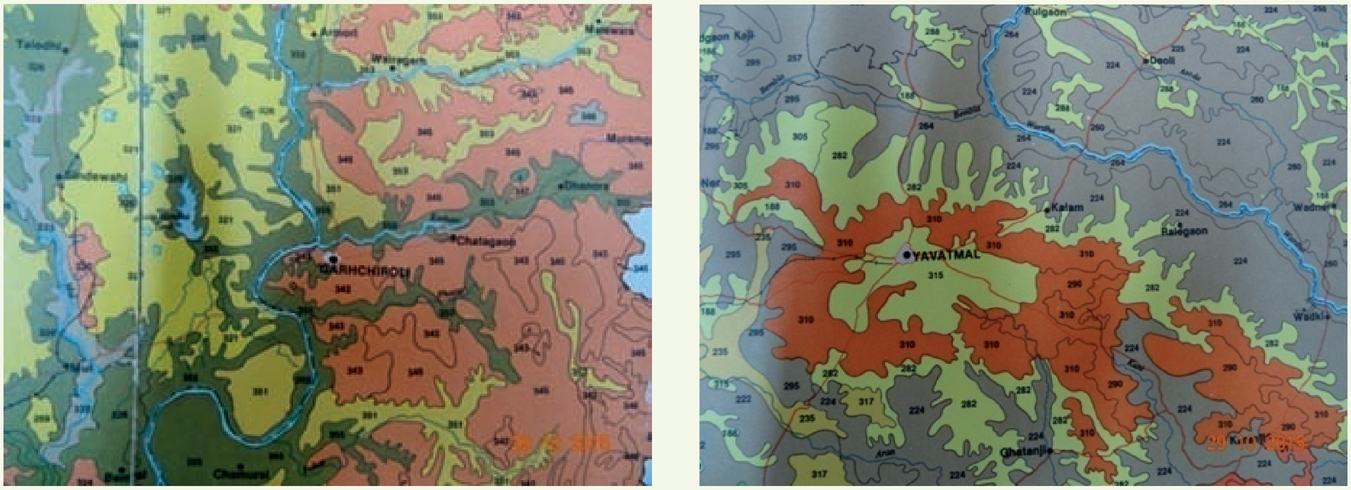


Fig. 3. Small-Scale Soil Resource Mapping (1:250000 scale) (Parts of Maharashtra)

For micro level planning field work is undertaken at 1:50,000 scale. Soil Survey of Jhilpi Watershed (4850 ha) having drainage density of 2.31 km/km^2 was carried out using IRS 1C LISS III (FCC Fig. 4) and map has been prepared as shown in Fig. 5.

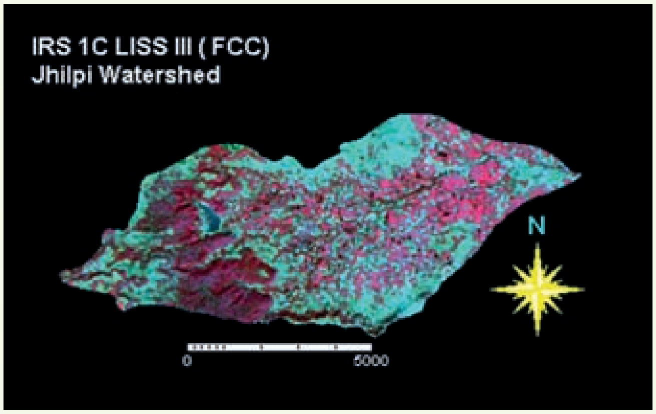


Fig 4. IRS 1C LISS III (FCC) of Jhilpi Watershed

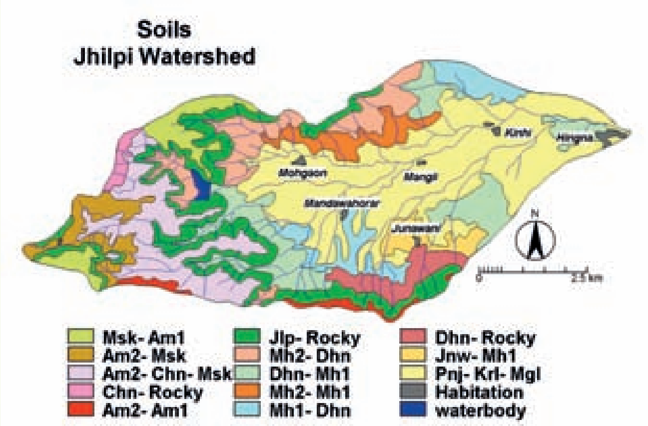


Fig. 5. Soils of Jhilpi Watershed

2.3 Soil Survey towards Land Use Planning at Different Levels

Land use planning is carried out at different levels viz. national or state, district or tehsil, and village (local)/ farm or watershed levels keeping in view the goals and available resources. Soil maps provide information on extent and distribution of soils, their potentials and constraints for specified use. Scale of soil map is determined based on observation density. As we proceed from small scale (1:1M or smaller) to large-scale (1: 50,000 or 1:10,000 scale or larger) map, the observation density increases and in turn the level of information and accuracy. Hence, the scale and quality of soil map is crucial in land use planning for targeted area.

National: Planning is concerned with national goals and the allocation of resources. Formulation of land use and tenure policies, budgeting, coordination of various ministries and departments, and formulation of suitable legislation wherever necessary. It is prepared mostly by the decision makers, who need all the relevant and necessary information. Soil map of 1:250,000 scale (showing association of soil families) serve the purpose where selected properties are considered.

***District*:** Most of the development projects are administered and implemented at district level. National priorities are translated into national goals to suit the needs of the area. Planning is focused on broad allocation of land resources to various uses, creation and improvement of infrastructure facilities, construction of irrigation works, roads, warehouses and establishment of credit and marketing facilities. Soil map of 1:50000 scale (showing soil series association as mapping unit) serves the intended purpose.

***Local or village level*:** Mostly confined to a village or a group of villages or watershed or catchments. Planning is closely associated with the local people and mostly based on their aspirations and past experiences. The plans formulated at higher levels are meant for local people and their implementation takes place mostly in the midst of local people. Soil map of 1: 10,000 scale or larger scale (showing phases of soil series) is required for site-specific interventions.

However, planning at different levels needs information (Table 2) at different scales and intensities as each level has its limitation in terms of applications, procedures and price. The preferred scale for national planning in 1:1 M or 1:250,000 scale or even smaller and the information should be made available in few sheets. District planning requires details at 1:50,000 scale or smaller up to 1:250,000 scale. For local or watershed planning maps between 1:10,000 and 1:25,000 are preferable for site-specific interventions.

2.3.1. Steps in Land Use Planning

Land use planning effort is launched by discussions between those who want the plan (land users and government) and the planners. This crucial first step should be a mutual exchange of ideas and information.

Table 2. Data and information for land use planning

Land resource data	-	climate
	-	landforms and soils
	-	land cover
	-	land resources
Land use related data	-	present land use and characteristics
	-	selected physiological characteristics of crops (as determining ecological requirements)
	-	land utilization types (LUTs) and production systems (present and potential)
	-	ecological requirements of LUTs, production systems, land use
Socio-economic data	-	population (including age and gender distribution, stakeholder)
	-	living conditions (including workload, cultural aspects, traditions, etc.)
	-	Access to markets
	-	costs of production and product prices
	-	socio-economics of communities
Land Legal data and information	-	relevant government policy documents, laws and regulations related to land
	-	present system of land allocation
	-	land tenure information
	-	traditional ownership and user rights
Institutional information	-	involved institutions and their mandates, resources and infrastructure
	-	links between institutions
	-	support services (extension, etc.)
General data and information	-	infrastructure, accessibility

References

Beckett, P.H.T. and Burrough, P.A. (1971). The relation between cost and utility in soil survey. IV. Comparison of the utilities of soil maps produced by different survey procedures and to different scales**.** *J. Soil Sci***. 22**:466-89.

Sehgal, J.L., Saxena, R.K. and Vadivelu, S. (1987). *Field Manual*, Bulletin No. **13**, NBSS&LUP, Nagpur.

Soil Survey Division Staff (2000). Soil Survey Manual (New Revised Edition). Handbook No. 18. United States Department of Agriculture.

Wilding, L.P. and Dress, L.R. (1983). Spatial variability and pedology. In ; *Pedogenesis and soil taxonmy. I Concepts and Interactions* (Eds.) L.P. Wilding, N.E. Smeck and G.F. Hall 83-116, Elsevier, Amsterdam.

Remote Sensing and GIS Applications in Soil Resource Mapping

Rajeev Srivastava
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

Geospatial technologies (Remote sensing, GIS and GPS) have demonstrated the potential to generate faster, cheaper and reliable spatial data on natural resources. The unique capability of space based sensors to provide a wide range of information available in the electromagnetic spectrum in a synoptic and more frequent manner has made this technology an inevitable tool in the sustainable development, utilization and monitoring of natural resources. The present lecture note discusses in brief the concept of remote sensing and GIS and its applications in soil resource mapping.

1. Introduction

Remote sensing technology has emerged as a powerful tool for generating reliable spatial information on various natural resources. Application of remote sensing technology for characterisation and mapping of soils are increasing rapidly due to great strides made in space-borne remote sensing in terms of spatial, temporal, spectral and radiometric resolutions. The multispectral and hyperspectral sensors are generating vast amounts of data in a cost-effective manner and at higher spatial and spectral resolutions. The current state-of-the-art space-borne sensors provide repetitive and synoptic coverage of any part of the earth, amenable to various projection and scales. Not only this, the remotely sensed data provide an opportunity to 'look back in time' for any comparison of the resources positioned between past and present. The advent of GIS and GPS has added a new dimension to resources survey and information integration. Through interfacing RS with GIS and GPS (commonly referred as geospatial technology), different management scenarios could be processed allowing the manager to analyze various management alternatives before selecting an alternative that would be most suitable.

In the following paragraphs, remote sensing, GIS and its application in soil resource mapping is discussed.

2. Remote Sensing

Remote sensing is the science of deriving information about an object or phenomena through analysis of data acquired by a device that is not in contact with the object or phenomena under investigation. Here the measurements are made in different spectral regions on interaction between the targets and electromagnetic radiation. The observations are synoptic, provide repetitive coverage of large areas and the data is quantifiable. Every object reflects/scatters a portion of electromagnetic energy incident on it depending on its physical properties. In addition, objects emit radiation depending on their temperature and emissivity. The reflectance/emittance of any object at different wavelengths follow a pattern, which is characteristic of that object, known as 'spectral signature'. Proper interpretation of the spectral signature leads to identification of the object. If the observation is made based on the electromagnetic radiation from the sun or the self emitted radiance, it is called 'passive remote sensing'. It is also possible to produce electromagnetic radiation of a specific wavelength or band of wavelengths to illuminate the terrain. The interaction of this radiation can then be studied by sensing the scattered radiance from the target. This is called 'active remote sensing'.

2.1. Remote sensing process

There are seven elements (Fig.1) which comprise the remote sensing process from beginning to end.

i. **Energy source or illumination (A)** - The first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

ii. **Radiation and the atmosphere (B)** - As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

iii. **Interaction with the target (C)** - Once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.

iv. **Recording of energy by the sensor (D)** - After the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.

v. **Transmission, reception, and processing (E)** - The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

vi. **Interpretation and analysis (F)** - The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.

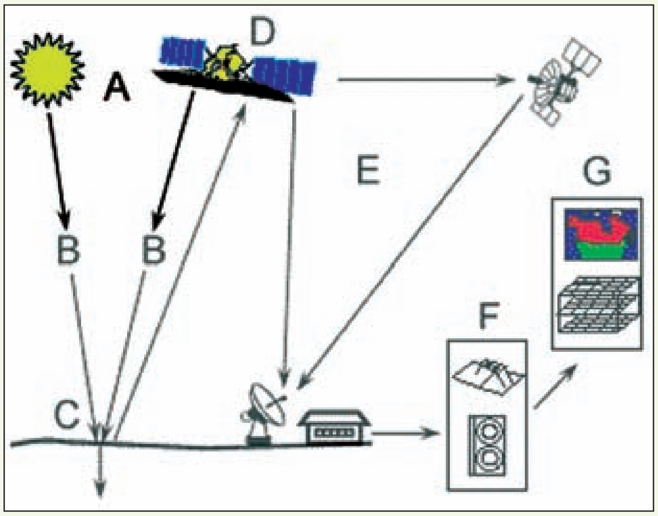


Fig. 1 Remote sensing process

vii. **Application (G)** - The final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

Solar and terrestrial radiation

The sun is the important source of electromagnetic radiation used in conventional optical remote sensing. The sun may be assumed to be a black body with surface temperature around 6000^0K. The sun's radiation covers ultraviolet, visible, IR and radio frequency regions and the maximum radiation occurs around 0.55 µm which is the visible region.

The earth can be treated as a blackbody at ~ 300^0K emitting electromagnetic radiation with peak radiation around 9.7 µm.

2.3. Radiation Laws

All objects above 0^o K (-273 °C) emit electromagnetic radiation at all wavelength. The thermal emission of radiation is due to conversion of heat energy (kinetic energy of the random motion of the molecules) into electromagnetic energy. Thermal emission of radiation depends upon two parameters namely temperature (T) and emissivity (E) of the material. The emissivity is a characteristic of the material and it is measure of its capability to emit radiation as compared to that of an ideal blackbody. The emissivity of a substance is related to its absorbtance. Good absorbers are good radiators whereas poor absorbers are poor radiators. For an ideal thermal emitter called a blackbody, the emissivity is equal to 1.

Stefan Boltzmann law: All objects above absolute zero (0 °k or –273 ° C) continuously emit electromagnetic radiation. The total energy radiated by an object of a particular temperature is given by Stefan- Boltzmann law, which states that,

$$M = \sigma T^4$$

Where M is the total radiant exitance from the surface of the material (Watt/m^2), s = Stefan- Boltzmann constant, with a value of 5.6697 x 10^{-8} $Wm^{-2}K^{-4}$ and T = absolute temperature (^{0}K) of the emitting material.

It is evident from the above equation that the total energy emitted from an object varies as T^4 and therefore total energy increases very rapidly with increase in temperature.

Wien's displacement law: The dominant wavelength, or wavelength at which a blackbody radiation curve reaches a maximum, is related to its temperature by Wien's displacement law, $\lambda m = A/T$,

Where, λm is wavelength (μm) corresponding to maximum spectral radiant exitance; A is a constant with value of 2898 μm ^{0}K; and T is temperature of the blackbody in ^{0}K.

Thus for a blackbody, the wavelength at which the maximum spectral radiant exitance occurs, varies inversely with its absolute temperature T. In day today experience, we observe that when a metal body such as a piece of iron is heated, it begins to glow and its colour changes successively to shorter wavelengths from dull red, to yellow and eventually to white. The average temperature of earth surface is around 300 ^{0}K and using Wien's law, the wavelength for peak emission is around 9.7 μm which means that earth predominantly emits radiation in thermal infrared region of electromagnetic spectrum.

2.4. Wavelength regions and bands

Electromagnetic spectrum is divided on the basis of wavelength into regions described in Table 1.

Table 1. Electromagnetic spectral regions

Region	Wavelength	Remarks
Gamma ray	<0.03 nm	Incoming radiation is completely absorbed by upper atmosphere and is not available for remote sensing
X- ray	0.03 to 30.0 nm	Completely absorbed by atmosphere. Not employed in remote sensing
Ultraviolet	0.03 to 0.4 μm	Incoming wavelength less than 0.3μm are completely absorbed by ozone in the upper atmosphere
Photographic UV band	0.3 to 0.4 μm	Transmitted through atmosphere. Detectable with film and photo-detector, but atmospheric scattering is severe.
Visible	0.4 to 0.7 μm 0.4- 0.5μm (Blue) 0.5- 0.6 μm (Green) 0.6- 0.7 μm (Red)	Imaged with film and photodetector. Includes reflected energy peak of earth at 0.5 μm.
Reflected IR band	0.7 to 3.0 μm 0.7 – 1.3 μm (NIR) 1.3- 3.0 μm (MIR)	Reflected solar radiation that contains no information about thermal properties of materials. The band from 0.7 to 0.9 μm is detectable with film and is called photographic IR band.
Thermal IR band	3 to 5 μm 8 to 14 μm	Principal atmospheric window in thermal region. Images at these wavelengths are acquired by optical mechanical scanners and special vidicon systems but not by film.
Microwave/Radar	0.1 to 30 cm	Longer wavelengths can penetrate clouds, fog, and rain. Images may be acquired in the active and passive mode.
Radio	> 30 cm	Longest wavelength portion of electromagnetic spectrum. Some classified radar with very long wavelength operates in this region.

The electromagnetic spectrum ranges from very short wavelength gamma rays (10^{-10}m) to long radio waves (10^6 m). The earth's atmosphere absorbs energy the gamma rays, X-ray, and most of the ultraviolet regions; therefore, these regions are not used for remote sensing. In remote sensing, the most useful regions are the visible (0.4 to 0.7 micrometer), the reflected IR (0.7 to 3 micrometer), the thermal IR (3 to 5 μm and 8 to 14 μm) and the microwave regions (0.3 to 300 cm).

Wavelength regions with high transmission of electromagnetic energy are called atmospheric windows and are used to acquire remote sensing images. These regions are further sub divided into bands, such as the blue (0.4 to 0.5 μm), green (0.5 to 0.6 μm), and red (0.6 to 0.7 μm) of the visible regions; near IR (0.7 to 1.3 μm) and mid IR (1.3 to 3 μm) of the reflected IR regions and thermal IR (beyond 3 μm).

2.5 Atmospheric effect

In passing through atmosphere, electromagnetic radiation is scattered and absorbed by gases and particulates. Besides the major atmospheric gaseous components of molecular nitrogen and oxygen, other constituents like methane, helium, and nitrogen compounds play an important role in modifying the incident radiation energy spectrum. The strongest absorption occurs at wavelength shorter than 0.3 μm. primarily due to ozone. There are certain spectral regions were the electromagnetic radiation is passed through without much attenuation and these are called atmospheric window. Remote sensing of earth surface is generally confined to these wavelength regions. Atmospheric windows used for remote sensing are 0.4- 1.3, 1.5- 1.8, 2.0- 2.26, 3.0- 3.6, 4.2- 5.0, 7.0- 15.0 μm, and 10mm to 10 cm wavelength regions of electromagnetic spectrum. The atmosphere may affect remote sensing data in two ways, through (i) scattering and (ii) absorption.

Scattering: It occurs when radiation is reflected or refracted by particles in the atmosphere, which may range from molecules of constituent gases to dust particles and large water droplets. The usual assumption is that scattered radiation, whether coming from the sun (downwelling) or reflected from the earth's surface (upwelling), is not attenuated but rather is redirected. Theoretically, scattering may be divided into three categories depending upon the relationship between the wavelength of radiation being scattered and size of the particle causing the scattering. They are Rayleigh scattering, Mie scattering and non-selective scattering.

Rayleigh Scattering:

It occurs when the radiation wavelength is much larger than the size of the scattering particles. The effect of Rayleigh scattering is inversely proportional to the fourth power of wavelength. Hence, there is much stronger tendency for short wavelength to be scattered by this scattering mechanism than longer wavelength. A 'blue' sky is a manifestation of Rayleigh scatter. In the absence of scattering, the sky would appear black.

Mie Scattering:

It occurs when the radiation wavelength is comparable to the size of the scattering particle. Water vapour and dust are the major causes of Mie scattering. This type of scattering tends to influence longer wavelengths compared to Rayleigh scattering. Although Rayleigh scattering tends to dominate under most atmospheric condition, Mie scattering is significant in slightly overcast condition only.

Non selective scattering:

It occurs when the scattering particle size is much larger than the radiation wavelength. Water droplets, for example, cause such scattering. They commonly have diameter in the range 5 to 100 μm and scatter all visible and near and mid infrared wavelengths about equally. Consequently, this scattering is nonselective with respect to wavelengths, equal quantities of blue, green and red light are scattered, hence fog and cloud appear white.

Absorption: Absorption occurs when the rays do not bounce off the surface and do not pass through it. Instead the rays are converted to some other form of energy such as heat. The most efficient absorber of solar radiation, in this regard, are *water vapour, carbon dioxide and ozone*. These gases tend to absorb electromagnetic energy in specific wavelength bands. The wavelength ranges in which the atmosphere is particularly transmissive of energy are referred as 'atmospheric windows' (Table 2). Remote sensing data acquisition is limited to these atmospheric windows.

Table 2. Atmospheric windows available for remote sensing

Spectral Regions	Wavelength
UV and visible	0.3- 0.75 µm
Near IR	0.77- 0.90µm, 1.00- 1.12µm, 1.19-1.34µm
Mid IR	1.55- 1.75µm, 2.05- 2.44µm
Thermal	3.05- 4.16µm, 4.05- 5.00µm, 8.00-9.20µm, 10.20- 12.40µm, 17.00-22.00 µm,
Microwave	2.06- 2.22 cm, 7.50- 11.50 cm, 20 cm and beyond

2.6 Spectral response of some earth surface features

When electromagnetic energy is incident on any given earth surface features, fractions of the energy are reflected, absorbed, and/or transmitted. Applying the principal of conservation of energy, we can state the interrelationship between these three-energy interactions as

EI (l) = ER (l) + EA (l) + ET (l)

Where EI denotes the incident energy, ER denotes the reflected energy, EA denotes the absorbed energy and ET denotes the transmitted energy, with all energy components being a function of wavelength. It is important to note that the portion of energy reflected, absorbed and transmitted will vary for different earth features depending on their material types and condition. These differences permit us to distinguish different features on an image. Since this characteristics is wavelength dependent, the proportion of reflected, absorbed, and transmitted energy will vary with wavelength. Thus two features may be undistinguishable in one spectral range and be very different in another wavelength band.

Concept of signatures

Any set of observable characteristics which directly or indirectly leads to the identification of an object and/or its condition is termed as signature (Fig. 3). Spectral, spatial, and temporal variations are three major characteristics of the targets which facilitate discrimination in optical remote sensing.

Spectral variations are the changes in the reflectance or emittance of objects as a function of wavelength. Colour of an object is a manifestation of spectral variation in reflectance in the visible region.

Spatial arrangements of terrain features providing attributes, such as shape, size and texture of objects that lead to their identification are termed as spatial variation.

Temporal variations are the changes of reflectivity or emissivity with time. They can be diurnal or seasonal, The variation in reflectivity during a growing cycle of a crop helps to distinguish crops which may have similar spectral reflectance, but whose growing cycle may not be the same.

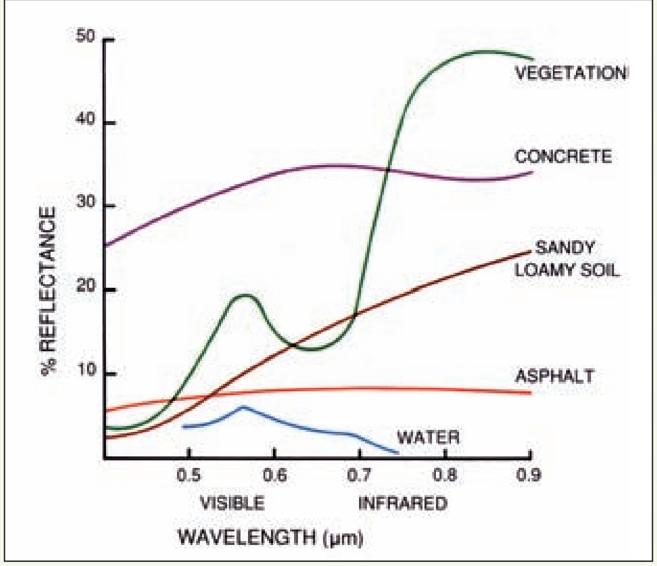


Fig.2. Spectral reflectance curves of some earth features

2.7 Characteristics of remote sensors

Spatial resolution: This is a measure of the area or size of the smallest dimension on the earth's surface over which an independent measurement can be made by the sensor.

Spectral resolution: The spectral resolution of the remote sensor characterizes the ability of the sensor to resolve the energy received in a given spectral bandwidth to characterize different constituent of earth surface.

Radiometric resolution: In remote sensing, the reflected radiation from different objects generate electrical signal (say voltage) as output from detector which are converted into digital number. This is analogous to grey shades scene in black and white photographs. The ability to distinguish the finer variation of the reflected or emitted radiation from different objects is characterized by the radiometric resolution.

Temporal resolution: This is another aspect which is specific to space-borne remote sensors. The polar orbiting satellite can be made to orbit in what is known as 'sun synchronous orbits'. This means that the satellite crosses over the equator at the same local solar time in each orbit. Such an orbit offers similar sun illumination conditions for all observations taken over different geographical locations along latitude (in the sun-lit area). By a suitable selection of spacecraft altitude and the inclination angle of the orbit the spacecraft can be made to cover the same area on the earth at regular intervals.

2.8. The IRS mission

In India, development of satellite platform for acquisition of remotely sensed data began with the Bhaskara mission of late seventies. The Bhaskara satellites had a two-band TV payload (spatial resolution of 1 Km) for land applications and satellite microwave radiometer (SAMIR) (spatial resolution of 125 Km) for oceanographic/atmospheric applications. The successful launch of IRS-1A (in 1988) and IRS-1B (in 1991) followed by IRS-P2 and IRS-P3 in 1994 and 1996 heralded the era of operational remote sensing programme in the country. The second generation satellite IRS-1C (in 1995) and IRS-1D (in 1997) carried three unique sensors viz. PAN (spatial resolution 5.8 m), LISS-III (spatial resolution 23.5 m in visible and 70.5 m in SWIR) and WiFs (spatial resolution 188 m). The unique combination of data available from IRS 1C/1D, covering different regions of the electromagnetic spectrum has enhanced scope for meeting the needs of natural resource management. The launch of third generation satellite IRS-P6 and Cartosat has further enhanced the utility of remotely sensed data in detailed characterization (1: 10,000 scale) of natural resources. IRS-P6 has three sensors LISS-IV (provides multispectral data with spatial resolution of 5.8 m), LISS-III (similar to IRS-1C/1D with SWIR band, spatial resolution 23.5 m) and AWiFs (4 bands with spatial resolution of 56m). The details of sensor characteristics of some of the Indian Remote Sensing Satellites and its application in soil mapping have been given in Table 3.

Table 3. Salient characteristics of IRS series of satellite

Satellite (Year)	Sensor	Spectral bands (µm)	Spatial resolution (m)	Swath (km)	Repeat cycle (days)	Level of soil mapping
IRS-1A/1B (1988, 1991)	LISS-I	0.45-0.52 (B) 0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	72.5	148	22	Small scale mapping (1:250,000 scale or smaller)
	LISS-II	Same as LISS-I	36.25	74	22	Medium scale mapping (1:50,000 scale)
IRS-P2 (1994)	LISS-II	Same as LISS-I	36.25	74	24	Same as above
IRS-1C/1D (1995-1997)	LISS-III	0.52-0.59 (G) 0.62-0.68 (R) 0-77-0.86 (NIR) 1.55-1.70 (SWIR)	23.5 70.5	141 148	24	Medium scale mapping upto 1:50,000 scale; or smaller and
	WiFS	0.62-0.68 (R) 0.77-0.86 (NIR)	188	810	24 (5)	Small scale mapping uto 1:1m scale
	PAN	0.50-0.75	5.8	70	24 (5)	PAN merged with LISS-III data upto 1:12,500 scale

IRS-P3 (1996)	MOS-A MOS-B MOS-C WiFS	0.755-0.768 (4 bands) 0.408-1.010 (13 bands) 1.6 (1 band) 0.62-0.68 (R) 0.77-0.86 (NIR 1.55-1.70 (SWIR)	1570x1400 520x520 520x640 188	195 200 192 810	24 24 24 5	WiFs data can be used for small scale mapping
IRS-P4 (Oceansat) (1999)	OCM MSMR	0.402-0.885 (8 bands) 6.6, 10.65, 18, 21 GHz (V&H)	360x236 150, 75, 50 and 50 km respectively	1420 1360	2 2	Generally not used in soil mapping
IRS-P6 (Resourcesat) (2003)	LISS-IV	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR)	5.8	70	24 (5)	Used in large scale mapping (1:12,500 and larger)
	LISS-III	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR) 1.55-1.70 (SWIR)	23.5	141	24	Same as LISS-III described above
	AWiFS	0.52-0.59 (G) 0.62-0.68 (R) 0.77-0.86 (NIR) 1.55-1.70 (SWIR)	56	737	24 (5)	Same as described for LISS-I above
IRS-P5 (Cartosat-1) 2005	PAN (Fore (+26^{0}) & Aft (-5^{0})	0.50-0.85	2.5	30	126 (5)	Large scale mapping (Cadastral level)
Cartosat-2 (2007)	PAN	0.45-0.85	0.8	9.6	310 (5)	As described for Cartosat-1

3. Geographical Information System

Geographic Information System (GIS) is defined as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geospatial data, in order to support decision making for planning and management of land use, natural resources, environment, transportation, urban facilities and other administrative records.

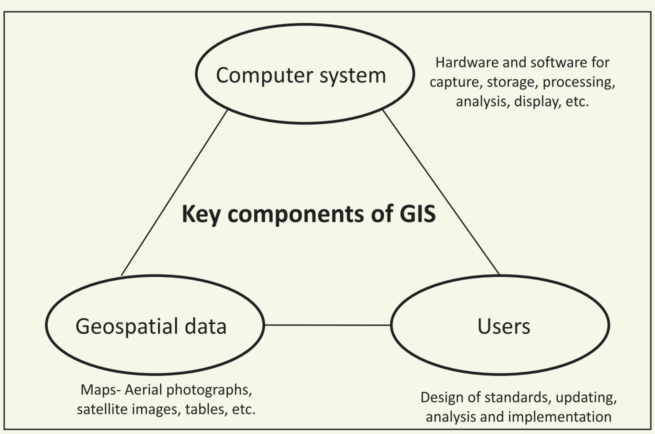


Fig. 3 Key components of GIS

The key components of GIS are a computer system, geospatial data and users, as shown in Fig. 3.

A computer system for GIS consists of hardware, software and procedures designed to support the data capture, processing, analysis, modeling and display of geospatial data.

The sources of geospatial data are digitized maps, aerial photographs, satellite images, statistical tables and other related documents.

Some commonly used GIS terminology

Spatial objects are delimited geographical areas, with a number of different kinds of associated attributes or characteristics.

A **point** is a spatial object with no area. One of the key attributes of a point are its geodetic location, often represented as a pair of numbers (such as latitude-longitude, or northing-easting). There may be a range of data associated with a point, depending on the application.

A **line** is a spatial object, made up of a connected sequence of points. Lines have no width, and thus, a specified location must be on one side of the line or the other, but never on the line itself.

Nodes are special kinds of points, usually indicating the junction between lines or the ends of line segments.

A **polygon** is a closed area. Simple polygons are undivided areas, while complex polygons are divided into areas of different characteristics.

Why is a GIS needed ?

These are the following reasons why a GIS is needed.	Once a GIS is implemented, the following benefits are expected:
- Geospatial data are poorly maintained. - Maps and statistics are outdated - Data and information are inaccurate - There is no data retrieval service - There is no data sharing	- geospatial data are better maintained in a standard format - revision and updating are easier - geospatial data and information are easier to search, analyse and represent - more value added product - geospatial data can be shared and exchanged freely - productivity of the staff is improved and more efficient - time and money are saved - better decision can be made

Comparison between GIS Versus Manual Works

Maps	GIS	Manual works
Storage	Standardized and integrated	Different Scales on different Standards
Retrieval	Digital Data Base	Paper Maps, Census, Tables
Updating	Search by Computer	Manual Check
Overlay	Systematically Done	Expensive and Time Consuming
Spatial Analysis	Very Fast Easy	Time & Energy Consuming
Display	Cheap and Fast	Expensive

4.0 Remote Sensing and GIS Applications in Soil Mapping

Soil surveyors consider the physiographic variation as a base for depicting the soil variability on a map. The general methodology of soil survey comprises pre-field interpretation using cadastral map, Survey of India toposheets, aerial photograph and satellite data (depending upon their availability) for delineation of various physiographic units, ground truthing for verification of physiogphic units, soil profile study, developing physiography- soil relationship and extrapolation of this relationship to other similar areas. The flow chart showing the general methodology used for soil mapping using remote sensing data is shown in Fig. 4.

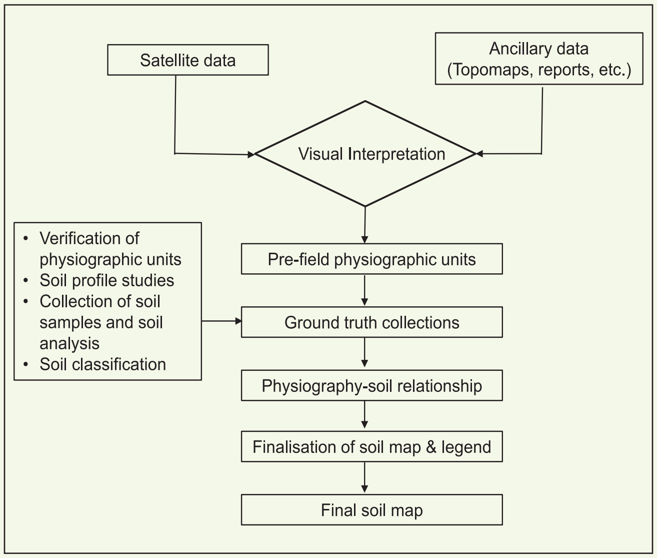


Fig.4. Flow chart depicting the general methodology for soil mapping

Among the two methods of remote sensing data interpretation viz. visual and digital, the former approach is predominantly used in soil mapping. Visual interpretation of satellite imagery is done based on shape, size, tone, shadow, texture, pattern, site and association. This has the advantage of being relatively simple and inexpensive. In digital interpretation, the computer aided techniques utilize the spectral variations for classification. The pattern recognition in remote sensing assists in identification of homogeneous areas, which can be used as a base for carrying out detailed field investigations.

4.1 Selection of optimal time satellite data for soil mapping

Remote sensing provides a complex overview of the earth surface, where the spectral characteristics of the vegetation, soil and the atmosphere are combined to form common reflectance value characterizing the surface ecosystem. In optical remote sensing, weather plays an important role in the availability of cloud-free satellite data. For mapping soils through remote sensing, it is important that considerable part of the land surface is exposed to direct solar radiation, so that reflection from the surface soils could be recorded by the satellite sensor. Thus, it becomes necessary to understand the land use/cropping pattern and life cycle of the field crops for selection of period related to data acquisition. For better visual interpretation of satellite image, it is also important that the image should have good contrast so that different land features could be delineated more precisely.

In a study (NBSS&LUP 2005) conducted jointly by NBSS&LUP and NRSA at Nagpur (representing part of Peninsular region), Gangtok, Sikkim (representing eastern Himalayan mountain region) and Meerut, U.P. (representing the Indo-Gangetic alluvial plains), it was found (Ravisankar and Srivastava 2009) that most optimal season for satellite data acquisition is between mid March to April for Peninsular region, February to March for Eastern Himalayan mountain region and March- April for the Indo-Gangetic plains for soil mapping. Verma *et al.* (1994) while mapping salt-affected soils of the Indo-Gangetic alluvial plain observed that satellite data acquired between the period 1st March to 1st week of April is most appropriate as it provides better contrast between salt-affected soils and crop.

4.2 Scale of soil mapping

The soil maps are required on different scales varying from 1:1 million to 1:4,000 to meet the requirements of planning at various levels because the scale of a soil map 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. The soil maps at 1:250,000 scale provide information for planning at regional or state level with generalized interpretation of soil information for determining the suitability and limitations for several agricultural uses and requires less intensity of soil observations and time. The soil maps at 1:50,000 scale where association of soil series are depicted, serve the purpose for planning resources conservation and optimum land use at district level and require moderate intensity of observations in the field. The large scale soil maps at 1:8,000 or 1:4,000 scale are specific purpose maps which can be generated through high intensity of field observations using large scale aerial photographs or very high resolution satellite data (Srivastava and Saxena 2004).

The spatial and spectral resolution of remote sensing data plays an important role in determining the scale of mapping. The coarse resolution data (spatial resolution 70m or higher) from IRS LISS-I, WiFS, AWiFs and LANDSAT-MSS sensors were found to be useful to prepare soil maps on 1: 250,000 scale or smaller. To map soils on 1: 50,000 scale, medium resolution remote sensing data from LANDSAT- TM, IRS LISS-II/LISS-III and SPOT- MLA are employed. Satellite data from IRS-P6 (LISS-IV sensor), Cartosat-1 and Cartosat-2 and IKONOS are now being employed for detailed characterization of soils on 1:10,000 scale and larger.

4.3 Hyperspectral remote sensing (hrs) and its applications in soil characterization

In remote sensing, hyperspectral is used interchangeably with spectroscopy or spectrometry, and it refers to spectra consisting of large number of narrow, contiguously spaced spectral bands. Hyperspectral data has the potential to provide more accurate and detailed information than possible with any other type of remotely sensed data.

Soil spectral library is an essential component in the analysis of HRS data for the prediction of soil properties. Soil spectral library refers to systematic collection of spectral reflectance data of soils whose basic properties (morphological, physical, chemical and mineralogical) are known and that can be used as reference to predict the properties of unknown soils based on soil reflectance data.

Over the past few decades, visible-near infrared (VNIR) reflectance spectroscopy (RS) has rapidly developed to become a fast and robust analytical method for characterization of various soil properties. The VNIR-RS of soil is based on the premise that the variation in the reflectance spectra of soil at different wavelengths is due to variation in the composition of the soil. Soil constituents have unique absorption features in these wavelength regions due to overtones and the combinations related to stretching and bending vibrations in molecular bonds such as C–C, C=O, C–H, N–H and O–H. As a consequence, VNIR reflectance spectra of soil basically contain information about the organic composition of a soil sample. Additionally, the prediction of some soil constituents that do not absorb within VNIR range may be possible through their correlations with spectrally active constituents. The advantages of using VNIR-RS include the simplicity of sample pre-treatment (sieving of soils), its lack of chemical reagents, its non-destructive nature, and the fact that it is rapid, inexpensive and accurate for analysis.

Srivastava *et al.* (2004) used spectral reflectance (350–2500 nm) data of some shrink–swell soils (n = 135) of Central India to develop spectral models using stepwise multiple linear regression (SMLR) technique for prediction of various soil properties. Good correlations were obtained for pH ($R^2 = 0.87$), OC ($R^2 = 0.71$), CEC ($R^2 = 0.77$) and clay ($R^2 = 0.61$) and R^2 for validation were between 0.56 and 0.77 for these soil properties.

Das *et al.* (2015) studied the spectral reflectance characteristics of soils of the Indo-Gangetic Plains covering parts of Punjab and Haryana states and calibrated soil reflectance (350-2500 nm) with soil properties of agronomic importance using partial least square regression (PLSR) technique for rapid prediction of soil properties. The application of calibration models on validation datasets (datasets not used for calibrations) resulted in very good prediction of soil organic carbon (n= 320, r^2= 0.81, RMSEP=0.116, RPD=2.30) and available K (n=320, r^2=0.78, RMSEP=0.243, RPD=2.13), ECe (n=402, r^2=0.94, RMSE=5.33, RPD=3.99), saturation extract Ca^{2+}+Mg^{2+} (n=401, r^2=0.81, RMSE=1.51, RPD=2.40), saturation extract Na^+ (n=402, r^2=0.88, RMSE=2.45, RPD=2.89), saturation extract Cl^- (n= 402, r^2= 0.92, RMSE= 2.16, RPD=3.44), saturation extract SO_4^{2-} (n=402, r^2= 0.67, RMSE= 2.21, RPD=1.60) and $CaCO_3$ (n=436, r^2= 0.66, RMSE= 0.79, RPD=1.72).

References

Das, B.S., Sarathjith, M. C., Santra, P., Sahoo, R. N., Srivastava, R., Routray, A.and S. S. Ray (2015) Hyperspectral remote sensing: opportunities, status and challenges for rapid soil assessment in India. *Current Science*, **108(5):**860-868.

NBSS&LUP (2005) Standardisation of methodology for large scale soil mapping using satellite data- a collaborative project between NBSS&LUP and NRSC, *NBSS Report No. 907*, National bureau of Soil Survey & Land Use Planning, Amravati Road, Nagpur

Ravisankar, T. and Srivastava, Rajeev (2009) Satellite imagery- their interpretation and applications in soil survey and mapping. (In): *Soil Survey Manual,* Bhattacharyya *et al.*(Eds) NBSS&LUP Publication No. 146, India, pp. 59-71.

Srivastava, Rajeev and Saxena, R.K. (2004). Technique of large-scale soil mapping in basaltic terrain using satellite remote sensing. *International Journal of Remote Sensing* **25(4):**679-688.

Srivastava, Rajeev; Jagdish Prasad and Saxena, R.K. (2004) Spectral reflectance properties of some shrink-swell soils of Central India as influenced by soil properties. *Agropedology* **14(1):** 45- 54.

Verma, K.S., Saxena, R.K., Barthwal, A.K. and Deshmukh, S.N. (1994) Remote sensing technique for mapping salt affected soils. *International Journal of Remote Sensing* **9:**1901-1914.

Geospatial Database Management in GIS

G.P. Obi Reddy, Pr. Scientist
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

The objective of geographic analysis in GIS is to transform the raw data into useful information to satisfy the requirements or objectives of decision-makers. The importance of GIS can only be realized when relevant tools are used to collect spatial data and integrate them with attribute data. Data used in GIS often are of many types, came from different sources and are stored in different ways. The analysis functions use spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models and such models highlight the underlying trends in geographic data and thus make new information available. In this paper the most common operations carried out by GIS like data input, database query, map algebra, and analysis etc., are discussed.

1. Introduction

The handling of spatial data usually involves the process of data acquisition, storage analysis and output. Creation of spatial database in GIS domain has become a very effective tool to aid and facilitate management decision-making. In recent times, GIS is being widely used as spatial analysis tool for effective and efficient means of data generation and management, analysis and display (Burrough, 1987). Data in GIS are mainly obtained from manual digitization and scanning of aerial photographs, paper maps, and existing digital data sets. Remote-sensing satellite imagery and GPS are promising data input sources for GIS. Before generation of any spatial data one has to understand the available data types, data analysis procedures and their capabilities in GIS to get realistic outputs. GIS provides tools and a method for the integration of different data into a format to be analyzed (ESRI, 1990 and 2000).

2. Database Generation in GIS

2.1 Data Capture

The true value of GIS can only be realized if the proper tools to collect spatial data and integrate them with attribute data are available. GIS provides tools and a method for the integration of different data into a format to be compared and analysed. Data sources are mainly obtained from manual digitization and scanning of aerial photographs, paper maps, and existing digital data sets. Remote-sensing satellite imagery and GPS are promising data input sources for GIS.

Manual Digitization: Manual Digitizing still is the most common method for entering maps into GIS. The map to be digitized is affixed to a digitizing table, and a pointing device (called the digitizing cursor or mouse) is used to trace the features of the map. These features can be boundary lines between mapping units, other linear features (rivers, roads, etc.) or point features (sampling points, rainfall stations, etc.) The digitizing table electronically encodes the position of the cursor with the precision of a fraction of a millimeter. The vertical wires will record the Y-coordinates, and the horizontal ones, the X-coordinates.

Scanning System: The second method of obtaining vector data is with the use of scanners. Scanning (or scan digitizing) provides a quicker means of data entry than manual digitizing. In scanning, a digital image of the map is produced by moving an electronic detector across the map surface. The output of a scanner is a digital raster image, consisting of a large number of individual cells ordered in rows and columns.

2.2 Data models in GIS

The three basic data models that GIS uses are vector, raster and TIN

Vector

Vector data models represent geographic phenomena with points, lines, and polygons. Points are pairs of x,y coordinates, lines are sets of coordinate pairs that define a shape, and polygons are sets of coordinate pairs defining boundaries that enclose areas. Coordinates are usually pairs (x,y) or triplets (x,y,z, where z represents a value such as elevation). The coordinate values depend on the geographic coordinate system in which the data is stored. Discrete features, such as customer locations and data summarized by area, are usually represented using the vector model.

Raster

A raster model otherwise known as a raster dataset (image), is, in its simplest form, a matrix (grid) of cells. Each cell has a width and height and is a portion of the entire area represented by the raster. The dimension of the cells can be as large or as small as necessary to represent the area and the features within the area, such as a square kilometer, square meter, or even square centimeter. The cell size determines how coarse or fine the patterns or features in your extent will appear. The smaller the cell size, the more detail the area will have. However, the greater the number of cells, the longer it will take to process, and it will require more storage space. Continuous numeric values, such as elevation, and continuous categories are represented using the raster model.

Triangulated Irregular Network (TIN)

In a triangulated irregular network (TIN) model, the world is represented as a network of linked triangles drawn between irregularly spaced points with x, y, and z values. TINs are an efficient way to store and analyze surfaces. Heterogeneous surfaces that vary sharply in some areas and less in others can be modeled more accurately, in a given volume of data, with a triangulated surface than with a raster. That is because many points can be placed where the surface is highly variable, and fewer points can be placed where the surface is less variable. In using only the points necessary, TINs also provide a more efficient method to store data.

2.3 Types of Information in a Digital Map

Any digital map is capable of storing much more information than a paper map of the same area, but it is generally not clear at first glance just what sort of information the map includes. Three general types of information can be included in digital maps:

Geographic information, which provides the position and shapes of specific geographic features.

Attribute information, which provides additional non-graphic information about each feature.

Display information, which describes how the features will appear on the screen.

2.4 Spatial Data models/structures

Geo-relational data model

The georelational approach involves abstracting geographic information into a series of independent layers or coverages, each representing a selected set of closely associated geographic features (e.g., roads, land use, river, settlement, etc). Each layer has the theme of a geographic feature and the database is organized in the thematic layers. With this approach users can combine simple feature sets representing complex relationships in the real world.

Topological Data Structure

Topology is the spatial relationship between connecting and adjacent coverage features. Topological relationships are built from simple elements into complex elements: points, arcs and areas. Topological data structure, in fact, adds intelligence to the GIS database.

Attribute Data Management

All Data within a GIS are stored within databases. A database is a collection of information about things and their relationships to each other. The principle characteristics of a DBMS are: - Centralized control over the database is possible, allowing for better quality management and operator-defined access to parts of the database; Data can be shared effectively by different applications; The access to the data is much easier, due to the use of a user-interface and the user-views. Data redundancy can be avoided as much as possible.

Relational Database

The relational data model is conceived as a series of tables, with no hierarchy nor any predefined relations. The relation between the various tables should be made by the user. This is done by identifying a common field in two tables, which is assigned as the flexibility than in the other two data models. However, accessing the database is slower than with the other two models. Due to its greater flexibility, the relational data model is used by nearly all GIS systems.

Tables

A table is a database component that contains a series of rows and columns, where each row, or record, represents a geographic feature—such as a parcel, power pole, highway, or lake—and each column, or field, describes a particular attribute of the feature—such as length, depth, or cost. Tables are stored in a database—for example, INFO, Access, dBASE, FoxPro, Oracle, or SQL Server.

Working with attributes

From a table, one can identify features with particular attributes and select them on the map. Over time, you might also update the attributes to reflect changes to geographic features, for example, a new subdivision extends your parcel database, or the construction of a dam alters a river network.

Joining data

Tables can also store information related to features such as warehouse inventories, monthly sales figures, and maintenance records. By joining this information to your spatial data, you can uncover new patterns and relationships that were not readily apparent.

2.5 Database Query

The selective display and retrieval of information from a database are among the fundamental requirements of GIS. The ability to selectively retrieve information from GIS is an important facility. Database query simply asks to see already stored information. Basically there are two types of query most general GIS allow: viz.,

i) Query by attribute

ii) Query by geometry

The attribute database, in general, is stored in a table with a unique code linked to the geometric data. This database can be searched with specific characteristics. However, more complex queries can be made with the help of SQL. GIS can carry out a number of geometric queries. There are five forms of primitive geometric query: viz.,

i) Query by point

ii) Query by rectangle

iii) Query by circle

iv) Query by line

v) Query by polygon

A more complex query still is one that uses both geometric and attributes search criteria together. Many GIS force the separation of the two different types of query. However, some GIS, using databases to store both geometric and attribute data, allow true hybrid spatial queries.

2.6 Analysis of geographic data

The heart of GIS is the analytical capabilities of the system. What distinguish the GIS system from other information system are its spatial analysis functions. The analysis functions use spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Such models illuminate the underlying trends in geographic data and thus make new information available. In data analysis the most common operations carried out by GIS are database query, map algebra, and distance- and context-related analysis. The objective of geographic analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers.

Data integration and conversion are only a part of the input phase of GIS. What is required next is the ability to interpret and to analyze the collected information quantitatively and qualitatively.

- **Spatial overlay:** Two themes are combined to form a new spatial feature (both geometric and attribute features are combined) known as spatial overlay. Three types of overlay can be performed: polygon-polygon, line-polygon, and point-polygon.

- **Buffer zone creation:** Distance operator in GIS is used for buffer zone creation. It shows the proximity or nearness from any point, line, or polygon. Using these operations, the characteristics of an area surrounding in a specified location can be generated. This kind of analysis is called proximity analysis and is used whenever analysis is required to identify surrounding geographic features. The buffer operation will generate polygon feature types irrespective of geographic features and delineates spatial proximity.
- **Map generalization:** Map generalization is a function to dissolve or merge adjacent polygon features.
- **Feature extraction;** Feature extraction is subset selection of a map, e.g., district soil map extracted from state soil map.

2.6.1 Overlay analysis

The heart of GIS is the analytical capabilities of the system. What distinguish the GIS system from other information system are its spatial analysis functions. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. There are basically two different types of overlay operations depending upon data structures.

Simple overlay: The layers were overlaid without assigning any weightage either for layer or classes. Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input to create an integrated analysis. Geographic problems often require the analysis of many different factors.

Weighted overlay: This process reclassifies values in the input rasters onto a common evaluation scale of suitability or preference, risk, or some similarly unifying scale. The input rasters are weighted by importance and added to produce an output raster. The Weighted Overlay process accepts only discrete rasters (integer values) as input. Continuous rasters should and must be reclassified to discrete rasters before they can be used.

2.6.2 Topological overlays and their functions

- **Topological overlay:** An analysis procedure for determining the spatial coincidence of geographic features.
- Union
- Identity
- Intersect
- **Union:** A topological overlay of two polygon coverages, which preserves features that fall within the spatial extent of either input data sets, i.e. all features from both coverages are retained.
- **Identity:** The topological overlay of a line or polygon coverage with another polygon coverage that computes the geometric intersection of the two coverages.
- **Intersect:** The topological integration of two spatial data sets that preserves features that fall within the spatial extent common to both input data sets.

The geo-processing tools below do not allow you to specify ranks for the input features; the input feature class will always be ranked higher than the overlay (clip, identity) features. Update is the exception to this rule, as the update features will be given a higher rank over the input features.

- Clip (Analysis)
- Split (Analysis)
- Erase (Analysis)
- Identity (Analysis)
- Symmetrical Difference (Analysis)

The range of geographical analysis procedures can be subdivided into the following categories.

- Database query.
- Simple overlay.
- Weighted overlay
- Proximity analysis.
- Network analysis.
- Digital Terrain Model.
- Statistical and Tabular Analysis.
- Spatial Analysis helps to
- Identify trends on the data.
- Create new relationships from the data.
- View complex relationships between data sets.
- Make better decisions.

2.6.3 Vector overlay

The vector overlay, however is far more difficult and complex and involves more processing. In simple vector overlay, the layers were overlaid without assigning any weightage either for layer or classes. Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input to create an integrated analysis. Geographic problems often require the analysis of many different factors. The weighted overlay process reclassifies values in the input rasters onto a common evaluation scale of suitability or preference, risk, or some similarly unifying scale. The input rasters are weighted by importance and added to produce an output raster. The Weighted Overlay process accepts only discrete rasters (integer values) as input. Continuous rasters should and must be reclassified to discrete rasters before they can be used. The typical vector overlay procedure is shown in Fig.1

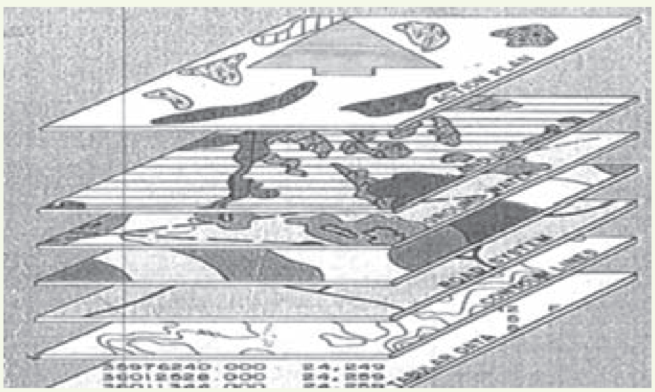


Fig.1 Typical vector overlay procedure in GIS

2.6.4 Raster overlay

It is a relatively straightforward operation and often many data sets can be combined and displayed at once. In raster overlay, the pixel or grid cell values in each map are combined using arithmetic and Boolean operators to produce a new value in the composite map (Fig.2). The maps can be treated as arithmetical variables and perform complex algebraic functions and it is called as map algebra.

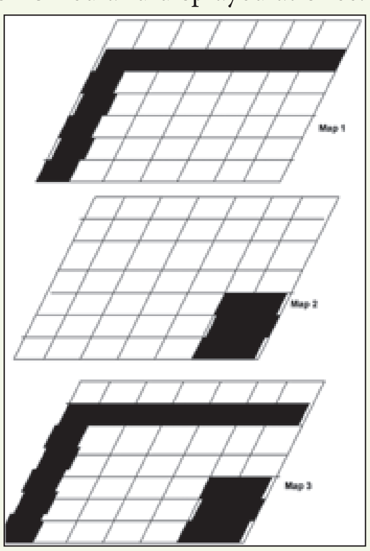


Fig.2. Typical raster overlay procedure in GIS

2.6.5 Logical Operators

The concept of map logic can be applied during overlay. The logical operators are Boolean functions. There are basically four types of Boolean Operators: viz., OR, AND, NOT, and XOR. During vector overlay, map features and the associated attributes are integrated to produce new composite maps. Logical rules can be applied to how the maps are combined. Vector overlay can be performed on different types of map features: viz.,

- Polygon-on-polygon overlay
- Line-in-polygon overlay
- Point-on-polygon overlay

During the process of overlay, the attribute data associated with each feature type is merged. The resulting table will contain both the attribute data. The process of overlay will depend upon the modelling approach the user needs. One might need to carry out a series of overlay procedures to arrive at the conclusion, which depends upon the criterion (Fig.3).

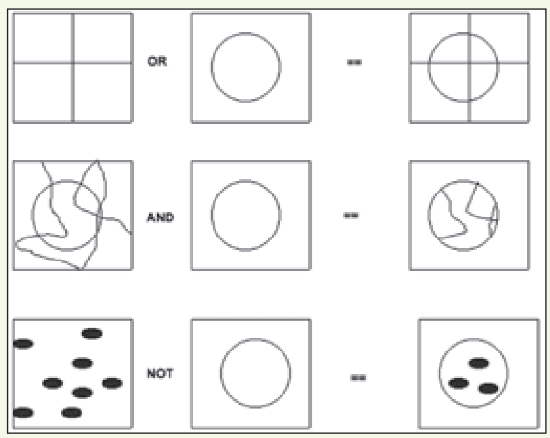


Fig.2 Typical raster overlay procedure in GIS

2.6.6 Modeling spatial problems

In general terms, a model is a representation of reality. Due to the inherent complexity of the world and the interactions in it, models are created as a simplified, manageable view of reality. Model help you understand, describe, or predict how things work in the real world.

There are two main types of models:

- Representation model –represent the objects in the landscape
- Process model –simulate processes in the landscape

A methodology is a set of analytical procedures that simulate real-world conditions within a GIS using their spatial relationships of geographic features. There are three categories of spatial modeling functions that can be applied to geographic features within a GIS:

- Geometric modeling (generating buffers, calculating areas and perimeters, and calculating distances between features);
- Coincidence modeling (topological overlay); and
- Adjacency modeling (pathfinding, redistricting, and allocation).

2.6.7 Representation models

Representation models try to describe the objects in a landscape. The way representation models are created in a geographic information system (GIS) is through a set of data layers. These data layers will be either raster or feature data. Raster layers are represented by a rectangular mesh or grid, and each location in each layer is represented by a grid cell, which has a value. Cells from various layers stack on top of each other, describing many attributes of each location. Fig.4 shows the various input layers in the model.

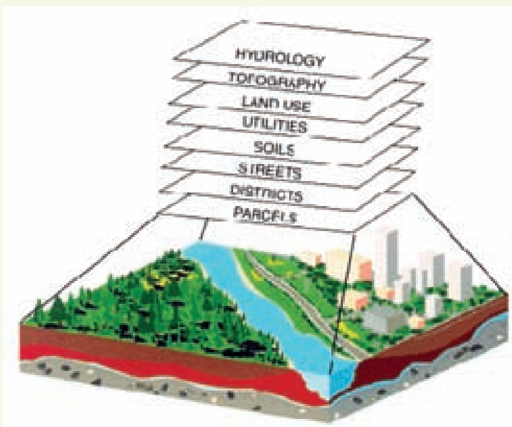
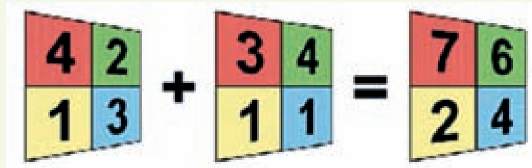


Fig.4 The pictorial view of the input layers in the model

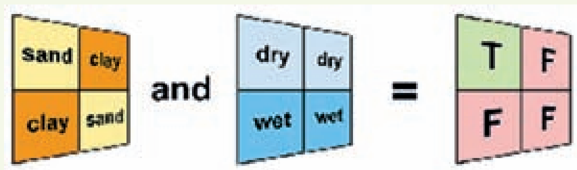
The representation model attempts to capture the spatial relationships within an object and between the other objects in the landscape. Along with establishing the spatial relationships, the GIS representation model is also able to model the attributes of the objects. Representation models are sometimes referred to as data models and are considered descriptive models.

2.6.8 Process models

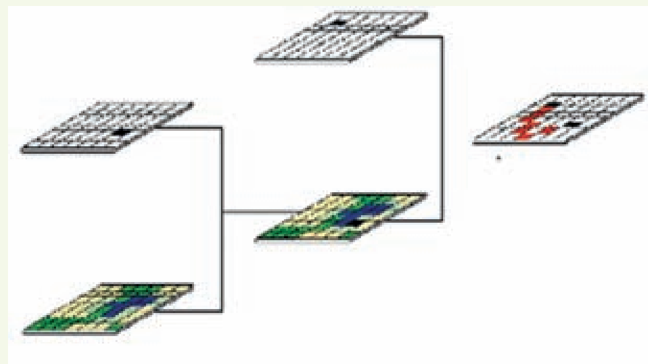
Process models attempt to describe the interaction of the objects that are modeled in the representation model. The relationships are modeled using spatial analysis tools. Since there are many different types of interactions between objects, process modeling is sometimes referred to as cartographic modeling. Process models can be used to describe processes, but they are often used to predict what will happen if some action occurs.



Complexity can be added through logic:



Additional complexity is added through specialized functions:



And even more complexity is added by combining several functions and logic:

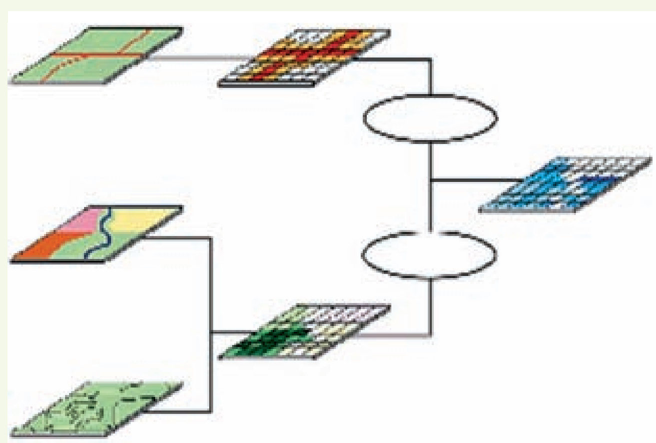


Fig.5. Some of the logical processes in the model

Some process models are simple, while others are more complex. Even more complexity can be added by adding logic, combining multiple process models. Some of the processes in the model are shown in Fig. 5.

For example adding the two rasters together in the model:

A process model should be as simple as possible to capture the necessary reality to solve your problem.

2.6.9 Types of process models

There are many types of process models to solve a wide variety of problems. Some include:

- **Suitability modeling**–most spatial models involve finding optimum locations.
- **Distance modeling**–what is the minimum distance between the two areas
- **Hydrologic modeling**–In which direction will the water flow
- **Surface modeling**–what is the pollution level for various locations

A set of conceptual steps can be used to build a model.

Buffer (Analysis)

Creates buffer polygons to a specified distance around the Input Features. An optional dissolve can be performed to remove overlapping buffers. Using these operations, the characteristics of an area surrounding in a specified location are evaluated. This kind of analysis is called proximity analysis and is used whenever analysis is required to identify surrounding geographic features. The buffer operation will generate polygon feature types irrespective of geographic features and delineates spatial proximity.

Geographic Analysis

Analysis of problems with some Geographic Aspects.

- Alternatives are geographic locations or areas.
- Decisions would affect locations or areas.
- Geographic relationships are important in decision-making or modelling.
- Some examples of its application:
- Nearest Neighbour.
- Network distances.
- Planar distances.

2.6.10 Relationship of Modeling to Analysis

- Decision Models search through potential alternatives to arrive at a recommendation.
- Decision support models process raw data into forms that are directly relevant to decision making.
- Data characterization models are used to develop a better understanding of a system to help characterize a problem or potential solutions.

2.7 Difficulties of Geographic Analysis

- Plenty of data.
- Spatial relationships are important but difficult to measure.
- Inherent uncertainty due to scale.
- Difficult to make data sources compatible.
- Difficult mathematics.
- Quantity vs. Quality Questions.
- Multiple objectives.
- GIS can address some (but not all) of these difficulties.

2.8 Presenting results/outputs

One of the most exciting aspects of GIS technology is the variety of different ways in which the information can be presented once it has been processed by GIS. Traditional methods of tabulating and graphing data can be supplemented by maps and three dimensional images. Visual communication is one of the most fascinating aspects of GIS technology and is available in a diverse range of output options.

References

Burrough, P.A. (1987). *Principles of geographical information systems for land resources assessment* (corrected printing): Oxford, Clarendon Press, 193 p.

Environmental System Research Institute, (1990). *Understanding GIS*: The ARC/INFO method. Redlands, CA: ESRI, 1V.

Environmental System Research Institute (2000). *GIS in Schools*. Redlands, CA: ESRI.

Application of Digital Elevation Models in Assessment of Water Harvesting Potential

P. Tiwary and S. Chattaraj
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

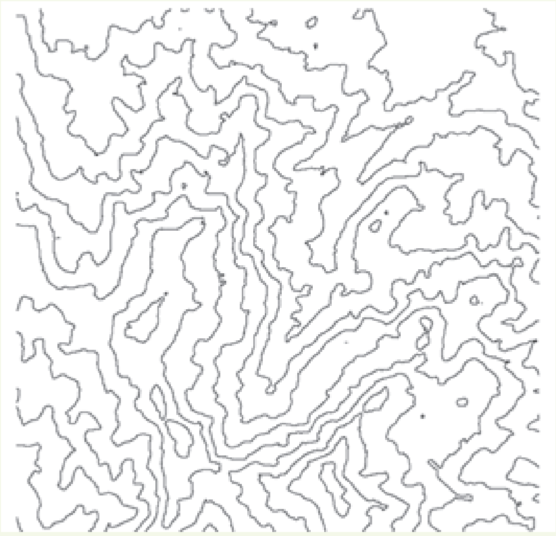
Fresh water availability has become a major issue in the developing countries where about one-fourth population is facing the harsh scarcity of fresh water. The scarcity of fresh water can be overcome by adopting rainwater harvesting techniques to store runoff. The modern techniques and/or technologies viz, computer simulation models, geographical information system (GIS) and remote sensing (RS) have been used widely in the assessment of runoff using SCS Curve Number method. The topographic features such as slope, aspect, channel networks, surface drainage pattern, etc., greatly influence the quantity and intensity of runoff. Digital Elevation Models (DEMs) are used in extracting the topographic features, watershed delineation and identification of suitable sites for water harvesting structures. For last few decades, great emphasis has been given on the application of DEMs in the various aspects of hydrological modelling in a watershed, e.g., watershed delineation, rainfall-runoff modelling, assessment of water harvesting potential, etc. In this lecture notes use of DEMs for assessing runoff potential for water harvesting is presented briefly.

Introduction

Water is essential for growth, bio-diversity, environment, agriculture and all types of living organisms. Presently, fresh water availability has become world human right issue due to continuous depletion of fresh surface and groundwater resources. World's quarter population living in developing countries is facing one harsh scarcity of water for domestic and agricultural purposes. To overcome the shortage of irrigation water for agriculture, there was a need to move towards water storage techniques like rainwater harvesting (Glendenning and Vervoort, 2011). The most important component for rainwater harvesting is runoff that is generated from the heavy rainfall and has a significant influence on the hydrological cycle. The assessment of runoff is also important for flood forecasting (Ratika et al., 2010). For last few decades, the modern techniques and/or technologies *viz*, computer simulation models, geographical information system (GIS) and remote sensing (RS) have been used widely in the assessment of runoff. Hydrologic modelling is commonly used to estimate runoff from a watershed which is one of the most important parameters in any water resources design project. One of the widely used applications of these estimates is to determine the design or flood discharge of a watershed. Moreover, modelling and analysis is generally carried out to determine the effects of hydrologic processes in the watershed of a study area and to determine the required parameters for the assessment of surface runoff. The topographical features of a watershed have great influence on its hydrologic response characteristics, the actual response of hydrologic processes has a direct correlation with the terrain relief anywhere in river basin, but both catchment area and landform are two crucial impact parameters (Black, 1996).

2. Digital elevation models

Digital Elevation Models (DEMs) are used in extracting the topographic features such as slope, aspect, curvature, to identify drainage features such as ridges, valley bottoms, channel networks, surface drainage patterns, and to quantify subcatchment and channel properties such as size, length, and slope (O'Callaghan and Mark, 1984). The accuracy of the topographic information is a function both of the quality and resolution of the DEM, and of the DEM processing algorithms used to extract this information. DEMs are also used for automated watershed delineation implemented in various GIS systems and custom applications.



Contour lines

2.1 Definition of Digital Elevation Model

- A DEM provides a digital representation of a portion of the earth's surface terrain over a two dimensional surface (UNEP/GRID)
- A DEM is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datums in the landscape (Moore et al., 1991)
- A DEM is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals (USGS, 1990)

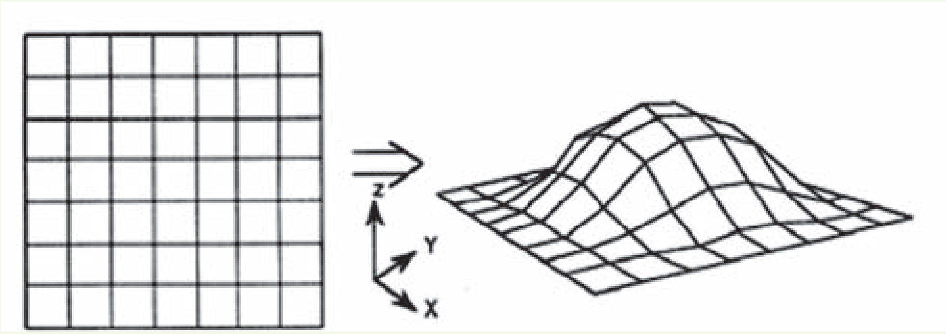
2.2 Structure of Digital Elevation Model

Line Model

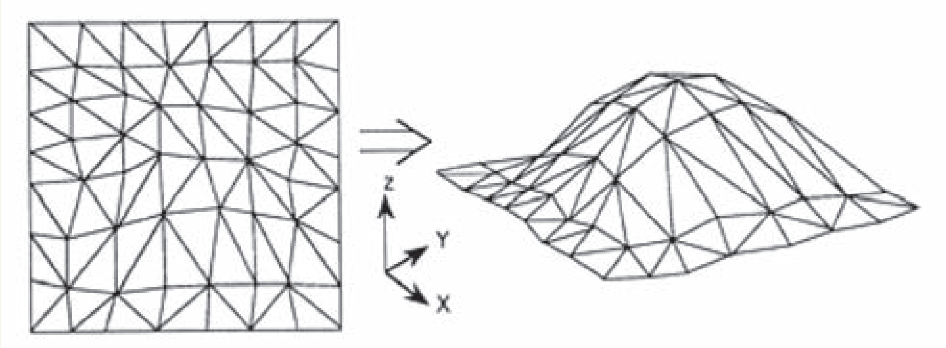
This type of DEM structure describes the elevation of terrain by contours (imaginary lines joining the points of equal elevations), the x,y coordinate pairs along each contour of specified elevation.

GRID Structure

In this type of DEM structure, elevation data are stored in an array of grids. Data structure of a GRID shares much similarity with the file structure



Grid DEM



TIN DEM

of computers: as two dimensional array (every point can be assign to a row and column). This similarity of storage structures, the topological relations between the data points are recorded implicitly.

Triangulated Irregular Network (TIN)

This type of DEM structure is a network of interconnected triangles with irregularly spaced nodes or observation points with x, y coordinates and z values. Advantage over GRID is its ability to generate more information in areas of complex relief, and avoiding the problem of gathering a lot of redundant data from areas of simple relief.

2.3 Availability and Creation of Digital Elevation Model

DEMs can be acquired from many sources of topographic information generated from photogrammetry, interferometry, ground and laser surveying and other techniques (Mukherjee *et al.*, 2013). Usually, aerial photos, high resolution satellite data, or field surveyed spot height and Light Detection And Ranging (LiDAR) data are used as input to generate high resolution/high quality DEM. Surveying data collection is not only time consuming but also expensive. Even though a good number of aerial photos, high resolution Synthetic Aperture Radar (SAR) and optical remote sensing data are available, it is not always easy and affordable to generate DEM over large areas. The DEM data such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and SRTM (Shuttle Radar Topography Mission) are acquired from the spaceborne satellite and are of coarser resolution. Recently, global free DEM including GDEM and SRTM offer almost global coverage and easily accessible data (Table 1).

Table 1. Different sources of digital elevation models available globally at free of cost

Source	Geographical Region	Spatial Resolution	Remarks	Source
National Elevation Dataset (NED)	U.S., Puerto Rico, Territorial Islands of the U.S., and Mexico	1-arc-second (30 m) 1/3-arc-second (10 m) 1/9-arc-second (3 m) 2-arc-second (60 m)	only Alaska Most preferred for continental U.S.	http://nationalmap.gov /viewer.html
Shuttle Radar Topography Mission (SRTM)	Global Global (between 60ºN and 56º S)	3-arc-second (90 m) *Optional*: 1 arc-second (30m) for U.S.	Version 1: "unfinished," contain voids Version 2: "finished," minimal voids	http://earthexplorer .usgs.gov/
Global Land Cover Facility (GLCF)	Global	3-arc-second (90 m) *Optional*: 1 arc-second (30 m) for U.S.	Subset SRTM data into tiles large enough to contain individual Landsat images.	http://glcf.umd.edu /data/
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	Global (between 83ºN and 83 ºS)	1-arc-second (30 m)		http://earthexplorer .usgs.gov/
Global Multiresolution Terrain Elevation Data 2010 (GMTED2010)	Global	30-arc-second (1 km) 15-arc-second (450 m) 7.5-arc-second (225 m)	Replaced GTOPO30, preferred for working with very large regions	http://earthexplorer .usgs.gov/

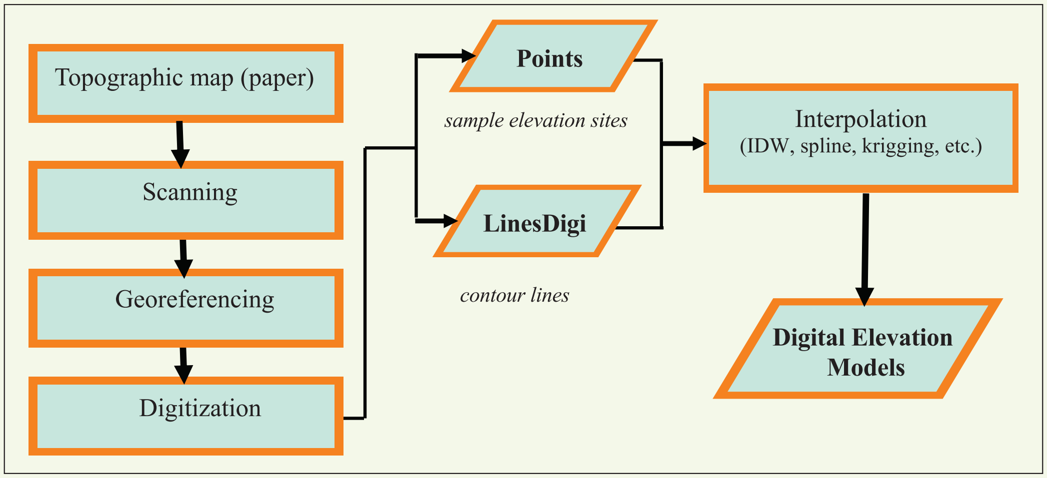


Fig. 1. Flowchart for creation of DEM from contour lines

As it is mentioned earlier, the elevation point data/ contour lines acquired from various sources, *viz.*, aerial photos, satellites, field survey and topographic map are generally used to create a DEM. However, for brevity, a flowchart for creation of DEM from contour lines is illustrated in Fig. 1.

There are many Geographical Information Systems (GIS) packages available that provide the necessary tools and algorithms to generate a hydrologically correct DEM from contour data, e.g. the ArcGIS Spatial Analyst and ArcHydro (Maidment, 2002). Contours are first converted to a Triangulated Irregular Network (TIN) surface, which is constructed by triangulating a set of vertices to form a network of triangles. Further, the TIN was interpolated to a raster DEM at a desired spatial resolution using ArcGIS Spatial Analyst. The resolution of the raster determines how well the raster represents the features of the TIN surface. The resulting DEM generated from contour lines contains topographic errors that create problems in hydrological models, such as pits and depressions, but are easily corrected to ensure continuous hydrological flow (Tarboton *et al.*, 1991).

2.4 Application of Digital Elevation Model

Digital elevation models (DEMs) are very important and useful in many applications, notably in the following domains where DEMs play a significant role in the improvement of analysis result, product development and decision making:

- Civil Engineering: cut and fill in road design, site planning, volumetric calculations in dams and reservoirs etc.
- Earth Sciences: for modeling, analysis and interpretation of terrain morphology e.g. drainage basin delineation, hydrological run-off modeling, geomorphological simulation and classification, geological mapping etc.
- Planning and resource management: site location, support of image classification in RS, geometric and radiometric correction in RS images, erosion potential models, crop suitability studies, pollution dispersion modeling etc.
- Surveying and Photogrammetry: in building high quality contours, used in survey or photogrammetric data capture and subsequent editing, ortho-photo production, data quality assessment and topographic mapping.
- Military Applications: inter-visibility analysis for battlefield management, 3-D display for weapons guidance systems and flight simulation, and radar line of sight analyses

For last few decades, great emphasis has been given on the application of DEMs in the various aspects of hydrological modelling in a watershed, e.g., watershed delineation, rainfall-runoff modelling, assessment of water harvesting potential, etc.

2.4.1 Assessment of Water Harvesting Potential

The need and importance of water harvesting and water conservation has been stressed in national water policy and agricultural policy of Government of India (Singh et al., 2009). The various rainwater harvesting structures like check dams, farm ponds, nalla bunds, percolation tanks, etc. are constructed at suitable sites to store the rain water. This holistic approach, in a watershed for conserving soil and water resources through site specific water harvesting structures, will not only conserve soil and water resources but also enhances the crop productivity. For designing and constructing any water harvesting structure, assessment of peak runoff rate and runoff volume/water harvesting potential for a watershed is prerequisite. DEMs provide the information on the topographic features like slope, maximum flow length, stream order, etc. which greatly influence the peak runoff rate and runoff volume generated from a watershed. DEMs also help in the delineation of a watershed which is a primary hydrological unit used in the study of rainfall-runoff processes. Therefore, in the succeeding sections, these aspects have been explained briefly.

Delineation of Watershed

Watershed delineation is one of the most commonly performed activities in hydrological modelling. Delineation of watersheds depends on the catchment drainage pattern of the watershed. This in turn depends on the relief of the area considered. Digital elevation models (DEMs) provide good terrain representation from which watersheds can be derived automatically by various GIS systems and custom applications (Garbrecht and Martz, 2000). While considering the digital representation of the terrain using the DEM, errors in data, such as artificial minimum points can lead to large

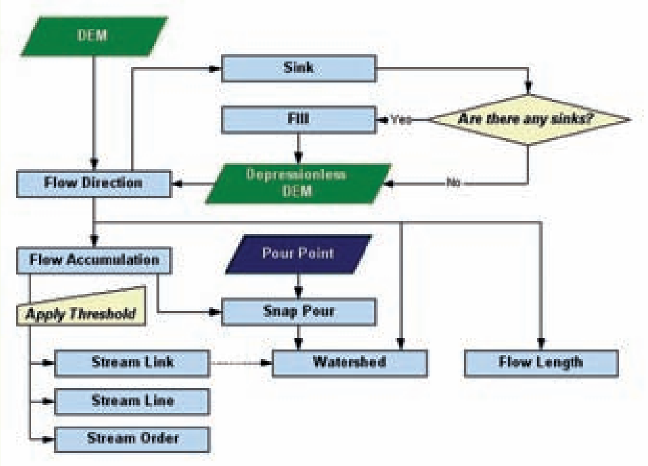


Fig. 2. Flowchart for Delineating a Watershed from digital elevation model

numbers of watersheds, which needs to be overcome by suitably preprocessing the data. The steps involved in delineation of watershed including preprocessing of the digital elevation data are illustrated in Fig. 2.

Assessment of Water Harvest/Runoff potential

The construction of water harvesting structures requires the information on peak runoff rate to flow safely through the structure and the volume of runoff generated from watershed that can be stored.

i) Estimation of Peak Runoff Rate

The peak runoff rate is estimated by the Rational method which is a simple and widely used method and is expressed as:

$$Q_p = 0.28*C*I*A \quad (1)$$

where:

Q_p = Peak runoff rate [m^3/sec]

C =Runoff coefficient [-]

I = Rainfall intensity [mm/hr] for a duration equal to the time of concentration

A = Catchment or drainage area [km^2]

The Rational method follows the assumption that:

- the predicted peak discharge has the same probability of occurrence (return period) as the used rainfall intensity (I),
- the runoff coefficient (C) is constant during the rain storm, and
- the recession time is equal to the time of rise.

In the modified version of the Rational Method, a storage coefficient is included to account for a recession time larger than the time the hydrograph takes to rise. The Modified Rational Method reads:

$$Q_p = 0.28 * C_s * C * I * A \quad (2)$$

where:

C_s = Storage coefficient [-]

The maximum runoff rate in a catchment is reached when all parts of the watershed are contributing to the outflow simultaneously. This happens when the time of concentration, the time after which the runoff rate equals the excess rainfall rate, is reached. In this exercise, the Kirpich/Ramser formula is used to calculate the time of concentration:

$$T_c = 0.0195 * L^{0.77} * S^{-0.385} \quad (3)$$

where:

T_c = Time of concentration [min]

L = Length of main river [m]

S = Distance weighted channel slope [m/m]

The digital elevation models are used to generate the length of main river or maximum flow length (L) and the distance weighted slope or the average slope of a watershed (S).

ii) Estimation of Runoff volume

The SCS-CN method (SCS, 1972) is widely used for estimating the runoff volume because of its flexibility and simplicity (Zhan and Huang, 2004). This method considers the influence of land use, land treatment, soil type and soil moisture conditions on generation of runoff volume and these factors vary both in space and time. Therefore, for accurate estimation of runoff volume, information on the spatial variability of soil type and land use is essential. Geo-informatics (information collected through remote sensing techniques and geographical information system) can play an important role in the quantification of spatial variability and hence, in accurate estimation of runoff volume. Moreover, for ungauged watersheds accurate prediction of the quantity of runoff from land surface requires much effort and time which can be minimized with use of geoinformatics.

Remote Sensing can facilitate studying the factors influencing the rainfall-runoff process, such as soil type, slope gradient, drainage, geology and land cover. It provides significant source for real-time and accurate data related to land and soil. The basic requirement of any hydrologic studies is a digital elevation model (DEM) generated from remote sensing techniques. DEM enables to derive various topographic attribute such as elevation, slope and aspect etc. which are essential to analyze watershed physical characteristics.

The SCS Curve Number (CN) technique is also known as the "Hydrologic Soil Cover Complex Number method". It combines the infiltration losses with initial abstractions and estimates rainfall excess or equivalently runoff volume as follows (Maidment, 1993; Singh, 1992):

$$Q = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S} \quad (4)$$

Where, Q = direct surface runoff; P = total precipitation; λ = initial abstraction ratio; and S = potential maximum retention after runoff begins.

The value of λ in Eqn. (4) is approximated to be 0.2 as a standard value. After substituting this value in Eqn. (4), the runoff generated can be expressed as follows (Ponce and Hawkins, 1996):

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (5)$$

Practically, the values of λ vary in the range of $0.1 \leq \lambda \geq 0.4$.

The potential maximum retention S can be estimated with the help of curve number from the following equation (Singh, 1992; Maidment, 1993; Subramanya, 2008):

$$S = \frac{25400}{CN} - 254 \quad (6)$$

Where, S= potential maximum retention (mm).

Theoretically, the range of CN varies from 0-100 but practically it varies in the range of 40-98. A CN value of 100 indicates that the potential maximum retention is zero (i.e., S = 0) and a CN value of 0 indicates that the runoff generation is zero (i.e., S = ∞) (Subramanya, 2008).

For the use of Eqn. (4) under Indian conditions, the λ values of 0.1 and 0.3 are recommended depending on the soil type and AMC type. Thus, Eqn. (5) has been modified for Indian conditions as follows (Subramanya, 2008):

$$Q = \frac{(P - 0.1S)^2}{(P + 0.9S)} \quad \text{for } P > 0.1S \quad (7)$$

and $$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \quad \text{for } P > 0.3S \quad (8)$$

Eqn. (7) is applicable for black soils under AMC of types II and III. However, Eqn. (8) is applicable for black soils under AMC of type I as well as for all other soils having AMC of type I, II and III. These AMCs correspond to the following soil conditions (Singh, 1992; Subramanya, 2008): (i) *AMC I*: Soils are dry but not to the wilting point and satisfactory cultivation can be done; (ii) *AMC II*: Average conditions; and (iii) *AMC III*: Heavy rainfall or light rainfall and low temperatures that occurred in the last 5 days; saturated soil. The limits of these three AMC classes are based on total rainfall magnitude in the previous 5 days.

The SCS method estimates curve number for only AMC II. Therefore, in order to obtain the curve number for AMC I and AMC III, the following formulae are used (Chow et al., 1988; Ponce and Hawkins, 1996):

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281 CN_{II}} \quad (9)$$

$$CN_{III} = \frac{CN_{II}}{0.427 - 0.00573 CN_{II}} \quad (10)$$

Where, CN_I, CN_{II}, and CN_{III} are curve numbers for AMC I, II and III, respectively. If CN_{II} is known, Eqns. (7) and (8) can be used to estimate CN_I and CN_{III}.

It should be noted that where land use patterns are not uniform in a catchment, a composite or weighted curve number (CN_w) should be considered (Maidment, 1993), which can be calculated as:

$$CN_W = \frac{\sum_{i=1}^{n} CN_i A_i}{\sum_{i=1}^{n} A_i} \quad (11)$$

Where, CN_i = runoff curve number for the i^{th} land use pattern, A_i = area under the i^{th} land use pattern, and n = total number of land use patterns.

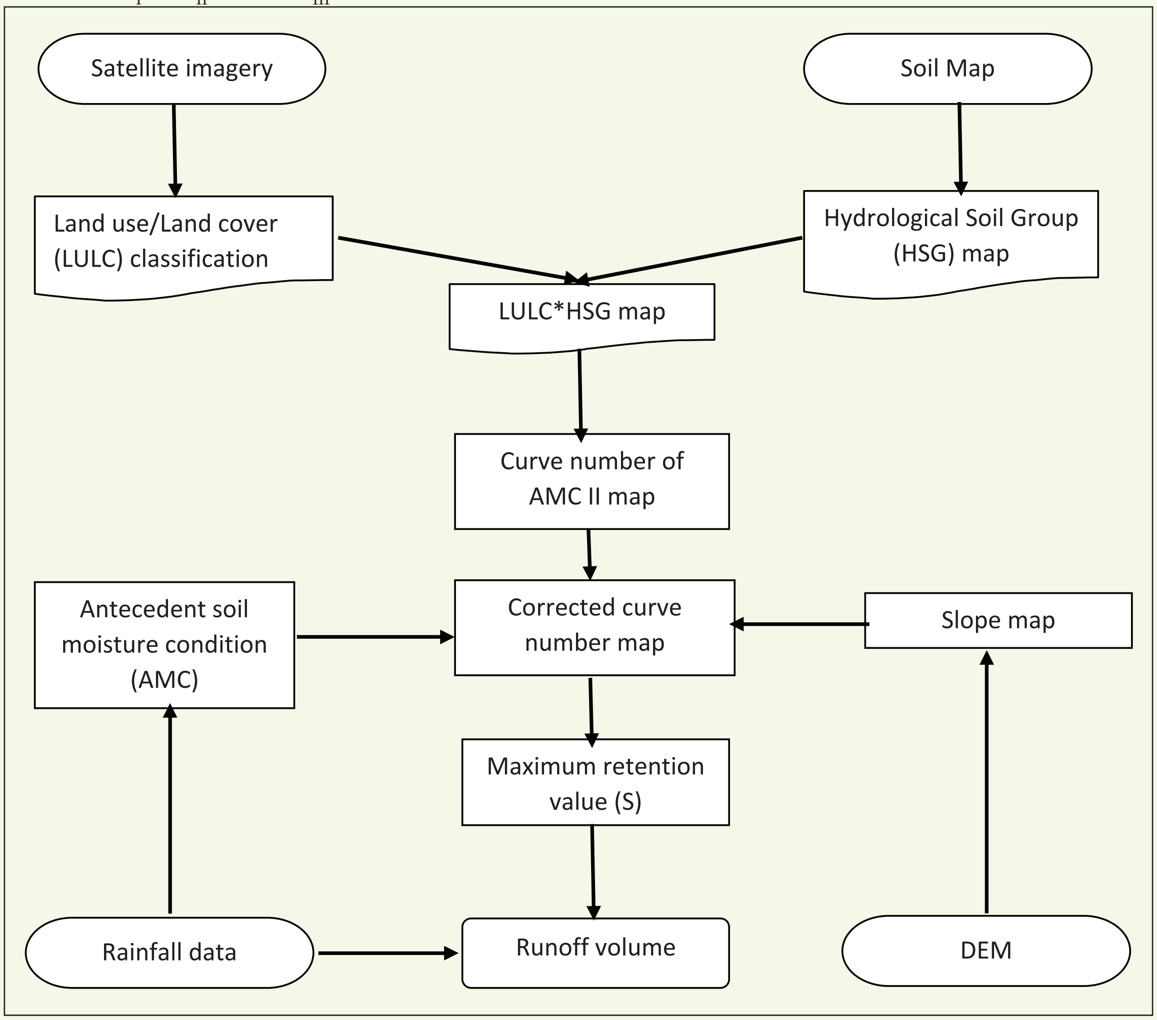


Fig. 3. Flowchart for estimating the runoff volume using the SCS-CN method

A flowchart for estimating the runoff volume using the SCS-CN method is shown in Fig. 3.

However, the standard SCS-CN method does not predict the runoff volume for the hilly areas and areas with steep slopes where the slope greatly influences the runoff volume. It is reported that the standard SCS-CN method underestimated large runoff events and overestimated small event (Huang et al., 2006). Also, in the treated watershed the standard SCS-CN method fails to predict the runoff volume correctly. The treatment measures are, generally, adopted as per the slope of land surface of the watershed. Therefore, Sharpley and Williams (1990) have proposed an adjustment for slope as follows:

$$CN_{II}\alpha = \frac{1}{3}\left(CN_{III} - CN_{II}\right)\left(1 - 2e^{-13.86\alpha}\right) + CN_{II} \quad (12)$$

Where $CN_{II}\alpha$ is the value of $CN_{II}\alpha$ for a given slope; $CN_{II}\alpha$ and are CN for soil moisture condition II (average) and III (wet), respectively; and α (m m^{-1}) is the slope of watershed.

According to Huang et al. (2006),

$$CN_{II}\alpha = CN_{II} \times K \quad (13)$$

Where $$K = \frac{322.79 + 15.63\alpha}{\alpha + 323.52} \quad (3)$$

Eqs. (12) and (13) were used to adjust the CN_{II} values for watershed slopes, assuming that CN_{II} obtained from the standard table (SCS, 1972).

2.4.2 Selection of Suitable Sites for Water Harvesting

The selection of suitable sites for water harvesting depends on various factor, viz., geology, geomorphology, lineament intersection, land use/land cover, soil texture, permeability/infiltration, rainfall/runoff amount, drainage condition (drainage buffer, drainage density/ stream order), slope and many other watershed characteristics. DEMs can be used for extracting information as many of these factors. Based on the slope, stream order, permeability and runoff potential, selection criteria for water harvesting sites is given in Table 2.

Table 2. Selection criteria for selecting suitable sites for water harvesting structures

Structure	Slope (%)	Permeability	Runoff potential	Stream order	Watershed area (ha)
Farm ponds	0-5	Low	Medium/high	1	1-2
Check dams	< 15	low	Medium/high	1-4	25
Subsurface dykes	0-3	High	Medium/Low	>4	> 50
Percolation tanks	6-7	High	Low	1-4	25-40

Source: Ramakrishnan et al., 2009

References

Black P.E. (1996). *Watershed Hydrology*, Syracuse, New York.

Chow V.T., Maidment D.R. and Mays L.W. (1988). *Applied Hydrology*. McGraw-Hill, New York.

Garbrecht J. and Martz L.W. (2000). Digital Elevation Model Issues in Water Resources Modeling. (In): Maidment D. and Djokic D. (Eds.), *Hydrologic and Hydraulic Modeling Support with Geographic Information Systems*. ESRI Press, Redlands, CA, pp. 1-28.

Glendenning C.J. and Vervoort R.W. (2011). *Hydrological impacts of rainwater harvesting (RWH) in a case study catchment:* The Arvari River, Rajasthan, India Part 2. Catchment-scale impacts. *Agric. Water Manag.*, **98**: 715-730.

Huang M., Jacgues G., Wang Z. and Monique G. (2006). A modification to the Soil Conservation Service curve number method for steep slopes in the Loess plateau of China. *Hydrological Processes,* **20**(3): 579-589.

Maidment, D.R. (2002). *ArcHydro: GIS for water resources*. ESRI Press, USA.

Maidment, D.R. (1993). *Handbook of Hydrology*. McGraw-Hill, New York.

Moore I.D., Grayson R.B. and Ladson A.R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Process*, **5**: 3-30.

Mukherjee S., Joshi P.K., Mukherjee S., and Ghosh A. (2013). Evaluation of vertical accuracy of open source digital elevation model (DEM). *Int. J. Appl. Earth Obs.*, **21**: 205-217.

O'Callaghan J.F. and Mark D.M. (1984). The extraction of drainage networks with lakes. *Water Resources Research*, **18**(2): 275-280.

Ponce V. M. and Hawkins R. H. (1996). Runoff curve number: Has it reached maturity? *J. Hydrol. Engrg.*, *ASCE*, **1**: 11-19.

Ramakrishnan D., Bandyopadhyay A. and Kusuma K.N. (2009). SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. *J. Earth Syst. Sci.*, **118**(4): 355-368.

Ratika P., Mohan P.P., Ghose M.K., Vivek S. and Agarwal S. (2010). Estimation of rainfall runoff using remote sensing and GIS in and around Singtam, East Sikkim. *Int. J. Geomat. Geosci.*, **1**:466-476.

SCS (1972). Hydrology.,' National Engineering Handbook, Supplement A, Section 4, Soil Conservation Service, USDA, Washington, D.C.

Sharpley A. N. and Williams J. R. (1990). EPIC Erosion Productivity Impact Calculator: 1. Model determination,' US Department of Agriculture. *Tech. Bull. No.* 1768.

Singh V.P. (1992). *Elementary Hydrology*. Prentice Hall, Englewood Cliffs, New Jersey.

Singh J.P., Singh D. and Litoria P.K. (2009). Selection of suitable sites for water harvesting structures in Soankhad watershed of Punjab using remote sensing and geographical information system (RS&GIS) approach – A case study. *J. Indian Soc. Remots Sens.*, **37**: 21-35.

Subramanya K. (2008). *Engineering Hydrology*. Tata McGraw-Hill Publishing Company Ltd., New Delhi.

Tarboton D. G., Bras R. L. and Rodriguez-Iturbe I. (1991) On the extraction of channel networks from digital elevation data. *Hydrological Process*, **5**: 81-100.

USGS (1990). Digital Elevation Models. Technical Instructions, *Data Users Guide* 5, National Mapping Program, Reston, Virginia, 51 p.

Zhan X. and Huang M.L. (2004). ArcCN-Runoff: An ArcGIS tool for generating curve number and runoff maps. *Environmental Modeling & Software*, **19**: 875-879.

Soil Geoportal Development and Some of its Applications

G.P. Obi Reddy, Pr. Scientist
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440 033

ABSTRACT

Soil Information System (SIS) contains basic topographic information, characteristics of soil profiles and their different layers and diagnostic horizons on the most important soil and land characteristics; validated models and soil processes. The recent advances in geospatial technology, enables us to store, manipulate, analyze, and present the spatial data. It allows to handle vast amounts of spatial data in digital form. A Geoportal enables us to store, search, process, synthesize, and present the spatial soil information. In the study a seamless soil information system (1:250,000 scale) and a prototype geoportal with uniform standards and formats with support of digital terrain models and satellite data as a base information for soils, soil loss, degraded/ wastelands datasets has been developed. It enables us to enhance the utility of soil data at regional scale and develop interactive spatial data mechanism for updation, retrieval with globally compatible projection systems and datum. Potential applications of soil geoportal include constructing visualization to know the extent of particular parameter related to soil types and its characteristics. In combination with other thematic layers in Geoportal, it is possible to obtain new layers that are the result of the intersection or difference of thematic layers to develop various applications.

1. Introduction

Decision-makers at various levels depend on reliable, up-to-date soil information in order to promote effective means of land use plans for sustainable agriculture. With the development of Geographic Information System (GIS) and the computer revolution of recent years, allowing a large amount of soils and associated data to be easily stored and retrieved, the emergence of a range of large-scale environmental problems across the globe has added to the general demand for better information on spatial variation and trends in the condition of soils and landscapes. The first way is through reducing risks in decision-making, and the second involves improving our understanding of biophysical processes. Reducing risk in decision-making requires the provision of information to be closely linked to, and preferably driven, by the decision-making process at different levels. Soil Information System (SIS) contains in addition to the basic topographic information–point information on the characteristics of soil profiles and their different layers and diagnostic horizons on the most important soil and land characteristics; validated models and soil processes. In the last few years, soil information has become increasingly important in many agricultural applications. With recent advances in geospatial technology, the ability for storing, manipulating, analyzing, and presenting spatial data has been greatly enhanced. It is now possible to handle vast amounts of spatial data in digital form. Through geoportal it is possible to store, search, process, synthesize, and present the spatial soil information (areas of soil associations and parent materials, geomorphological maps, layers of other soil-forming and site-influencing factors, land use and interpretation layers), to connect them with the non-spatial information and to generate various derivative thematic information.

2. Design of Soil Information System (1:250,000 Scale) – A Geoportal

Based on the available soil sheets at 1:250,000 scale, NBSS&LUP developed GIS based statewise soil information systems by adopting certain data standards and formats. In order to meet the demands from the user community and changing the capabilities of geospatial technologies, a seamless soil information system (1:250,000 scale) - A prototype geoportal with uniform standards and formats with a support of digital terrain models and satellite data as a base information for soils, soil loss, degraded/wastelands datasets has been developed. It enables us to enhance the utility of soil data at regional scale and to develop interactive spatial data mechanism for updation, retrieval with globally compatible projection systems and datum. The GIS based soil information system has two distinct utilization capabilities - the first pertaining to organization, querying and obtaining information and the second pertaining to integrated analytical modeling. However, both these capabilities depend upon the core of the GIS database that has been organized.

The design of GIS based soil database will include three major elements:

Conceptual design: Basically laying down the application requirements and specifying the end-utilization of the database. The conceptual design is independent of hardware and software and could be a wish-list of utilization goals.

Logical design: It is basically the specification part of the database. This design sets out the logical structure of the database elements, schemas, protocols and work flows.

Physical design: This pertains to the hardware and software requirements, consideration of file structure, memory and disk space, access and speed, etc.

Each stage is interrelated to the next stage of the design and impacts the organization in a major way. For example, if the concepts are clearly defined, the logical design is easier done and if the logical design is clear the physical design is also easy.

Soil Information System essentially consists of three main components:

- The spatial database, containing all spatial soil maps, which shows the geographical extents to create thematic maps.
- The laboratory and soil profile database contains the results of soil analyses, i.e. basic chemical and physical data (soil properties), as well as inorganic and organic contaminants.
- The method database is intended to document and select standardized methods, e.g. for the derivation of the filtering capacity, groundwater recharge or soil productivity from soil maps and from the relevant basic pedological data.

Soil Information System developed for geoportal consists of spatial and attributes database. In addition, there are a set of relationships that define the links between these.

I. Spatial (the map). Geographic objects in a entity-oriented are of three kinds:

- Polygons, representing delineations of map units;
- Lines, representing boundaries between delineations as well as linear features at the map scale;
- Points, representing point observations (sample sites) and point features.

II. Attributes (information about the mapped entities)

- Attributes of individual polygons, including their area and shape;
- Attributes of polygon classes (map units), including the soil(s) found in polygons of the class and their spatial arrangement within the polygons;
- Attributes of individual polygon boundary lines, including their length, accuracy and precision (implicit width);
- Attributes of individual polylines, including their length and width;
- Attributes of line classes, including the soil(s) or special feature(s) found along lines of the class;
- Attributes of individual points, including the details of an observation;
- Attributes of point classes, including the soil(s) or special feature(s) found at points of the class.

III. Relationships (links), for example:

- Spatially, map units are made up of delineations;
- Thematically, map units are made up of components that can't be mapped separately.

The major steps involved in deployment of Soil Information Systems for geoportal includes

I. *Data organization:* to show the logical relation of data, e.g. a profile is made up of a sequence of horizons; a map unit has several component soil types;

II. *Data storage:* to save data for later use;

III. *Data retrieval:* to examine the saved data;

IV. *Data manipulation and transformation:* to derive new data from old, e.g. information about an entire map unit derived from information about its constituents;

V. *Data analysis:* to solve problems using data, e.g. land evaluation; environmental risk assessment; and soil management recommendations.

2.1 Data Standardization For Geoportal

2.1.1 Data Standards

Determination of standards of databases, their structure, the data capture technique is the preliminary condition for a successful connection of geo-oriented databases and for building geographic information systems. Thus basic data standards for soil data were determined. Soil database can be defined as a collection of geometric and analytical databases. Geometrical data includes soil information layers with objects, types, formats and attributed data includes field data, laboratory analytical data and other derived datasets.

2.1.2 Development of metadata

In order to build a strong spatial soil database to establish integrity and consistency of all data, metadata would be crucial. Metadata and metadata servers enable users to integrate data from multiple sources, organizations and formats. Metadata are 'data about the data'. They describe the dataset to all users. Even a simple description may be considered metadata, but nowadays the term is reserved for a detailed, formal description. Metadata for geographical data may include the data source, its creation date, format, projection, scale, resolution and accuracy. Metadata will be specified and assembled based on the existing, international standards (ISO). Metadata standards have to be developed by adopting the FGDC or OGC standards. Metadata development contains the following principal sections:

- Identification_Information: identifies the dataset and gives its geographic limits
- Data_Quality_Information: how reliable is the data? This explains how the data were collected, sampling designs, analytical techniques etc. For interpolated maps, the interpolation method must be specified.
- Spatial_Data_Organization_Information: explains which spatial model was used to represent the data
- Spatial_Reference_Information: explains the co-ordinate system used for georeference
- Entity_and_Attribute_Information: explains the attributes (variables) in the database, for example, the meaning of codes, and the structure of attribute tables
- Distribution_Information: explains how to obtain the data, including on-line access, and any restrictions on the use of the dataset.
- Metadata_Reference_Information: explains who is responsible for the metadata, and which standard it follows

2.1.3 Data Dictionary

The data dictionary consist of record types (tables) created in the database by systems generated command files, tailored for each supported back-end DBMS. Data dictionary section, date element wise, its short name, data type, unit of measure, minimum value, maximum value and brief description on data elements and its sub classes to be specified.

2.1.4 Designing the data forms

In soil information system, for every input parameter numerical data stored in the Access databases data forms have to be designed by specifying the conditions like field size, format and other validation conditions. Similarly data query from is to be developed in order to query the spatial database from the attribute and geometrical database.

2.1.5 Entity-Relationship (ER) diagram

An entity-relationship (ER) diagram is a specialized graphic that illustrates the relationships between entities in soil database. ER diagrams often use symbols to represent three different types of information. Boxes are commonly used to represent entities. Diamonds are normally used to represent relationships and ovals are used to represent attributes. Once themewise all the data elements are listed, standardized and grouped, for similar kind of elements under broad functional categories, the Entity-Relationship Model (ER Model) can be developed keeping their relationships, data flow and data queries in view. Keeping the data flow in view, primary key and foreign keys have to be specified in the relationship. Placing foreign keys in worksheets creates one-to-many relationships among the data. That type of structure is what enables the user to retrieve records quickly from large databases. The tables in complex databases often contain multiple foreign keys. The developed soil attribute database in backend can be linked with the geometric data stored in GIS, through the use of a common field. For example based on the unique profile number it can be imported numerical data about the profile into the GIS database to get the spatial distribution of the profiles. Similarly, new spatial maps can be created, showing for instance the chemical and physical properties of the soil units.

2.1.6 Data formats

Data formats include georeferenced data (vectors, polygons, grids, points) and statistical data referenced to geographical entities (e.g. administrative regions). Data submitted to the Data Management System should follow certain standards.

eXtensible Markup Language (XML)

XML is emerging as the international standard for exchange of information, and it is easy to export XML data in most modern Graphical interface (GI) software systems like ArcGIS. However due to the often huge size of geographic data sets, XML has had limitations. Depending upon the necessity, data could be exchanged using some of the formats like ESRI Shapefiles, ESRI Personal Geodatabases, Erdas Imagine or TIFF, ESRI Coverages and Grids via Exchange File Format (E00) have to be adopted. These data need to be linked to a geographic entity via a common feature code.

ii) Geography Markup Language (GML)

The Geography Markup Language (GML) is an XML encoding for the transport and storage of geographic information, including both the spatial and non-spatial properties of geographic features. It was developed by OpenGIS Consortium (OGC) and is different to the SVG standards. It exclusively concerns with storage and transportation of geographical data. The basic element for the representation of geographical contents is <feature> element. Within this element both spatial and geometrical data is stored. GML is concerned with the representation of the geographic data content. GML can used to encode both spatial and non-spatial geographic information of soils. GML is used to express geographic information in a manner that can be readily shared on the Internet.

2.2 Soil Geoportal

A soil geoportal framework have the ability to systematically organize, search, discover, access, visualize and even update geospatial data and services via a customized user interface for internal and external users. A fundamental objective of the Soil Geoportal is to provide a means for referencing and accessing geospatial information that is distributed and made available using a variety of technologies. It also supports all principal metadata standards and electronic data communication standards. It also has capabilities that integrate data made available in a large variety of formats.

2.2.1 Framework elements of Soil Geoportal

In order to meet the goal of development of soil information system for improving access the digital spatial and aspatial soil data in the form of a geoportal, the procedure is structured in four main parts.

In the first part a framework for the provision of spatial soil and soil related data will be defined.

In the second part the development of a schema for describing the spatial soil and soil related data and services take centre stage.

In the third part the focus is set on harmonization and semantic interoperability of selected soils and associated data sets. The soil and soil related data will be analysed, necessary metadata will be identified and provided and specific datasets will be systematically harmonized.

In the fourth part the establishment of an integrated network and the soil portal for improving the access to data and metadata take centre stage. In order to consider the needs of the target users of the soil portal, user requirements will be considered. Within the GS Soil portal an access to all decentralized distributed data and metadata will be possible. Within the soil portal access to all distributed data and metadata will be possible.

2.2.2 Soil Geoportal Architecture

The basic idea of the Soil Portal is to develop a standalone geoportal, where all soil and soil related information can be cataloged; stored, searched, visualized and can also be transferred to other spatial data infrastructures. The conceptual frame work of soil geoportal is shown in figure 1. The target users for the portal are any kind of users from soil and environmental experts to interested citizens. The provided information can be viewed and queried at different administrative levels: from national, regional, sate and district level. Within the GS Soil Portal different kind of information shall be bundled: especially different kind of data, textual documents, metadata and maps.

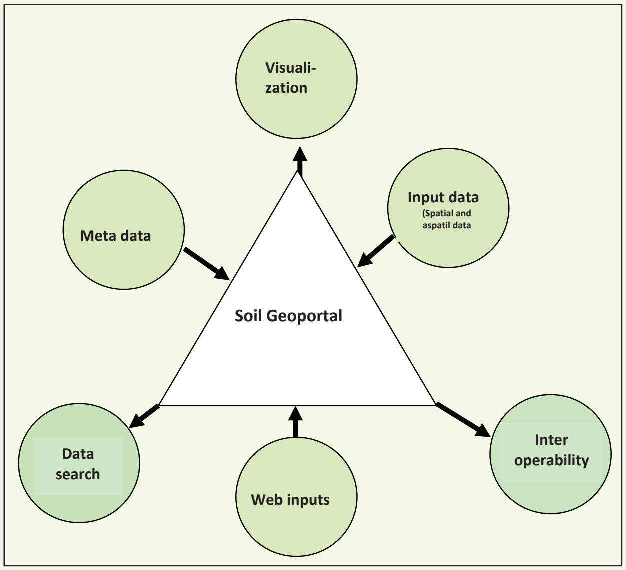


Fig. 1. Architecture of the Soil Geoportal (stand alone)

2.2.3 Designing a Geoportal

A geoportal provides the ability to securely search, discover, access, visualize and even update geospatial data via a customized web user interface. The main obstacle encountered by GI providers for making their data widely available is the diversity of their formats. A geoportal overcomes this problem by abstracting all possible data formats into a single generic model. This abstraction is performed by OGC/ISO standards-based web services, which can expose initially heterogeneous data. Then, any data can be combined, visualized, overlaid and analyzed together. With OGC/ISO standards, interoperability can be implemented. The catalog itself is a service that is able to retrieve the data of which the metadata match the search criteria. The catalog allows the user to find data relevant to application needs.

2.2.4 Spatial data query

Spatial queries of soil information can be divided as spatial, non-spatial and mixed. The languages like SQL and QBE could be used to query the structured data. The spatial query through GIS based soil information system includes.

At a given site: These include the questions about a given site: 'What is the soil class?'. The site is identified either interactively (on-screen) or by its coordinates obtained from some other source (map or field measurement). This question is easily answered because of the link between spatial and attribute data. In a topological-entity GIS, a point-in-polygon search identifies the delineation containing the point. In a grid GIS, the coordinates refer to a specific grid cell. The delineation or grid cell refer to the soil class primary attribute tables.

Finding a given site: These include the questions about a given site: 'where is the soil class?' at a site. The site is identified either interactively (on-screen) or by its coordinates obtained from some other source (map or field measurement). This question is easily answered because of the link between spatial and attribute data.

Locating areas of interest: These include the question: 'Where can soil of a particular class be found?'. The class in question is identified in the attribute tables, and the GIS is asked to select all delineations of the class. Summary statistics can be calculated on this set of delineations, e.g. total area, histogram of areas.

3 Some of the Applications of Soil Geoportal

Some of the applications of soil geoportal are discussed below:

3.1 Thematic Mapping and Analysis

Thematic mapping plays an important role to understand the spatial nature of a particular soil theme and helps to interpret them for various applications. The availability of soil based thematic maps caters to the needs of various users and developmental agencies to plan and manage the soil resources. Potential applications of soil geoportal include constructing thematic maps visulizing the extent of particular parameter related to soil types. In combination of other GIS layers, it is possible to obtain new layers that are the result of the intersection or difference of thematic layers connected to the corresponding databases.

3.2 Soil-Landscape Modelling

Soil information systems can be combined with digital elevation models and satellite radiometric data for regional soil mapping (Dobos et al., 2000). Bell et al., (1994) combined a statistically based soil-landscape model and a GIS to create soil drainage class maps. The landscape attributes used were parent material, terrain and surface drainage feature variables. Different terrain attributes, such as plane curvature, compound topographic index, and upslope mean plane curvature could be used to predict the various terrain parameters within a uniform geology and geologic history.

3.3 Land Evaluation

The qualitative systems are empirical assessment systems and are based on the knowledge and understanding of the area. As soil is the most important component of the land resource, soil evaluation is crucial for land evaluation (Dent and Young, 1981, Rossiter, 1996). Land capability classification is an interpretative grouping made primarily for agricultural purposes (Klingebiel and Montomery, 1961). Land suited for cultivation is grouped in class I to class IV according to the degree of limitations. In land evaluation, land capability classes and subclass, represents groups of soils having the same kind of limitations for agricultural use. Four kinds of limitations are recognized at subclass level viz. 'e' for water or wind erosion, 'w' for drainage problem, wetness or overflow 's' for soil limitations affecting the plant growth and 'c' for climatic limitations (IARI, 1971). The soil irrigability classes can be worked out according to their limitation for sustained use under irrigation regardless of their location or the size of the individual areas (IARI, 1971). The spatial and non-spatial databases available in soil portal could be effectively used to assess the land capability and land irrgability classes of given geographical area.

3.4 Soil Suitability Evaluation

The land suitability evaluation forms a prerequisite for land use planning (Sys et al., 1991). Soil suitability classifications express soil productivity potentials in terms of the possibility of growing specific crops. In land suitability evaluation systems, the detailed soil based thematic database play a critical role in defining the soil productivity potentials in terms of the possibility of growing specific crops. The topographic characteristics, the climatic conditions and the soil quality of an area are the most important determinant parameters of the land suitability evaluations. Soil geoportal allows the construction of models from which land suitability maps can be produced from a set of thematic maps.

3.5 Assessment of Soil Erosion Risk

Often, a quantitative assessment is needed to infer the extent and magnitude of soil erosion problems so that effective management strategies can be resorted. Rainfall erosivity, soil erodibility, topography, vegetative cover, management and conservation practices are the major factors affecting the soil erosion. The detailed information on soils and their characteristics helps to understand the various processes of soil erosion and assess the soil erosion risk in given area. The most important soil parameters that influence soil erodibility include soil texture, stability of soil structure, soil permeability and infiltration, organic matter and soil mineralogy (Singh et al., 1981). Erosion control measures require quantitative and qualitative evaluation of potential soil erosion on a specific site and the knowledge of terrain information, soils, cropping systems and management practices. Using the grid soil samples collected at specific interval could be used to predict the soil loss using the established empirical model (USLE). These factors could be integrated in GIS to assess the soil loss in a given geographical area.

3.6 Assessment of Land Degradation

Land degradation includes soil erosion, salinization, soil contamination, loss of soil organic matter, decline in nutrient levels, acidification, and loss of soil structure. Water erosion is one of the most significant environmental degradation processes, and is made up of sheet, rill and gully erosion. NBSS&LUP in collaboration with CSWCR&TI, CSSRI, CAZRI, NRSC and NAAS harmonized the degraded and wastelands data sets of the country in a GIS framework to arrive at the realistic estimates. In GIS based model, the spatial layers on water erosion (soil loss), acid soils, salt affected soils, wind erosion, dense and open forest and other layers like area under glaciers, rockout crops, mining/industrial waste and water logged areas layers were considered to worked out the status and extent of degraded and wastelands and reported 120.72 Mha area is under different categories of degraded and wastelands in the country (ICAR and NAAS, 2010). In conjunction with other relevant layers, these spatial datasets could be effectively used to derive various thematic information by using Geoportal.

3.7 Development of Spatial Decision Support Systems

Spatial Decision Support System (SDSS) provides a framework for integrating Database Management System (DBMS) with analytical models, graphic display, and tabular reporting capabilities and expert knowledge of decision makers. The modelling capability of geoportal allows the user to develop SDSS to generate criterion-based scenarios in different climatic and terrain conditions. The database components of the SDSS can supply input data for the models and the resulting output can be returned to the database for later display through the user interface, in table, chart or map form. Geoportal based SDSS helps in modelling capability with simulation techniques to solve complex land resource management problems. By developing a comprehensive database on soils, climate and livelihood options land use scenarios, changes occurring with time will help to develop strategies for area specific land use options, which can provide better livelihood options for sustainable development.

4. Conclusions

The development of GIS based soil information system and prototype geoportal enables us to catalog, store, manage, process and analyze large soil databases in a digital environment. In the first part a framework for the provision of spatial soil and soil related data is important. The development of a schema for describing the spatial soil and soil related data is also crucial for development of geoportal. The development of tools for spatial data query and mining and necessary pre and post processing tools will enhance the capabilities of soil geoportal. By augmenting data discovery tools with spatial data mining, it is envisaged that users will get related datasets that they would have been otherwise overlooked. Integration of soil information systems with remotely sensed data and decision support systems in geoportal provides enormous potential to address the various emerging issues in land use planning and sustainable natural resource management.

References

Bell, J.C., Cunningham R.L. and Havens, M.W. (1994). Soil drainage class probability mapping using a soil-landscape model. *Soil Science Society of America Journal*, **58**: 464-470.

Dent, D. and Young, A. (1981). *Soil survey and land evaluation*. London, England: George Allen and Unwin.

Dobos, E., Micheli, E., Baumgardner, M.F., Biehl, L. and Helt, T. (2000). Use of combined digital elevation model and satellite radiometric data for regional soil mapping. *Geoderma* **97**(3-4).

IARI. (1971). *Soil Survey Manual*, IARI Publ., New Delhi, 121.

ICAR and NAAS. (2010). *Degraded and Wastelands of India Status and Spatial Distribution*, Indian Council of Agricultural Research and National Academy of Agricultural Science, New Delhi p 158.

Klingebiel, A.A. and Montomery. P.H. (1961). *Land Capability Classification*, U.S. Department Agriculture Handbook, No. 210:1021.

Rossiter, D.G. (1996). A theoretical framework for land evaluation, *Geoderma* **72**: 165–202.

Singh, G., Babu Ram and Subhas C. (1981). *Soil loss prediction research in India*, ICAR Bulletin No. T-12/D-9, Central Soil and Water Conservation Research and Training Institute, Dehradun, India.

Sys C., Van Raust, E. and Debaveye, J. (1991). *Land Evaluation, Part 2. Methods in Land Evaluation.* Agricultural publications No.7, Belgium.

Land Use Planning – Concept and Approach

T.K. Sen, Principal Scientist
Division of Land Use Planning
National Bureau of Soil Survey & Land Use Planning, Nagpur 440010

ABSTRACT

Land is a finite resource. There is a need for optimal utilization of land resources. The country can no longer afford to neglect land, the most important natural resource, so as to ensure agricultural sustainability and avoid adverse land use conflicts. Optimal utilization of land resources can be achieved through scientific land use planning. The concept and methods of land use planning are discussed at length.

1. Introduction

Our demands for agricultural land, grazing, forestry, wildlife, tourism and other developmental activities are greater than the land resources available. In the developing countries, these demands become more pressing every year. Under the shortage and excessive exploitation of land resources, the search for effecting land use planning approaches initiated long back in the 1960s. In the 1980s participatory planning approaches increasingly replaced the technical top-down planning.

The Agenda 21, ratified by more than 170 nations at the Earth Summit in Rio de Janeiro in 1992, mentions frequently that land use planning (LUP) plays a key role in natural resource management. In the case of competing stakes and interests in the use of land, it allows settlements of arising conflicts and conciliating interests in such way that agreements can be reached which guarantee sustainability of land resources. Through the process, over time, LUP has appeared to be an integrated planning approach of natural resources. As population and human aspirations increase, land becomes an increasingly scarce resource, calling for land-use planning. Land-use planning is important to mitigate the negative effects of land use and to enhance the efficient use of resources with minimal impact on future generations. Land use planning on scientific basis can lead to sustainable development.

2. Land use planning

Land-use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances. LUP is an iterative process. Biophysical and socioeconomic data collected through standard survey can be interpreted and evaluated for several purposes like suitability for agriculture through technical classification of soils, hydrological groupings, suitability for sewage disposal, trafficability, building construction, etc. Soil survey interpretation and land evaluation precede land use planning. The principles of LUP are by and large similar at all the levels be it regional or watershed/village level.

2.1 Goals of Land Use Planning

Goals define what is meant by the "best" use of the land. These are be specified at the outset of a particular planning project. Goals may be grouped under efficiency, equity and acceptability and sustainability.

Efficiency: Land use must be economically viable, so one goal of development planning is to make efficient and productive use of the land. For any particular land use, certain areas are better suited than others. Efficiency is achieved by matching different land uses with the areas that will yield the greatest benefits at the least cost.

Equity and acceptability: Land use must also be socially acceptable. Goals include food security, employment and security of income in rural areas. Land improvements and redistribution of land may be undertaken to reduce inequality or, alternatively, to attack absolute poverty

2.2 Land Use Planning Approach

Every land-use planning project is different. Objectives and local circumstances are extremely varied, so each plan will require a different treatment. A sequence of ten steps has been found useful as a guide (FAO, 1993). Each step represents a specific activity, or set of activities, and their outputs provide information for subsequent steps.

Step 1. Establish goals and terms of reference. Ascertain the present situation; find out the needs of the people and of the government; decide on the land area to be covered; agree on the broad goals and specific objectives of the plan; settle the terms of reference for the plan.

Step 2. Organize the work. Decide what needs to be done; identify the activities needed and select the planning team; draw up a schedule of activities and outputs; ensure that everyone who may be affected by the plan, or will contribute to it, is consulted.

Step 3. Analyse the problems. Study the existing land-use situation, including in the field; talk to the land users and find out their needs and views; identify the problems and analyse their causes; identify constraints to change.

Step 4. Identify opportunities for charge. Identify and draft a design for a range of land-use types that might achieve the goals of the plan; present these options for public discussion.

Step 5. Evaluate land suitability. For each promising land-use type, establish the land requirements and match these with the properties of the land to establish physical land suitability.

Step 6. Appraise the alternatives: environmental, economic and social analysis. For each physically suitable combination of land use and land, assess the environmental, economic and social impacts, for the land users and for the community as a whole. List the consequences, favorable and unfavorable, of alternative courses of action.

Step 7. Choose the best option. Hold public and executive discussions of the viable options and their consequences. Based on these discussions and the above appraisal, decide which changes in land use should be made or worked towards.

Step 8. Prepare the land-use plan. Make allocations or recommendations of the selected land uses for the chosen areas of land; make plans for appropriate land management; plan how the selected improvements are to be brought about and how the plan is to be put into practice; draw up policy guidelines, prepare a budget and draft any necessary legislation; involve decision-makers, sectoral agencies and land users.

Step 9. Implement the plan. Either directly within the planning process or, more likely, as a separate development project, put the plan into action; the planning team should work in conjunction with the implementing agencies

Step 10. Monitor and revise the plan. Monitor the progress of the plan towards its goals; modify or revise the plan in the light of experience. Steps 1 to 6, are, in fact processes of land evaluation. The figure given below shows the steps involved in the iterative process of Land Use Planning.

2.3 Land Use Planning at different levels

Land-use planning can be applied at three broad levels: local, district and national. These are not necessarily sequential but correspond to the levels of government at which decisions about land use are taken. Different kinds of decision are taken at each level, where the methods of planning and kinds of plan also differ. However, at each level there is need for a land-use strategy, policies that indicate planning priorities, projects that tackle these priorities and operational planning to get the work done.

At local/village/watershed/farm level: Detailed information on physical factors at soil series phase level, existing climate and present land use coupled with socio-economic information help to plan at farm family level.

At district level: Climate, present land use information and information on Benchmark soils help to have isogrow zones for sectoral allocation of resources at district level.

At national/state/regional level: Agro-ecozones, land systems approaches provide information for development and fund allocation to priority areas for planning at state/regional level.

The greater the interaction between the three levels of planning, the better. The flow of information should be in both directions (in all the steps). At each successive level of planning, the degree of detail needed increases, and so too should the direct participation of the local people.

2.4 Land Evaluation for Land Use Planning

Land evaluation is the assessment of land performance when used for specified purposes. As such it provides a rational basis for taking land-use decisions based on analysis of relations between land use and land, giving estimates of required inputs and projected outputs. Land evaluation is an integral part of land use planning. The principal objective of land evaluation is to select the optimum land use for each defined land unit, taking into account both physical and socio-economic considerations and the conservation of environmental resources for future use (FAO 1994). Every evaluation should address itself to the following questions.

- How is the land currently managed, and what will happen if present practices remain unchanged
- What improvements in management practices, within the present use are possible?
- What other uses of land are physically possible and economically and socially relevant?
- Which of these uses offer possibilities of sustained production or other outputs?
- What adverse effects, physical, economic or social, are associated with each use?
- What recurrent inputs are necessary to bring about the desired production and minimize the adverse effects?
- What are the outputs (products, services and other benefits) of each form of use?

2.4.1 Land Evaluation Principles

Certain principles are fundamental to the approach and methods employed in land evaluation. These basic principles are as follows:

i. *Land suitability is assessed and classified with respect to specified kinds of use.* This principle embodies recognition of the fact that different kinds of land use have different requirements. As an example, an alluvial flood plain with impeded drainage might be highly suitable for rice cultivation but not suitable for many forms of agriculture or for forestry. The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirements, e.g. for soil moisture, rooting depth etc. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.

ii. ***Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land***. Land in itself, without input, rarely, if ever possesses productive potential; even the collection of wild fruits requires labour, whilst the use of natural wilderness for nature conservation requires measures for its protection. Suitability for each use is assessed by comparing the required input, such as labour, fertilizers or road construction, with the goods produced or other benefits obtained.

iii. *A multidisciplinary approach is required.* The evaluation process requires contributions from the fields of natural science, the technology of land use, economics and sociology. In particular, suitability evaluation always incorporates economic considerations to a greater or lesser extort. In qualitative evaluation, economics may be employed in general terms only, without calculation of costs and returns. In quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in the determination of suitability. It follows that a team carrying out an evaluation requires a range of specialists. These will usually include natural scientists (*e.g.* geomorphologists, soil surveyors, and ecologists), specialists in the technology of the forms of land use under consideration (e.g. agronomists' foresters, irrigation engineers, experts in livestock management), economists and sociologists

iv. *Evaluation is made in terms relevant to the physical economic and social context of the area concerned.* Such factors as the regional climate, levels of living of the population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable, and availability of capital, form the context within which evaluation takes place. It would, for example be unrealistic to say that land was suitable for non-mechanized rice cultivation, requiring large amounts of low-cost labour, in a country with high labour costs. The assumptions underlying evaluation will differ from one country to another and, to some extent, between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding and to assist in comparisons between different areas, such assumptions should be explicitly stated.

v. *Suitability refers to use on a sustained basis.* The aspect of environmental degradation is taken into account when assessing suitability. There might, for example, be forms of land use which appeared to be highly profitable in the short run but were likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability and cause the land to be classed as not suitable for such purposes.

This principle by no means requires that the environment should be preserved in a completely unaltered state. Agriculture normally involves clearance of any natural vegetation present, and normally soil fertility under arable cropping is higher or lower, depending on management, but rarely at the same level as under the original vegetation. What is required is that for any proposed form of land use, the probable consequences for the environment should be assessed as accurately as possible and such assessments taken into consideration in determining suitability.

vi. *Evaluation involves comparison of more than a single kind of use.* This comparison could be, for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing uses. Occasionally a proposed form of use will be compared with non-use, i.e. leaving the land in its unaltered state, but the principle of comparison remains. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. If only one use is considered there is the danger that, whilst the land may indeed be suitable for that use, some other and more beneficial use may be ignored.

2.4.2 Land utilization type, land use requirements, land qualities, land characteristics, and diagnostic criteria in land evaluation

Land Utilization Type (LUT). It is a kind of land use described or defined in a degree of detail greater than that of a major kind of land use. In case of *irrigated* agriculture, a land utilization type refers to a crop, crop combination or cropping system with specified irrigation and management methods in a defined technical and socio-economic setting. In rainfed agriculture, a land utilization type refers to a crop, crop combination or cropping system with a specified technical and socio-economic setting. A land utilization type for forestry consists of a technical specifications in a given physical, economic and social setting.

Land Use Requirements (LUR).It is a condition of the land necessary for successful and sustained implementation of a specific Land Utilization Type. Each LUT is defined by a *set* of LURs. These are the requirements of a specific land use. For example, plants require water in order to grow, this might be called the 'moisture requirement'. The soil must be maintained without chemical degradation, this might be called the 'avoidance of salinization' requirement. LURs can be assembled into comprehensible groups, e.g. 'crop requirements', 'management requirements', 'conservation/environmental requirements.

Land Qualities (LQ). It is a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use. "A land quality is the ability of the land to fulfill specific requirements" for the LUT for each LUR there is a corresponding LQ. Land qualities are the 'supply' side of the land use equation: what the land can offer to the use. In some sense, this is just a semantic difference, or a different point of view, from the Land Use Requirements. For example, the land can supply a certain amount of water to the crop, this might be called the 'moisture availability' Land Quality. On the other hand, the crop has a requirement for water; this 'moisture requirement' Land Use Requirement corresponds to the 'moisture availability' Land Quality. Land Qualities are usually complex attributes of the land, i.e., they can't be directly measured or estimated in routine survey. Examples are water availability, oxygen availability, workability, nutrients availability etc. Land Qualities act more-or-less independently to affect suitability. This is to avoid a proliferation of LQs in the evaluation. In practice, LQs may interact (e.g., moisture availability and soil fertility) but much of the complexity is avoided by abstracting from Land Characteristics the LQs.

Land Characteristics' (LC). Land Characteristics (LC) are simple attributes of the land that can be directly measured or estimated in routine survey in any operational sense, including by remote sensing and census as well as by natural resource inventory. Examples are climate, topography, soil depth, surface soil texture, flooding etc. In general, the effects of a LC on suitability are not direct, but through their resultant. This is because a single LC may affect several qualities often in contradictory ways, e.g., sandy soils may have low fertility and water holding capacity, but may be easy to till and there are no problems with aeration of the roots. Here the soil texture is the LC, and the others are LQ. The FAO Framework, however, does allow the use of LCs directly to assess suitability, but it is generally clearer to use LQ as an intermediate level of evaluation, both because the total complexity of the problem is broken down into more manageable units, and because LQs in themselves provide useful information to the land evaluator.

A **diagnostic criterion** is a variable which has an clear influence on the output from, or the required inputs to, a specified use, and which serves as a basis for assessing the suitability of a given area of land for that use. This variable may be a land quality, a land characteristic, or a function of several land characteristics. For every diagnostic criterion there will be a critical value or set of critical values which are used to define suitability class limits.

2.4.3. Land Evaluation Approaches.

A general evaluation, based on limitations of land characteristics, is best illustrated in the U.S.D.A. **Capability Classification.**

The system of Riquier *et al.* (1970) is an example of a parametric approach for general evaluation; with however specific reference to arable land, pasture, and forest and tree crops. The suitability for irrigation can be achieved through different methods. The system elaborated by the U.S.B.R. and adapted to F.A.O. standards, illustrates a methodology based on limitations of land characteristics. The principle of the F.A.O. classification, as presented in the framework for land evaluation, is important and commonly used across the world. A methodology has been suggested by Sys, *et.al* (1991) to apply FAO classification system for evaluation for specific land utilization types.

Although many systems have been employed to evaluate the quality of agricultural soils from time to time, the following are some of the important ones.

2.4.3.1 USDA Land Capability Classification.

This method was established by the Soil Conservation Service of USA according to the system proposed by Klingebiel and Montgomery (1966) and has been widely used throughout the world with numerous adaptations. It is a categorical system that uses qualitative criteria. The inclusion of a soil within a class is made in the inverse manner that is, without directly analysing its capacity, but rather its degree of limitation with respect to a parameter according to a concrete use. Some factors that restrict soil use can be used to define the productive capacity (intrinsic: soil depth, texture, structure, permeability, rockiness, salinity, soil management; extrinsic: temperature and rainfall) and yield loss (slope of the terrain and degree of erosion). Five systems of permanent agricultural exploitation are considered: permanent soil cultivation, occasional soil cultivation, pasture, woods and natural reserves. This system seeks maximum production with minimum losses in potential. Three levels of classification ware established: classes, subclasses and units. Also, 8 classes with increasing limitations in use are defined from I to VIII. As a function of the permitted uses, 4 use groups can be distinguished: permanent soil cultivation (or any type of exploitation; Class I, suitable soils; Class II, good soils but with some limitations; Class III, soils acceptable but with severe limitations), occasional soil cultivation (pastures, woods or natural reserves; Class IV, not recommended for agricultural use for severe limitations and/or required careful management); no soil cultivation, only pastures (in forests or natural reserves; Classes V, VI and VII) and natural reserves (Class VIII).

Depending on the type of limitation, various subclasses of capacity are established: e, for erosion risks; w, for wetness and drainage; s, for rooting and tillage limitations resulting from shallowness, drought risk, stoniness, or salinity; c, for climatic limitations. The capability units represent similar proposals of use and management.

This system has many advantages. The classes are defined with criteria that are very general, simple and easy to understand as well as adapt to very diverse regions, but it proves difficult to apply with objective criteria. All the evaluation characteristics that make up the agricultural capacity have identical weight. The same class, with only one parameter (the maximum limiting factor) that classifies the soil within a certain class, embraces highly different soils. This system provides a highly general classification of soil capacity, since it dispenses with many soil characteristics of undeniable interest, but has the advantage of not requiring a detailed knowledge of the soil. Its use proves quite subjective, though it adapts well to the experience of the evaluator. Its results materialize very well on a map, avoiding the erroneous evaluations that parametric methods can produce. The definitions of the different classes are given in the Tables 1 and 2.

Table 1. Principles for the definitions of the arable classes

Arable Land Classes				
Parameters	**Class I**	**Class II**	**Class III**	**Class IV**
Definition	Few limitations restrict their use	Moderate Limitations	Severe limitations	Very severe limitations
Range of crops	All crops give optimal yields	Most crops give nearly optimal	Limited crops don't yield satisfactorily	Yield marginal

Slope Erosion (e)	Level No or low erosion	Gentle slope, Moderate Moderate Susceptibility to wind or water erosion	Moderate steep slope Wind and water erosion	Steep slope Very high wind and water erosion
Wetness (w) Flooding Drainage	Not subject to damaging overflow Well drained	Occasional overflow Moderate Permeability limitation	Frequent overflow Water logging, very slow permeability	Frequent overflow Excessive water logging
Physical soil condition(s)	Hold water well, good workability Deep (+100 cm)	Unfavourable workability, less ideal depth (50-100 cm)	Low moisture holding Shallow depth (25-50 cm)	Low moisture <25 cm
Fertility	Well supplied with plant nutrients	Responsive to fertilizers	Low fertility	Low fertility
Salinity and Alkalinity	No or Slight	Slight to moderate easy to correct	Moderate salinity sodium hazard	Severe salinity, sodium hazard
Management requirement	Ordinary	Careful management	Very careful	Very careful

Table 2. Principles for the definitions of the non-arable classes

Parameters	**Pastures**		**Forest**	**Recreation and wild life**
	Class V	**Class VI**	**Class VII**	**Class VIII**
Definition	Not suited to cultivation	Severe limitations	Very severe limitations	Unsuitable for any crop
Range of crops	Pastures	Pasture or range	Woodland	Recreation and wild life
Slope and Erosion (e)	Nearly level no erosion	Very steep severe erosion	Very steep severe erosion	Erosion hazard
Wetness (w) Flooding	Frequent overflow	-	-	-
Drainage	Drainage feasible	-	Too wet soils	Too wet soils
Soils (s) conditions	Stony or Rocky	Stoniness low moisture capability. Too shallow	Stoniness. Too shallow	Low moisture strong capacity stoniness. Too shallow.
Fertility	-	-	-	-
Salinity and Alkalinity	-	Severe salinity and sodium hazard	-	-
Management requirement	Pasture	Pasture	-	-

2.4.3.2 *Storie Index (1933)*

This represents the first parametric approach that was developed. It is an index that uses the multiplicative scheme. In addition, it uses intrinsic properties of the soils (genetic profile, parent material, profile depth, texture, drainage, nutrients, acidity an alkalinity), characteristics of the soil surface (slope and microrelief) and aspects of soil conservation (degree of erosion). The evaluation properties are grouped into four factors that are quantified in the corresponding tables. The factors are weighed *a priori*, the more important being related on a scale from 5 to 100 and the less important factors from 80 to 100. Rating of the suitability of soil for specific use can be made from soil survey data by estimating some type of index based on soil characteristics. Storie Index (Storie 1976, 1978) is one such rating, which expresses numerically the relative degree of suitability of soil for general intensive agriculture. The rating, being based on soil characteristics only, may not serve as index of land value. The four important general factors viz. (i) soil profile characteristics, (ii) surface texture, (iii) slope, and (iv) other factors like drainage, alkalinity etc., are assigned ratings percentage multiplication of which is used as an index for evaluation. A rating of 100 per cent expresses most favourable conditions and lower per cent indicates less favourable condition. The index rating of 80-100 is assigned Grade 1 – excellent; 60-79 is assigned Grade 2 – good; 40-59 Grade 3 – fair; 20-39 Grade 4 – poor; 10-19 Grade 5 – Very poor and index rating of less than 10 is assigned Grade 6 – not suitable for agriculture (FAO, 1976). Storie Index Rating (SIR) system was developed for the purposes of an appraisal according to land types. It is based on the product of the factors even one moderate factor reduce the value of Index considerably. Its use, hence, is limited.

2.4.3.3 *Productivity index of Riquier et al. (FAO, 1970).*

The basic concept of this method is that agricultural-soil productivity, under optimal management conditions, depends on the intrinsic characteristics. This is a multiplicative parametric method to evaluate soil productivity, from a scheme similar to the Storie index. The concept of productivity is defined as the capacity to produce a certain quantity of harvest per hectare per year, expressed as a percentage of optimal productivity, which would provide a suitable soil in its first year of cultivation. The introduction of improvement practices leads to a potential productivity or potentiality. The quotient between the productivity and the potentiality is called the improvement coefficient.

The evaluation is made for three general types of use: agricultural crops, cultivation of shallow-rooted plants (pastures), and deep-rooted plants (fruit trees and forestation).

The determining factors of soil depth are: wetness, drainage, effective depth, texture/structure, base saturation of the adsorbent complex, soluble-salt concentration, organic matter, cation-exchange capacity/nature of the clay and mineral reserves. The parameters of the soil surface (e.g., slope, erosion, flood tendency, or climate) are not considered

The different parameters are evaluated in tables and, as also occurs in the Storie index, the evaluation factors present different weights.

Productivity is expressed as the product of all these factors expressed in percentages. Five productivity classes are defined: class P1 = excellent; class P2 = good, valid for all types of agricultural crops; class P3 = medium, for marginal agricultural use, suitable for non-fruiting trees; class P4 = poor, for pasture or forestation or recreation; class P5 = very poor or null, soils not adequate for any type of exploitation.

The improvement coefficient is the ratio between the productivity and the potentiality and represents a good index for evaluating the feasibility of these possible improvements

This is a quantitative method, precise (although the partial scoring of the different parameters is quite arbitrary), objective (the only objective is the mathematical method), simple and easy to calculate. The evaluations reflect the degree of suitability of the different evaluation parameters, so that it proves easy to determine the possible improvements for each soil. The evaluation parameters as well as the resulting assessment can be adapted to local conditions.

2.4.3.4 *Soil Fertility Capability Classification (FCC).*

This was proposed by Buol *et al*., (1975) and modified by Sanchez *et al*. (1982) to evaluate soil fertility. In this system, three levels or categories were established. The first, the type, was determined by the texture of the arable layer, or of the first 20 cm, if this is thinner. Its denomination and range are: S, sandy (sandy and sandy loam); L, loams <35% clay (excluding sandy and sandy loam); C, clayey > 35% clay; O, organic > 30% organic matter to 50 cm or more.

The type of substrate is the second level and is used when there is a significant textural change in the first 50 cm of the soil. It is expressed with the same letters, adding ÒRÓ when a rock or a hard layer is found within this depth.

The third level is comprised of the modifiers, which are the chemical and physical parameters that negatively influence soil fertility. These are numerous and are represented by lower-case letters.

In the denomination of the soil class, the principle limitations for use are directly represented. For example, for an Orthic Solonchak, the FCC class that represents it is LCds, which signifies that it is a soil susceptible to severe erosion (L), limited drainage (C), dry soil moisture regime (d) and with salinity (s).

2.4.3.5 *Land Irrigability Classification.*

A general system for evaluation for irrigation has been elaborated by USBR (United States Bureau of Reclamation 1951).In this system (USBR, 1953) soils are first categorised according to physical factors (topography, drainage and water quality) and socio-economic factors (development costs, etc.). Separation of land irrigability classes is made on specified limits of soil properties and other physical parameters. Land irrigability system can be used for selection of irrigable lands, estimation of water requirements, development costs and benefits from irrigation. Such information will help in land use planning decisions (AISSO, 1970; Beek, 1981).

This system also provides six suitability classes for irrigation based on the soil and land characteristics and the payment capacity. The sub-classes provided are based on deficiencies or problems with respect to topography (t), soil(s) and drainage (w).

- Soils are categorized based on their suitability for sustained use under irrigation.
- Physical factors (topography, drainage and water quantity).
- Socio-economic factors

Class 1(A)	:	Lands that have few limitations - Nearly level (<1%) - Deep (>90 cm) - Favourable permeability (5.0-50 mm/hr) - Texture (sl, cl) surface 30 cm - Moisture holding capacity (12 cm)
Class 2(A-B)	:	Lands that have moderate limitations for sustained use under irrigation. - 1-3% slope - 45-90 cm depth - Texture (loamy sand, clay) - Permeability (1-3.5 mm/hr) (50-1300 mm/hr) - Moisture holding capacity(9-12 cm)
Class 3 (C)	:	Lands that have severe limitations for sustained use under irrigation. - Slopes (3-5%) - Unfavourable soil depth (22.5-45.0 cm) - Texture (sand, clay) - Permeability (0.3-1.3 mm/hr) (130-250 mm/hr) - Moderate severe salinity or alkalinity (8-12 mmhos/cm) (ESP >15%) - Unfavourable drainage (poor, ESP>15%, excessively drained) - Moisture holding capacity (6-9 cm)
Class 4 (D)	:	Marginal lands for sustained use under irrigation - Slope (5-10%) - Soil depth (7.5-22.5 cm) - Texture (sand, clay) - Permeability (0-3 mm/hr) (>250 mm/hr) - Moisture holding capacity (2-6 cm) - Very severe salinity (12-16 mmhos/cm) alkalinity (ESP> 15%)
Class 5	:	Lands that are temporarily classed as not suitable for sustained use under irrigation.
Class 6(E)	:	Lands not suitable for sustained use under irrigation.

		- Slope (>10%)
		- Texture (any texture)
		- Depth (<7.5 cm)
		- Permeability
		Salinity and alkalinity – ESP > 15%
Subclass	:	Groups of land irrigability units with some dominant limitation
		s - Soil
		t - Topography
		d - Drainage
Irrigability units:		Grouping of lands that are nearly alike in suitability for irrigation
		2 s(a), 2s (b), 2s (c)

2.4.3.6 *Actual and potential productivity*

Riquier *et al.* (1970) have evolved a system of soil appraisal in terms of actual and potential productivity. It is a modified version of Storie Index. Nine factors *viz*. moisture, drainage, depth, texture, base saturation, soluble salts, organic matter, CEC and mineral reserves are rated on a scale 0-100 and the percentages cumulatively multiplied to obtain Productivity Index (P). In a similar manner the Potentiality Index (P') is calculated after effecting the management measures. The ratio P: P' indicating the extent to which productivity can be improved is called the co-efficient of improvement. Soils with rating index 65-100 are excellent, 35-64, 20-34 average, 8-10 poor and below 8 – extremely poor. Maps showing productivity and potentiality index can also be prepared. It is evident that the land evaluation system of Riquier et al. (1970) does not explain the variability in the yield. Like Storie Index, this system of land evaluation has the limitation in that one limiting factor reduces the Index of Productivity. Also, assigning values to factors like drainage is difficult. Perhaps, factors should be chosen according to the limitations affecting the crop growth within a particular region to obtain a more realistic productivity rating.

2.4.3.7 *The FAO Framework for Land Evaluation (1976)*

The FAO Framework for Land Evaluation (FAO 1976 and subsequent guidelines: for rainfed agriculture, 1983; forestry, 1984; irrigated agriculture, 1985; extensive grazing, 1991) is considered to be a standard reference system in land evaluation throughout the world (Dent and Young, 1981; van Diepen el al., 1991), and has been applied both in developed as well as developing countries.

This framework is an approach, not a method. It is designed primarily to provide tools for the formulation of each concrete evaluation. The system is based on the following concepts: i) Land is qualified, not only the soil. ii) Land suitability must be defined for a specific soil use (crop and management). iii) Land evaluation was to take into account both the physical conditions as well as economic ones; iv) The concept of land evaluation is essentially economic, social and political. v) The evaluation requires a comparison between two or more alternative kinds of use. vi) The evaluation must propose a use that is sustainable. vii) A multidisciplinary approach is required (Purnell, 1979; van Diepen et al., 1991).

In the scheme, four categories are recognized. The highest category is the order that it reflects, in broad features, whether a soil is suitable or not for a given use. Two orders are recognized:

S = Suitable. Land in which the benefits exceed the costs and sustained use does not incapacitate the soil over a sufficiently long period of time.

N = Not suitable. Land can be classified as not suitable for a certain use for diverse reasons. The use proposed may be deemed technically impractical, as in irrigation of abrupt rocky terrain, or that it causes serious environmental degradation, as in cultivation on steep slopes. Frequently, however, the reason is economic, in that the profit expected does not justify the cost required.

The second category is the class that reflects degrees of suitability within the order. These are numbered consecutively in Arabic numerals.

For the order S, three classes are considered:

S1 = Highly suitable. Without limitations for sustained use or minor limitations that do not affect productivity nor appreciably increase costs.

S2 = Moderately suitable. Moderately serious limitations that reduce profits or involve risks of degradation in the sustained use of the soil.

S3 = Marginally suitable. The limitations for the sustained use are serious and the balance between the costs and benefits make the use only marginally justifiable. Its use is normally justified on other than economic grounds.

In the order N, three classes are also recognized:

N1 = Not currently suitable. Land with limitations that could be eliminated by technical means or investment, but that these changes are at present unfeasible.

N2 = Permanently unsuitable. Serious limitations of generally a physical nature, which are assumed to be beyond solving over the long term.

X = Land for conservation. Unsuitable for exploitation, being lands of special protection, due to their conservation, wildlife, of special scientific, ecological or social interest (e.g., parks, reserves or recreational zones).

The limits between the orders (S and N) and between the different classes (S1, S2, S3 and N1, N2) are established by the presence of limiting factors. One limiting factor is a characteristic of the soil that hampers its use, reduces productivity, increases costs and implies degradation risk, or all of the above.

These limiting factors are used to define the third category of the system, which is the subclass. In the symbol of each subclass, the number of limitations involved should be kept to the minimum one letter, or, rarely, two. The limitations proposed include: t, slope; e, erosion risk; p, depth; s, salinity; d, drainage; c, bioclimatic deficiency; r, rockiness; i, flood risk.

Finally, the fourth category is the unit that establishes the differences within the subclasses as a function of the desired use. All of the units within a subclass (S2rA, S2rM, ...) have the same degree of suitability at the subclass level (S2) and analogous characteristics of limitation at the subclass level (r). The units differ from each other in their characteristics of production or in secondary aspects of their management demands. Their examination enables a detailed interpretation at the planning level of the exploitation. The units are distinguished by upper-case letters that are placed at the end. There is no limit at all for the number of units examined within a subclass. These defined are: A, intensification in the agricultural use without need of great improvements; M intensification in the agricultural use with need of major improvements (irrigation, etc.); P, use for pasture for livestock; F, forestation.

Altogether, the Framework FAO represents a highly useful and flexible system which is easily adapted to local characteristics. The main drawbacks are: i) the conceptual confusion caused by using pre-existing terms; ii) the poor distinction between the physical, social and economic characteristics.

2.5 Land Evaluation Modeling.

There are a large and increasing number of computer models relevant to different aspects of land-use planning. Most models consist essentially of quantitative predictions based on input data, for example the prediction of plant evapotranspiration from weather data or the prediction of net present return from data on inputs, production, costs and prices. It is noted that:

Models are only as reliable as the data which are entered into them;

Wherever possible, models should be calibrated for the planning area, its climate, soil types, etc.; data should be entered and the results compared with an independent measure, for instance crop yield.

2.6 The Future of Land Use Planning.

New ways of effective land-use planning include information management through GIS (geographic information systems), computer simulation, and spatial-temporal data modeling on present land use, alternative scenarios, and assessment of consequences. While zoning and regulation are the primary methods adopted by land-use planners, public education often is a neglected area that is increasingly being recognized. Other methods that planners use include economic incentives, institutional reform, and investment through multiagency cooperative projects.

Land-use planning is becoming complex and multidisciplinary as planners face multiple problems that need to be addressed within a single planning framework. Such problems include nonpoint-source pollution, water allocation, urbanization, ecosystem deterioration, global warming, poverty and unemployment, deforestation, desertification, farmland deterioration, and low economic growth. Watershed-scale planning is gaining popularity among communities and agencies so that biological, physical, and socioeconomic components of the landscape system can be integrated into the planning framework.

3. Summary and Conclusions

FAO has developed approaches to land-evaluation and land-use planning that has been successfully applied in various parts of the world for over 30 years. These approaches are essentially frameworks that can be modified to suit local conditions.

References

All India Soil and Land Use Survey Organization (AISLUSO) (1970). *Soil Survey Manual*, I.A.R.I., New Delhi, 123 pp.

Beek, K.J. (1981). From Soil survey interpretation to land evaluation. Parts 1 and 2. Soil Survey Land Evaluation 1:6-12 and 23-30.

Dent, D. & Young, A. (1981). *Soil survey and land evaluation.* George Allen & Unwin, London.

FAO. (1976). *A Frame work for Land Evaluation.* Soils Bulletin. No. 32, FAO, Rome.

FAO. (1976). *A framework for land evaluation.* FAO Soils Bulletin No. 32. Rome, FAO. 72 pp. Also published as Publication 22. Wageningen, the Netherlands, ILRI. 87 pp.

FAO. (1983). *Guidelines: land evaluation for rainfed agriculture.* FAO Soils Bulletin No. 52. Rome, FAO. 237 pp.

FAO. (1984a). *Land evaluation for forestry*. FAO Forestry Paper No. 48. Rome, FAO. 123 pp.

FAO. (1985a). *Guidelines: land evaluation for irrigated agriculture*. FAO Soils Bulletin No. 55. Rome, FAO. 229 pp.

FAO. (1985b). *The role of legislation in land use planning for developing countries*. FAO Legislative Study No. 31. Rome, FAO. 160 pp.

FAO. (1989b). *Rapid appraisal of tree and land tenure*. FAO Community Forestry Note No. 5. Rome, FAO.

FAO. (1991a). *Guidelines: land evaluation for extensive grazing*. FAO Soils Bulletin No. 58. Rome, FAO. 158 pp.

FAO. (1991b). *Land use planning applications. Proceedings of the FAO Expert Consultation, 1990*, Rome, Italy, 10-14 December 1990. World Soil Resources Reports 68. Rome, FAO. 206 pp.

FAO. (1993). *Guidelines for Land use planning*, FAO developmental series-1,Rome,Italy,FAO,96 pp.

Klingebiel, A.A. and P.H. Montgomery (1966). *Land Capability Classification*. Agri. Book No. 210 Soil Conservation Series, U.S.D.A., Washington D.C.

Riquier, J., Bramo, D. and Cornel, J.F. (1970). *A new system of soil appraisal in terms of actual and potential productivity*, FAO-AGL-TESR/70/6, Rome.

Storie, R.E. (1954). Land classification as used in California for the appraisal of land for taxation purposes. Trans. 5th Int. Congr. Soil Sci. **3**:407-12 (Revised, 1978).

Storie, R.E. (1976). *Storie Index Soil rating* (revised, 1978) Spec. Publ. Div. Agric. Sci. No. 3203, Univ. California.

Sys (1975). *Guidelines for the interpretations of land properties for some general land utilization types*, Soil Bulletin, 29, FAO, Rome.

Sys, C. (1985). *Land Evaluation Part I, Part II and Part III.*

Role of Non-Edaphic Factors in Land Use Planning

N.G. Patil and S.K. Singh
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

Land Use Planning (LUP) in India focuses mostly on evaluation of the soils to support designated use. The land evaluation therefore has a strong edaphic/soil-centric approach.. While soils characteristics are of prime importance in LUP, there are many other factors that influence LUP. Spurt in demand (e.g. pulses), technological advances (e.g. Bt cotton), minimum price support (e.g. rice and wheat crop in Indo-Gangetic Plains) are some of the examples of the factors that have overridden soil suitability/edaphic factors in India during the recent past. Land use and crop choice is now a complex product of multiple factors ranging from demand/price at global scale to the local factors like proximity to market or availability of power. This article dwells upon the role of non-edaphic factors playing crucial role in LUP. Common property resources (non-timber forest produce, drainage lines, water bodies, pasture lands), livestock resources, social factors, economic factors influence the land use decisions but are seldom incorporated in LUP. Globally LUP is considered incomplete without adequate weightage to socio-economic factors, environment protection and sustainability. Such information in India is scattered and acquisition of the data is need based with varying scales. Consequently, land use planning in the country lacks integration of bio-physical information with socio-economic factors. The environment perspective is a recent development and is in infant stage. However, we need to utilize the available information despite constraints. The paper looks at the role of some of the non-edaphic influencing LUP decisions.

1. Introduction

Land use planning (LUP) begins with land evaluation and land evaluation in turn begins with soil information. Thus soil data or soil survey is vital component of LUP. It is therefore intelligible that LUP research in India in right earnest had to wait till late eighties when soil surveys were initiated. Till then soil information of the country was limited to traditional classification such as red soils, black soils *etc*. Obviously prior to eighties, no LUP work could be found in the literature. Research in LUP in India is mostly confined to the work done at ICAR-NBSS LUP. Though there are sporadic reports from other research institutions, the emphasis is mostly on land evaluation and at best LUP suggestions based on results of evaluation and the wisdom of the researchers. Real life implementation of LUP or even acceptance of suggested LUP as a guiding document is not reported. There are many reasons for low acceptability of LUP, but one major reason is that the LUP focuses mostly on ability of the soil to support designated use. The research efforts, in general, identified three broad categories of state intervention (1) introduction of new crops and livestock components based on soil suitability and potential for enhanced agricultural productivity (2) introduction of new varieties commensurate with the soil information/properties and (3) adoption or changes in land management techniques. All these categories had soil information at the core.

It is logical to know the lands before planning their usage. Thus bio-physical attributes of land were accorded high importance. Highly sloping lands for example were considered inappropriate for agriculture and hence were deemed suitable for usage as forest and /or pastures. Further the land evaluation mostly focused on edaphic factors. In developing countries like India, majority of the population derives livelihood from agriculture and land use decisions are driven by overriding socio-economic needs. For instance, a farmer may accord higher priority to cereal crop for meeting family needs irrespective of soil quality. Other farmer may decide to buy cereals from fellow farmer or market and hence grow non-cereal crop. Farmers near sugar mill prefer sugarcane crop if water is available neglecting the suitability of the soil to sugarcane. Clearly, evaluation based on edaphic factors is rendered as an academic exercise. Such experience is not specific to India alone, reports from other parts of the world also suggest limited utility value of evaluation/plans based on edaphic factors.

2.1 MODERN LAND USE PLANNING

While most of the LUP work in India is based on edaphic factors and climate, the trend has changed globally. Now LUP is considered incomplete without adequate weightage to socio-economic factors, environment protection and sustainability. The information to be collected for LUP can be broadly categorized as:

1) Bio-physical information

2) Socio-economic information

3) Environmental information

Such detailed information in India is scattered and acquisition of the data is need based with varying scales. Consequently, land use planning in the country lacks integration of bio-physical information with socio-economics. The environment perspective is a recent development and in infant stage.

Besides the three factors listed above, Governance policies in general and natural resources management policies in particular play a vital role in shaping land use plans. In developed world, land use planning activities emerged only after strong soil database were built through soil survey. India also has a soil database at 1:250000 scale. Given its size, the detailed survey (*e.g.* 1:1000 scale) would take decades to acquire soil data. Experts opine that the emphasis should be laid on utilizing the available soil data irrespective of scale limitations as the country can not wait for surveys. Development of geo-spatial tools has significantly altered the capabilities of soil surveyors but these enhanced capabilities should be used for optimal utilization of data and perhaps validation as and when required rather than renewed surveys.

While soils characteristics are of prime importance in LUP, there are many factors that influence LUP. Spurt in demand (*e.g.* pulses), technological advances (*e.g.* Bt cotton), minimum price support (*e.g.* rice and wheat crop in Indo-Gangetic Plains) are some of the examples of the factors that have overridden soil suitability/ edaphic factors in India during the recent past. Land use and crop choice is now a complex product of multiple factors ranging from demand/price at global scale to the local factors like proximity to market or availability of power. While socio-economic factors have great relevance in India, the ecological/environmental factors have little or no attention. The issues like management of salt affected soils, ground water pollution due to agro-chemicals, loss of bio-diversity have not so far been considered in land use planning. Most of the developed countries have developed criteria for identification of the prime lands (lands that are of national importance for food security) and delineated the areas to be protected for sustained agricultural productivity. In Indian context such studies are limited. Recently Naidu *et al.* (2014) reported delineation of prime lands for the state of Andhra Pradesh. Such exercise however needs to be taken up at national level. Naidu *et al* (2014) used 1:250K soil survey data for this purpose. Such delineation is not expected to assist the decision makers much in land acquisition that occurs at local level. Because of the scale limitations, a polygon indicating prime land may contain large swathes of problem soils or soils with major limitations. As of now we have to contend with the available data. As soil information on larger scale becomes available, delineation of prime lands will require revisiting. Preparedness of any management unit (village/watershed/ district/region) to overcome challenges of drought in short term and climate change in long term hinges on how smartly we use the available information and append it with more data using modern tools. The content of this article dwells upon the bio-physical factors like water resources, socio-economic factors, environmental factors, land use changes occurring in the context of India and the policies with direct bearing on land use.

2.1.1 Water Resources

Water is the most important input for agriculture. In Indian context, its importance is highly significant because of the dependence on monsoon as a primary source of water. By including 'length of growing period' as an important criteria for ascertaining soil moisture availability to agricultural crops, the evaluator/planner invariably includes water component to either examine soil suitability for a chosen crop or in suggesting an alternative. However, surface water resources and ground water resources seldom find a mention or assessed comprehensively so as to prepare land use plans that are based on inventory of available soil and water resources in a planning unit. Based on the experience following points could be noted while preparing land use plans. 1) Land use plan with small/minor irrigation development could possibly be a better option for disadvantaged and small/marginal farming population usually located upstream of any medium and major irrigation project and hence by default becomes displaced lot while irrigation beneficiaries downstream get an opportunity for economic gains. Apart from providing scope to small holder to exercise access and control over irrigation resources and technologies, it will mitigate ill effects of climate variations and vulnerability and 2)The current development set up or state departments are not acquainted with the minor irrigation development strategies. Though different schemes of various departments promote opening new wells, subsidized or free oil engines/pumps, farm ponds *etc*., co-ordination or synergy is lacking. Therefore land use plans must be discussed with concerned agencies before recommending strategies or tools. Since ground water is a main source of irrigation in the country, its significance in LUP is further elaborated below.

Groundwater Resources: India has emerged as the global leader in ground water irrigation and water policy of the country is yet to fully accord due recognition to this shift from gravity to groundwater irrigation. Despite spending billions of rupees, the surface storage does not seem to have enhanced substantially as evident from recent Maharashtra reports. According to Shah (2009) area irrigated by surface structure has actually declined by over 3 million ha. On the other hand, area irrigated by groundwater has increased. Therefore it is essential to assess surface as well as groundwater resources of a planning unit for preparation of effective land use plan. Shah, (2009) estimates that energy consumption for groundwater pumping accounts for 16-25 Mt carbon constituting 4-6 % of national carbon emission. More irrigation/pumping to counter climate change would further increase the share. Irrigation permits intensification and diversity of land use. In fact the crop choices tend to become water intensive whenever water becomes available. Formulation of land use plans and more importantly implementation is an arduous task because stakeholders then tend to be driven by economic considerations with greater vigour as against water limiting conditions. In Indo Gangetic Plains (IGP), surface structures have revolutionized livestock/ pastoral economy of the western IGP but millions of wells drilled by the farmers to overcome uncertainties of canal network have related it as unintended system of groundwater recharge. Similar unintended recharge may exist in a land management unit. Such possibilities further strengthen the need for assessing ground water resources. Irrigation development in general is a state activity and hence development of water resources depends on political will, availability of funds, priorities accorded to the region or area and many other factors. However, land use plan cannot be confined to state initiated developments alone. On farm water management is perhaps the easiest part of LUP that farmers are likely to implement without significant hurdles. The illustrative studies/cases of water resources management as a part of LUP implementation in Gondia and Dhule districts clarifies this point further.

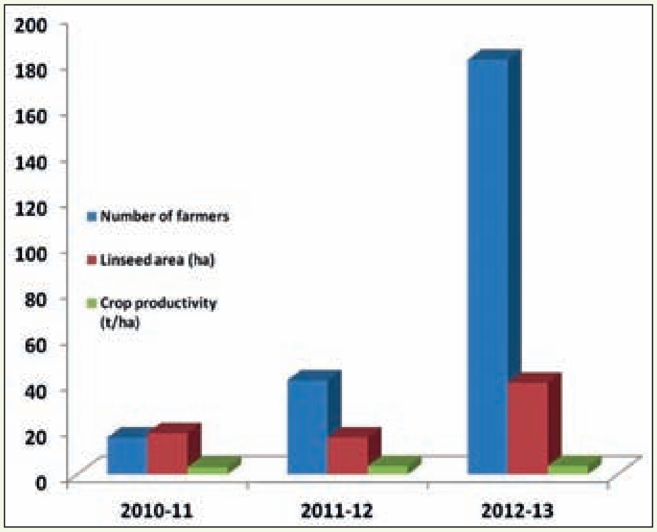
Rainwater Management: In high rainfall districts of Vidarbha (Maharashtra) and Central India, rainfed paddy is the major crop. Under the National Agriculture Innovation Project on developing efficient land use systems through land use planning, few interventions were taken up. Results of these interventions highlight the importance of rainwater management as a part of LUP. Establishment of paddy nursery in June as against current practice of seeding in July or waiting till adequate onset of monsoon was the major intervention to utilize rainwater optimally. In adopted villages, community nursery was raised in each village to overcome challenges thrown by late onset of monsoon. Shortage of water was offset by a community action wherein all the villagers joined together to utilize the only available water resource, *i.e.* a lone tube well in each of the three villages. This intervention has resulted in enhancement of crop yield. Major economic benefits are-minimum 56 % increase in paddy yield, increased area under *rabi* crop area (30%), reduction in input cost (seed cost reduced significantly (Rs.1837/- and labor cost Rs.3500/- per ha) for paddy farmers. The details of rice yield in Gondia clusters are given in Table 1.

Table 1. Rice yield in Gondia clusters during 2009-14

Year	(t/ha)	Area (ha)	Total Yield (t)	Income (Rs/ha)
2009-10	2.98	6.68	19.90	35760
2010-11	2.78	18.12	50.37	33360
2011-12	2.01	21.26	42.73	24120
2012-13	2.84	24	68.18	34080
2013-14	2.33	30	70.05	30355
Mean	2.59	20.01	50.24	**31535**

Baseline 1.62 t/ha—income Rs.17000/ha

***Rabi* Interventions (Managing rainwater) :** Early harvest of rice as a result of community nursery facilitated *rabi* crop as residual soil moisture became available. During the first two years red gram was grown by NAIP farmers that provided an additional income of Rs.12270/ha (4.09 q/ha). However the farmers found it hard to adopt red gram or any other pulse crop because of the tillage required. The clods formed in the paddy fields become hard requiring timely tillage which was not readily feasible. Therefore linseed was introduced as Utera crop. PKV-NL-260 variety of linseed was introduced for utera farming due to its short duration, moderate resistance to powdery mildew, bud fly and blight. Adoption of linseed increased area under oilseed cultivation in the. It is evident from Figure 1 that linseed cultivation in *Rabi* has successfully replaced traditional rice- fallow system. By 2013-14 the number of farmers growing linseed as utera crop had reached 200 despite no input /assistance from the project. This technology



has added Rs. 12880/- per ha to the local economy & provided employment opportunity. The potential for up scaling this technology is very high because Gondia district alone has rice – fallow system. It is also notable that rice-fallow system is practiced in 11.65 .million ha in India. This technology is therefore recommended for regional up scaling.

The above examples clearly demonstrate that water resources need to be assessed before preparation of any land use plan. The surface water bodies available around the village could also be identified as crucial community property resources for sustainable livelihood. For example, many districts have one or more community water tank. Beds of these tanks become dry as waterline recedes. This land space could be utilized for growing short duration crop like watermelon by a group of landless persons. Another use of such water bodies is fish farming. One of the objectives of land use planning is building resilience in the wake of impending climate changes. It involves reducing sensitivity of farmers to shock like floods, drought, prolonged dry spells *etc*. is an essential ingredient of LUP. In other words, it is all about using water resources intelligently. The measures like community nursery or utilization of tank bed are straightforward examples of integrated LUP. However, buffering strategies in response to variable water supplies especially for small and marginal farmers is perhaps the most challenging area of work. Any technology that enhances soil moisture storage, surface and subsurface storage of water will increase resilience to climate change. It is also important that the water is accessible to the farmers, while well established technologies can be adapted to increase storage capacity , utilization efficiency and hence productivity. It is second part that will have to be drastically altered to mitigate the culpability. For instance in surface irrigation schemes releasing water at most critical stages of crop growth with equitable distribution can boost the production levels. Any lapse however can be highly detrimental. Thus formulation of responsive policies can reduce losses. Such changes do not occur at village level. Therefore policies need to be formulated at regional or sub-district level. Nevertheless LUP without due consideration to reigning policies is likely to be confined to papers only.

2.1.2 Livestock Resources

Another non edaphic factor that has direct bearing on land use plans is livestock population in a planning unit. The high livestock population and limited pasture land or fodder availability in general is a big constraint in India. Crop choices made by farmers also greatly affect the fodder availability. For instance, in rainfed farming, crops like sorghum and maize are important not only as cereals (part of family diet) but also as source of fodder. It is observed that decline in area under these crops is greatly affecting farmer's ability to raise livestock. In many districts, decline of area under sorghum and maize exhibits direct relationship with increased mechanization. The farmers turn to more remunerative crops after selling livestock. Another reason is the care that livestock requires. The system of cowboys is slowly declining. In fact many farmers can not afford wages of a cowboy and are turning to mechanization through hired tractors/implements or purchase. The ideal LUP should factor in such changes/ trends and if possible ensure fodder/pasture availability within the management unit by minimising dependence on external sources or transport/purchase.

Livestock unlike crops provides regular income throughout the year. This income enables them to procure agricultural inputs or any other family needs. The cash can be obtained through sale of saleable livestock or livestock products such as milk, eggs, manure. Income can also be obtained through draught power on rental. Thus this valuable asset can be considered as a cash in buffer being disposed either regularly (milk, eggs, meat) or in emergencies (sale of adult animal or its services). In mixed farming approach it is best suited enterprise due to a positive interrelationship between these two. The agricultural residues can better be utilized for feeding of livestock and agricultural practices can be supported through draught power, manure supply or any other critical inputs by livestock. Further, since agriculture is being deficient to provide a better employment for increased population, engagement of this unskilled manpower in animal husbandry would be better option from both employment generation and increasing production of food of animal origin point of view. Integration of livestock and crops facilitates recycling of organic wastes being used for maintaining soil fertility. Though the livestock show decline in population in some parts of the country, they are often considered important for mitigating disasters especially drought. Livestock and migration are the ways and means of cope up mechanism especially during poor monsoon years. A third of milch and draught-power animals, half of goat possessions and a fourth of poultry have depleted over time in tribal regions of the country. This is a price the tribal have paid for mitigating disasters like drought, family mishaps, health problems, ceremonies *etc*. The livestock they possess is not productive, there are other issues related to feed, health as well. For instance stall feeding is not followed in majority of the area. Thus options of LUP may include introduction of improved livestock or upgrading it.

2.1.3 Socio-economic Factors

Land–use change is arguably the most pervasive socioeconomic force driving changes and degradation of ecosystems. Deforestation, urban development, agriculture, and other human activities have substantially altered the Earth's landscape. Such disturbance of the land affects important ecosystem processes and services, which can have wide–ranging and long–term consequences (JunJie Wu 2014). Fragmentation of agricultural land is another serious constraint in India. Generations after generations have passed on the land rights to expanding family members resulting in continuous decline in land held by an individual. In fact it is a source of chronic poverty. A poor resource base is being fragmented for years narrowing further already limited production base. During scarcity rainfall years, relatively better off tribal resort to migration. Therefore land use plans must accord priority to rainwater management from the socio-economic perspective as well. In difficult terrain with good amount of rainfall, it is advisable to harness surface and groundwater resources with small water conservation and harvesting structure like gabions, nallah bunds, check dams, earthen embankments, and farm ponds. Formation of informal groups with an incentive like assistance in water conveyance from public institutions will be a first step in this regard. It is well established that land availability in India has been declining with increasing population. Currently, it stands at 0.26 ha per person as per census 2011. In disadvantaged districts, it ranges from 0.02 to 0.55 ha /person. But land availability should not be seen in isolation. The Doda district in Jammu and Kashmir has poor land availability but good forest cover and snow-clad mountains. The undulating terrain makes it impossible to practice agriculture. Livestock is a main source of living in this district. In East India (districts cutting across states of U.P., Bihar, and West Bengal), high population and its unabated growth has been a hallmark. Almost all the 39 districts with poorest of per capita cultivated land availability are located in Eastern part throw up a complex situation wherein most productive soils, ample irrigation water availability, no competition for land uses (from sectors such as industry, forest *etc.*), waterlogging, natural disasters like floods and high population co-exist. Another 49 districts have relatively more but less than national average per capita cultivated land. Thus total 88 districts are characterized by a poor man to cultivated land ratio signifying need to divert human population to other vocations. Districts like Murshidabad in west Bengal have shown very high agricultural productivity. Though, many districts have not yet realized the potential productivity despite better conditions for agriculture, it is evident that the population is a bigger drag than other constraints. Fragmented land holdings are further divided with growth of family size. Thus 88 districts with more than 18 million population (66 % of total disadvantaged districts population), or two third of the poor in India have to derive livelihood from a very small piece of land without any opportunities such as income through non timber forest produce (NTFP) or crafts using locally available resources. Almost all the 39 districts with poor per capita cultivated land availability located in eastern part of the country throw up a complex situation wherein most productive soils, ample irrigation water availability, no competition for land uses (from sectors such as industry, forest *etc.*), water-logging, natural disasters like floods and high population co-exist. Land use planning in these distrcits is thus a completely different challenge.

2.1.4 Common Property Resources (CPR)

Common Property Resources are the sources of livelihood for significant part of population in rural India. Landless villagers often depend upon community held or state held lands for deriving their livelihood. A fisherman does not own any water body but derives livelihood from it or tribals often make their livelihood by hunting and gathering in CPRs. Hence land use plans are incomplete without these resources and strategies to utilize them. Depletion of CPRs like village lands, water tanks, pastures and forest resources over the years has led to declining livelihood resources. Income from NTFP has been declining. Tribal search deeper into the forests for the non-timber forest produce (NTFP) those were earlier available in the fringes. This endangers precious resources, wild life, environment and importantly their own safety as well. We need to prepare NTFP utilization plans for different regions/districts and even villages depending on the quantum of available NTFP and rejuvenate the NTFP plantations so as to use them in a sustainable manner while conforming to conservation plans. Currently, common property resources (forests) supplement the income significantly in Chhattisgarh, Orissa, Himachal Pradesh, Jammu and Kashmir, Gujrat, Rajasthan, North East India *etc.*

2.1.5 Environmental factors

Environmental factors are not considered very often in India while formulating land use plans. The major problem is lack of data as well as quantification of its impact. But it could be stated with certainty that land use changes are affecting environment. Encroachment in forest lands for agriculture is a common phenomenon in many parts of the country. Conversion of forest lands to agricultural lands, wetlands to crop production and irrigation water diversions have brought many wildlife species to the verge of extinction. Forests provide many ecosystem services. They support biodiversity providing critical habitat for wildlife remove carbon dioxide from the atmosphere, intercept precipitation, slow down surface runoff and reduce soil erosion and flooding. These important ecosystem services will be reduced or destroyed when forests are converted to agriculture or urban development. For example, deforestation, along with urban sprawl, agriculture, and other human activities, has substantially altered and fragmented the Earth's vegetative cover. Such disturbance can change the global atmospheric concentration of carbon dioxide, the principal heat–trapping gas, as well as affect local, regional, and global climate by changing the energy balance on Earth's surface (Marland *et al.* 2003). Urban development has been linked to many environmental problems, including air pollution, water pollution, and loss of wildlife habitat. Urban runoff often contains nutrients, sediment and toxic contaminants, and can cause not only water pollution but also large variation in stream flow and temperatures. Habitat destruction, fragmentation, and alteration associated with urban development have been identified as the leading causes of biodiversity decline and species extinctions (Czech, Krausman and Devers 2000; Soulé 1991). Urban development and intensive agriculture in coastal areas and further inland are a major threat to the health, productivity, and bio-diversity of the marine environment throughout the world (JunJie Wu 2014).

2.2 Role of Supporting Institutions in LUP

As discussed earlier acceptability of land use plans is voluntary in India because there are no supporting institutions or mechanism to ensure implementation of LUP. Co-operative institutions in states like Maharashtra and Gujrat have played a key role in influencing crop choices. Development of sugar industry in Maharashtra and dairy industry in Gujrat are fine examples of how land use is influenced by institutions and industries, both being interdependent. Typically industrial development is perceived as alien to LUP. However small scale agro-based industry and enterprises could be integrated into land use plans. In one such experiment in Dhule district of Maharashtra (NAIP Report 2014), villagers (village Laghdwal) 112 farmers were involved in promoting a seed bank for gram while 139 participated in sorghum seed production during 2012-14. The village produced 25.6 t of seed valued at Rs. 8.24 lakh. More than 50% of the seed was sold to fellow farmers in nearby villages. The seeds were readily adopted and the farmers earned an average Rs. 30,600/ha from gram and Rs. 11340/ha from sorghum. Moreover, the participant farmers stopped purchase of seed from external markets. In another case, a Mini Rice Mill plant of 500 kg per hour processing capacity with polishing facilities and 67 % recovery was installed at the same village in December, 2010 (as a part of LUP) and training was imparted. A Cluster level Committee

Fig. 1 Rice mill-an example of integrated land use plan.

was formulated for maintenance and market linkages. It runs the mill. Paddy husk is now sold to cattle industries and the mill generates employment for six rural youths (Fig. 1). Such enterprises thus could be integrated into land use plans with due considerations to the local needs.

Land care groups, pasture land management groups are some other examples of village level institutions that could play major role in implementation of LUP.

It is notable that implementation of land use plans in general has been an activity of only one institute in India *i.e.* NBSS and LUP. Apart from the work in hundred odd villages over the period of three decades, there is no notable or reported LUP implementation activity in India. The study villages represent geographically minuscule area with likely inadequate representation of the landscape. Implementation of land use plan for relatively bigger administrative/management units like block, tehsil or district has not been reported so far in India primarily because it is not feasible for a researcher to pursue execution of LUP in the absence of institutional support. There is a perceptible lack of interest in state agricultural universities and research centres of ICAR. The district level land use planning has thus been restricted to preparation of plans and then leaving implementation to the administrators and line departments. In the near future also the same conditions are expected to prevail leaving little scope for any changes in approach to implementation of LUP unless the plethora of rules and regulations are amended to achieve synergy benefits of scientific LUP. However, it is not the lack of institutions but the lack of linkages between different development departments and institutions that appears to be the main hurdle in formulation of effective land use plans. For instance, clearance of proposal to build a water reservoir by irrigation or water supply department in area owned by forest department could take years because of the processes and multi-point checks that the proposal has to undergo. It may not be advisable to create specialized institutions as strengthening of existing structure through sensitizing, imparting skills, raising awareness level and better coordination would enhance the utility of land use plans prepared with scientific rationale.

2.3 Governance Policies and Implications

It is needless to say that governance policies influence the way natural resources are managed in the country. Land and Water are subjects within the purview of the States. However, 'Forest' was a State subject earlier, and was brought to the concurrent list in 1976. The subject 'Environment' is not under any list but is covered under the Directive Principles of State Policy and Fundamental Duties enshrined in the Constitution 'to protect and improve the environment'.

Similarly, voices were raised to ensure that a suitable policy for water conservation be designed, mainly to prevent pollution of water bodies from the industrial effluents. Water (Prevention & Control of Pollution) Act, 1974 as amended in 1988 deals with issues for the prevention, control and abatement of water pollution in the country. Water polluting industries are required, under the Act, to obtain consent from Pollution Control Boards set up in every State for the purpose of taking appropriate measures to prevent and control pollution from effluents.

The list of central policies which have a bearing on land use, include

- National Water Policy, 1987
- National Land Use Policy Outlines, 1988
- National Forest Policy (NFP) of 1988
- Policy Statement of Abatement of Pollution, 1992
- National Livestock Policy Perspective, 1996
- National Agricultural Policy 2000
- National Population Policy, 2000
- National Land Reforms Policy
- National Policy and Macro-level Strategy and Action Plan on Biodiversity, 2000

In addition, there are legislative frameworks which have to be conformed to by any state while planning a land use policy. These include:

- Forest (Conservation) Act, 1980
- Environment (Protection) Act, 1986
- Water (Prevention & Control of Pollution) Act, 1974 as amended in 1988
- Wildlife (Protection), 1972 as amended in 1988

- Constitutional Amendments (73rd and 74th Amendments) of 1992
- Municipality Act, 1992 (74th Amendment Act, 1992)

The Central Government has also under consideration, three drafts which have a direct relevance with land use, including the Draft Grazing and Livestock Management Policy, 1994, Draft National Policy for Common Property Resource Lands (CPRLs) and the Biodiversity Bill, 2001.

Some of these policies like Constitutional Amendments (73rd and 74th Amendments) of 1992, popularly known as the Panchayati Raj act, can play a big role in the administrative structure for regulating land use.

2.3.1 National Land Use Policy (1988)

The "National Land Use Policy guidelines and action points" were prepared by the Government of India, Ministry of Agriculture after intensive deliberations. In the said policy, framing of suitable legislation and its sincere enforcement were stressed by imposing penalties, on violations thereof. The said policy guidelines were placed before the 'National Land Use and Waste Land Development Council' under the chairmanship of Prime Minister and its first meeting was held on 6th February, 1986. The Council agreed to the adoption of policy and circulated the same throughout the country for adoption after suitable considerations at the state level. Of the nineteen points, some of the most important ones are:

1. Land Use Boards at the State level should be revitalized.
2. Land Use Policy must be evolved by all users of land within Government jointly and must be enforced on the basis of both legislation for enforcing land use as well as their promotional and preserving methods.
3. Urban Policy must be restructured so as to ensure that highly productive land is not taken away. Town planning should also provide for green belts.
4. A national campaign should be launched for educating the farmers and Government Departments about the need to conform to an integrated land use policy
5. Cropping pattern should be reviewed specially in drought prone/desert areas, so that maximum advantage is taken of improved soil and water management practices.
6. Land and soil surveys should be completed and inventory of land resources should be prepared in each State so that resources allocation is based on a reliable data base.
7. Heavy penalties should be imposed against those who interfere with land resources and its productivity. It must be recognized that environmental protection cannot succeed unless this is done.
8. The problems of water logging, salinity and alkalinity must be brought under control by the use of appropriate technologies and by the adoption of proper water management practices.
9. The management of Command Areas should be reviewed, restructured and revitalized within a specified time limit so that water is used efficiently. Necessary investments for treating the catchments must be met to prevent the collapse of irrigation system due to premature siltation.
10. Technologies relating to dry farming, land shaping and water harvesting must be propagated and adopted in the interest of moisture conservation and optimal use.
11. Land Use Planning should be integrated with rural employment programmes in such a manner that loans and subsidies are given only for those productive activities which represent efficient land use.
12. Rights of tribals and poorer sections on common land should be protected through legal and administrative structures.
13. Stall feeding should be popularized, especially in such areas where grazing land is already degraded.
14. Special Fodder Development Programme in selective blocks should be launched together with a Livestock Development Programme. The aim should be to limit the Livestock population to economically productive stock.
15. Plantations for meeting commercial and industrial needs should preferably be located far away from the habitat.
16. The policy of supplying forest raw materials on subsidized basis to users other than the rural poor

should be reviewed so that raw material is supplied at the prevailing market price, with a view to induce such users to go in for massive afforestation programmes, as also to motivate small and marginal farmers to grow forest based raw material for industry at remunerative prices.

17. The use of alternative packaging material, such as corrugated card boards etc. instead of wooden packaging, must be explored and encouraged.

The policy was finally adopted in 1988 but has not really been able to move things. The Policy has been circulated to all concerned for adoption and implementation through enactment of suitable legislation. The policy, however, did not make the desired impact, mainly due to the fragmented handling of different components of agriculture like water, land and soil.

However, a Land Resource Management Policy and Approach now is being finalized in consultation with FAO, the Lal Bahadur Shastri National Academy of Administration and the National Institute of Rural Development (NIRD). The policy is intended to have dynamic conservation, sustainable development and equitable access to the benefits of intervention as its thrust. Land being a State subject, many States have enacted legislation on land.

The framework for the Land Use Policy to be developed by each state is already available in the Guidelines for Land use Policy (1988) of the Government of India. The states are now required to fit in the particular scenario that exists in the region. These could be a policy for land use in the *Usar* or Ravine areas of U.P. Once such policies are framed, suitable legislations can be enacted within their realm. Problem-based decision making is likely to be more successful than other approaches. Each state thus needs to look into:

- What is the scenario of land *vis-a-vis* land use and why: status, trends, pressures, driving forces;
- What are the consequences of land degradation and how it is affecting the society and its global consequences?
- What is being done about it? How effective are these responses?
- What further actions could be taken for a more sustainable future?

Guiding principles of Land Use Policy should be its formulation in accordance with the geographical, climatic and soil conditions (Agro-ecological regions) in the State. The policy of the State should strive to achieve self reliance, self generating economy, sustainability and conservation development and management of the eco system, particularly land resources viz. soil – water – plant – animal sub-systems, betterment of socio-economic conditions of the people, increase productivity and enhance production.

2.4 Human Resources Development

Land use planning is a specialized work and one needs to acquire a set of skills. Unfortunately such highly skilled manpower is not available in the country. Given the high variability in socio-economic conditions and challenges that India faces, expertise in the field of LUP can only be developed in situ. National Bureau of Soil Survey and Land Use Planning can help the nation to develop required manpower. Practical training of land use planners, administrators, researchers, and decision makers is very limited. In fact there is a complete lack of awareness even at all the tiers of governance. A revenue officer like District magistrate or Sub Divisional Magistrate is empowered to allow conversion of land use without any scientific criteria in judging the proposed conversion. He/she is well ill informed about the soil quality or the potential agricultural production that is likely to be lost. Neither there is socio-economic consideration nor an ecological consideration. Thus the immediate concern would be to force a rethink on such policies. The necessity of economic feasibility and social acceptability of land use decisions has been now highlighted. However, these are only small steps.

2.5 Need for a New Approach

The potential of land for various uses depends on both biophysical and socio-economic conditions. However, as discussed earlier, studies in India and abroad have been restricted to evaluation of soils, terrain and climate for intended and existing land uses. Other factors like socio-economic conditions have been rarely analyzed. Implementation of LUP is not possible without coordination amongst different stake holders, institutional support and legal framework. Because of the land ownership issues and different agencies involved, agricultural scientists in India have confined research to agricultural land use planning and thus, landscape as a unit of planning is under emphasized. Moreover, evaluation of physical environment is also limited. It is essential to incorporate water resources as a critical input and develop land use plans that consider optimum utilization of water resources at different planning scales. The edaphic approach is too sectoral and lacks multidisciplinarity. Hence shift from soil based approach to resource based approach (including all resources available to villagers) is essential.

References

Czech, B., Krausman, P.R., and Devers, P.K. (2000). Economic associations among causes of species endangerment in the United States. *BioScience* ***50*** :593–601.

Gregg Marland, Roger A. Pielke, Sr., Mike Apps, Roni Avissar, Richard A. Betts, Kenneth J., Davis, Peter C., Frumhoff,, Stephen T., Jackson, Linda A., Joyce, Pekka Kauppi, John Katzenberger, Kenneth G. MacDicken, Ronald P. Neilson, John O. Niles, Dev Dutta, Niyogi, S., Richard J. Norby, Naomi Pena, Neil Sampson, Yongkang Xue (2003). The climatic impacts of land surface change and carbonmanagement, and the implicationsfor climate-change mitigation policy. *Climate Policy* **3**:149–157.

JunJie, Wu (2014) Land Use Changes: Economic, Social, and Environmental Impacts. available at http://www.choicesmagazine.org/magazine/article.php?article=49

Naidu, L.G.K., Dharumarajan, S., Lalitha, M., Srinivas, S., Ramamurthy, V. and Singh, S.K. (2014). Categorization and delineation of prime and marginal lands of Andhra Pradesh for different uses. *Agropedology* **24** (02): 253-261.

NAIP Report (2014) available at URL: http://naip.icar.org.in/download/77735/NBSSLUP-nai-c3.pdf/NBSSLUP-nai-c3.pdf

Shah, T., Giordano, M. and Wang, J. (2009). Irrigation Institutions in a Dynamic Economy: What Is China Doing Differently from India? *Economic and Political Weekly* **39** (31): 3452–3461.

Soulé, M.E. (1991). Conservation: tactics for a constant crisis. *Science* **253**: 744–750.

Participatory Land Use Planning for Resource Management

T.N. Hajare
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

Participatory land-use planning (PLUP) is essentially bottom-up land-use planning; carried out with active participation of the concerned community. PLUP evaluates and proposes the best possible uses for land resources in a village in order to Improve the livelihoods of the local population. Important land resources in a village include soil, water and plants, which are used for producing crops, timber, housing, drinking water, and for supporting livestock, etc. Their optimal use depends on the biophysical conditions of the land, people's ability to utilize the land, people's socio-economic conditions and their expectations. PLUP serves as an improved land stewardship through systematically analyzing these conditions and proposing improved land-use options, taking into consideration all the above factors. The implementation of PLUP is ensured through ownership over the process by the community and through reliance on local Institutions.

1. Introduction

Participatory land-use planning (PLUP) is essentially bottom-up land-use planning; carried out with active participation of the concerned community. PLUP evaluates and proposes the best possible uses for land resources in a village in order to Improve the livelihoods of the local population. Important land resources in a village include soil, water and plants, which are used for producing crops, timber, housing, drinking water, and supporting livestock, etc. Their optimal use depends on the biophysical conditions of the land, people's ability to utilize the land, people's socio-economic conditions and their expectations. PLUP serves as an improved land stewardship through systematically analyzing these conditions and proposing improved land-use options, taking into consideration all the above factors. The implementation of PLUP is ensured through ownership over the process by the community and through reliance on local Institutions.

2. Participatory Land Use Planning

2.1 Advantages of PLUP

A land-use plan prevents and solves conflicts over land resource, secures rights and tenure, facilitates discussion among social groups, incorporates formal legal requirements of land-use, documents traditional land use rules and regulations, ensures that interests of entire community are reflected, excludes external interests, improves ecological condition of land resources, helps to develop new sources of income (e.g. ecotourism), secures the resource base, improves and empowers local governance, improves accountability of the local administration and compromises local, regional and national interests.

2.2 Drawbacks of PLUP

PLUP is difficult in areas with private ownership and may raise false expectations in case its limitations are not fully clarified beforehand. Conflicts over land-use objectives between different (socio-economic) groups, as well as uncertainty over future plans and technologies further limit the scope of land-use planning

2.3 Where do we need PLUP?

The need for land use planning arises whenever there is a competition for land in any form or in regions or sub-regions where severe degradation of natural resources (for example soil erosion or forest destruction) takes place, conflicts over land and natural resources increase and/or the productivity remains limited although possibilities for intensification, diversification and development exist.

Implementation-oriented and sustainable land use planning processes need to be participatory by involving the rural population which manages the land and natural resources. In this regard, emphasis is put on dialogue. Since participation in terms of grass-root level decision-making and ownership is often carried out at local level, the term participatory land use planning is commonly used for land use planning processes on a local scale ("village-level"). However, regional or national land use planning procedures can also involve direct grass-root level involvement or are ideally based on the local level plans.

Participatory land use planning is an integrative process based on the dialogue amongst all stakeholders aiming at the negotiation and decision for a sustainable form of land use in rural areas as well as initiating and monitoring its implementation. The objective of participatory land use planning is to achieve sustainable land use, that is, a type of land use which is socially just and desirable, economically viable, environmentally sound and culturally and technically compatible. It sets in motion social processes of decision-making and consensus-building concerning the use and protection of private, communal or public land.

Participatory land use planning aims at:

- Optimising the actual land use,
- Resolving conflicts which arise between competing uses and between the needs of different interest groups,
- Choosing sustainable options that best meet identified needs,
- Rehabilitating and conserving natural resources,
- Supporting the general development process,
- Raising awareness concerning environmental problems and processes among the population and authorities

2.4 Principles of Land Use Planning (LUP)

- Land use planning oriented to local conditions
- It considers local environmental knowledge
- It takes into account traditional strategies for solving problems and conflicts
- It is a bottom-up process based on self-help and self-responsibility
- It is a dialogue
- It is a process leading to an improvement of the capacity of stakeholders
- It requires transparency
- It requires stakeholder differentiation and gender sensitivity
- It is based on inter-disciplinary cooperation
- It is an interative process
- It is implementation-oriented.

2.5 What is meant by participation in the context of PLUP?

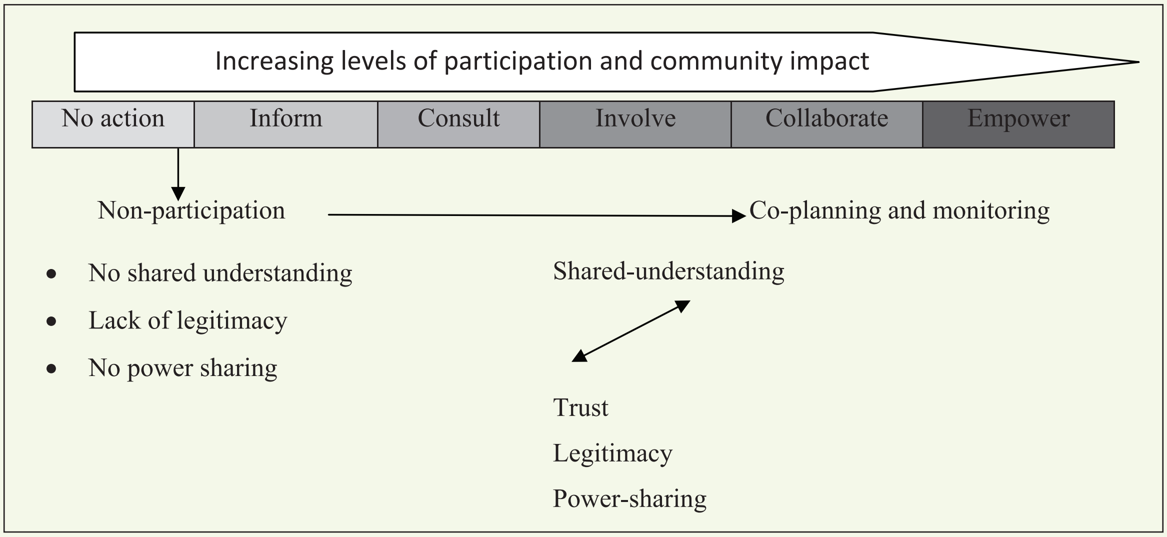
Different concepts and levels of participation exist in land use planning. The International Association for Public Participation distinguishes five levels of participation.

- to inform,
- to consult,
- to involve,
- to collaborate, and
- to empower.

Each of these levels has a specific public participation goal and employs different techniques to reach the goal. Participatory land use planning aims at achieving highest level of participation in order to ensure that people have a greater voice in planning and decision-making, become empowered, developed ownership for planning and implementing activities and to sustainability manage their land and the natural resources they rely on.

In order to involve the local population to the highest extent in the analysis and planning process, participatory rural appraisal (PRA) – tools are commonly used in participatory land use planning processes. These tools have been proved to be very helpful in the context of participatory development and land use planning in many countries. The boxes hereafter provide an idea of the approach.

In the Indian context six major steps could be followed towards participatory land use planning. There are depicted in the following flow chart.



1. Baseline survey of the village including information on current agricultural practices, crop yields, livestock, implements, equipments, credit availability, agriculture inputs used, animals, fodder needs, sources of income, literacy, consumption pattern, infrastructure etc. (Fig.1).

2. Identification and mapping of all the village's natural resources and profiling of the village history including, population, ethnicity, demorgraphy, cultures, communications, infrastructure, resource uses, etc. Facilitation of village/gramsabha discussion about the natural resources management issues and how best to plan for their management, and prioritising and ranking problems and solutions (Fig.2).

3. Discussion amongst the expert group to identify technical interventions necessary to tackle prioritized issues involving state departments engaged in various related activities such as livestock, health, fisheries development, agriculture extension, *etc*.

4. Discussion among the expert group to tackle the prioritized issues

5. Appropriating/earmarking available funds for activities to be taken up, and initially focus on activities which will show quick results to gain the confidence of the villagers.

6. Implementation of action plans/village - land use plan.

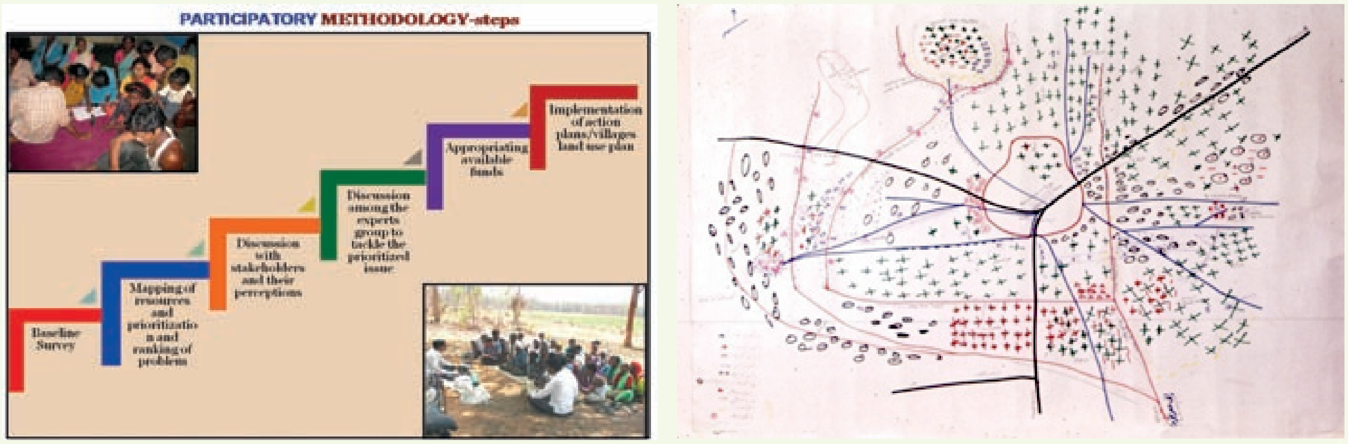


Fig.1. Community resource mapping with participation


Fig.2. Pictures from land use planning exercises in Gondia district during NAIP project

3. Case Studies of Participatory Land Use Planning

A few case studies conducted at village level under the National Agriculture Innovation Project sponsored sub project "Efficient land use based integrated farming system for rural livelihood security in Aurangabad, Dhule and Gondia districts of Maharashtra" are discussed here to bring out the advantages of Participatory Land Use Planning.

Farmers used to wait for onset of monsoon for paddy transplanting and thus nursery of paddy crop would get delayed. This wait resulted in delayed transplanting and crop would be too young to utilize rain water when it rains maximum in the month of July and August. To overcome these constraints, community nursery was raised for the entire village at a single location where irrigation water was available. Consequently, paddy was transplanted 3 weeks earlier than usual practice. (NAIP Report, 2014). The experience indicates that it is not feasible to prepare only entire nursery for the entire village at one place because of the social problems involved. Certain socio-economic considerations such as caste barriers, personal relations, gender issues prohibit bonding of the community. Therefore during the subsequent years, multiple small groups of 10 to 15 farmers were formed based on the interests of the farmers and logistics. It facilitated (Fig.3):

Fig.3. Early paddy nursery preparation.

- An early preparation of nursery, which served the purpose of timely transplanting.
- Seedlings were ready for transplanting at the on-set of monsoon
- Protection from early recession of rains/ moisture shortage
- Increased yields
- Less dependence on irrigation during dry spell
- Early *kharif* harvest & availability of soil moture for *rabi* crop
- Increased *rabi* crop area.

3.2 Participatory Approach for Successful *rabi* Crop for paddy

In Gondia, Chandrapur, Bhandara and Gadchiroli districts of the East Vidarbha the main crop in kharif is paddy. Almost all the farmers grow paddy and most of them grow single crop. The reason for aversion to *rabi* crop was cited to be the uncontrolled grazing that included domestic and wild animals. A gramsabha was conducted and the villagers were encouraged to use community approach to overcome the constraints. Regulations were laid down to control grazing. The persuasion resulted in sowing of 80 ha land with Bengal gram (Fig.4) by using the improved plough (converted into makeshift seed drill by putting pipe with funnel attachment) to ensure the seed goes in the soil up to 0-1 cm depth. That benefits 200 farmers. The intervention has led to around 30 per cent increase in the area sown under second crop which was meager over the past years. (NAIP Report, 2014)

Fig.4. Gram crop in rabi after paddy

3.3 Participatory approach a boon to marginal farmers for sustainable livelihood

Laghadwal village of Sakri tahsil in Dhule district of Maharashtra was selected for NAIP (C-3) sub-project activities from April, 2009.

Fig.5. Bumper yield of onion variety 'N-2-4-1'

Shri. Ratan Uttam Bhoye from Laghadwal village with 7 other tribal farmers decided to cultivate commercial onion crop during summer season, 2010-11Varieties 'N-2-4-1 and Agri Found Light Red' of onion cultivated with MPKV recommended technology on 7.20 ha area on 8 farmers' fields (Fig.5). The average productivity of onion was 20.1 t/ha with net income of Rs. 1,02,765/ ha during the first year of introduction of crop. From this income some of them have constructed onion storage structures (Table 1).

Table : 1. Economics of onion production in Laghadwal village, Tal- Sakri, Dist- Dhule (M.S.)

Crop : Onion **Season :** Summer-2010-11

Sr. No.	Name of farmer	Variety	Area (ha)	Bulb yield (qt)	Market rates (Rs/qt)	Total gross income (Rs)	Cost of cultivation (Rs.)	Net Returns/ acre (Rs.)	B:C ratio
1.	Ratan Bhoye	AFLR	1.00	200	800	160000	24020	135980	6.66
2.	Ramlal Gavali	N-2-4-1	1.80	600	425	255000	43236	211764	5.90
3.	Mangu Pawar	AFLR	0.80	150	760	114000	19216	94784	5.93
4.	Raman Jagtap	AFLR	1.00	180	250	45000	24020	20980	1.87
5.	Murli Bagul	*Puna Fursungi*	0.20	35	770	26950	4804	22146	5.61
6.	Banshi Kokani	AFLR	1.00	200	750	150000	24020	125980	6.24
7.	Shivram Bagul	AFLR	0.60	90	710	63900	14412	49488	4.43
8.	Suresh Pawar	AFLR	0.80	140	700	98000	19216	78784	5.10
	Total		7.20	1595	--	912850	--	--	--
	Average		--	--	645.63	--	24020	102764.7	5.22

3.4 Management of community water tank

Village water tanks were utilized for raising fish crop in participatory mode in Gondia villages. The community tanks in the target villages were leased from the forest department for pisciculture after resolving the dispute among villagers. The participating farmers were trained at CIFE, Hoshangabad (M.P) for one week period. In this PLUP activity, landless villagers earned their livelihood by using the available resources optimally, as shown in Table 2.

Table : 2. Benefits of pisciculture participating in Gondia Distt.

Fish breed	Year	No of Beneficiaries	No. of fish seed Provided (in 000)	Production KG	Additional income (Rs)
Katla, Rohu, Mrigal	2009-10	36	Fries -82, Fingerlings -84	2320	1,39,740
	2010-11	18	Fingerlings 60, remaining they added	750	60,000
	2011-12	18	Farmers SHG added	500	40,000

(NAIP Annual Report, 2012)

4. Further Reading:

Examples of manuals and good practice documents on participatory land use planning

- *Local Level Participatory Land Use Planning Manual*. Ethiopia. Available at:http://www.landportal.info/sites/default/files/llplup_update_f_december_05_2012_1.pdf
- *Manual on Participatory Agriculture and Forest Land Use Planning at Village and Village Cluster Levels*. Lao People's Democratic Republic Available at: http://www.landportal.info/resource/documents/manual participatory agriculture and forest Land use planning.
- *Participatory Land Use Planning Toolbox*. Lao People's Democratic Republic Available at: http://www.cifor.org/online library/browse/view -publication/publication/3 922.html
- *Technical Manual for Land Use and Settlement Planning Process*. Lesotho. Available at: http://www.giz.de/en/downloads/enlesotho land Use settlement technical manual.pdf
- *Manual for Participatory Land Use Planning* Facilitators Namibia. Available at:http://www.iapad.org/publications/ppgis/Manual_PLUP%20Namibia_final_01_09.pdf
- *Land Use Planning. Concept, Tools and Applications*. Available at:http://www.landportal.info/sites/default/files/giz2011enland use planning.pdf
- *Guidelines for land use planning*. Available at:http://www.fao.org/docrep/t0715e/t0715e00.HTM
- *Planning with Uncertainty. Using Scenario Planning with African Pastoralists*. Available at:http://www.pubs.iied.org/pdfs/12562IIED.pdf
- "*PLUP" Fiction: Landscape Simulation for Participatory Land Use Planning in Northern Lao PDR* Available at:http://www.bioone.org/doi/full/10.1659/MRD JOURNAL
- *Application of Scenario Analysis and Multi agent Technique in Land Use Planning: A Case Study on Sanjiang Wetlands*. Available at:http://www.hindawi.com/journals/tswj/2013/219782
- *PLA Notes 31: Participatory Monitoring and Evaluation* Available at:http://www.pubs.iied.org/6131IIED.html?b=d

References

Amler, B., Betke, D., Eger, H., Ehrich, C., Kohler, A., Kutter, A., Lossau, A. von, Müller, U., Seidemann, S., Steurer, R.; Zimmermann, W. Working Group on Integrated Land Use Planning (1999). *Land Use Planning. Methods, Strategies and Tools*. Eschborn: GTZ. pp. 212.

Chaturvedi, A., Hajare, T., Patil, N. and Sarkar, D. (2012). Participatory land use planning for community resource management and livelihood security. Policy paper no 1, NBSS&LUP, Nagpur

FAO/UNEP (1999). *SD Dimensions*, Choudhury, Keya and Louisa, J.M. Jansen (Eds.). FAO Land and Water Development Division, available at http://www.fao.org/sd/EIdirect/land/EPre0081.htm

GTZ (to be printed in 2010). *Land Use Planning. Concept, Tools and Applications*. Eschborn.

Haub, Olaf (2009): Understanding of Land Use Planning and its relevance in Namibia. NID/MLR. Windhoek. 24 pages

International Association of Public Participation (1997). Spectrum of public participation. Available at: http://www.iap2.org/associations/4748/files/IAP2%20Spectrum_vertical.pdf

Gaesing, K., Ayele, K., Tefera, H. and Guchie, A. (2003). *Guidelines for Participatory Land use planning*. Land Use Planning and Resources Management Project in Oromia, Ethiopia. Addis Ababa: GTZ. 86 pages

NAIP (2012). Efficient land use based integrated farming system for rural livelihood security in Aurangabad, Dhule and Gondia district of Maharashtra, Annual Report.

NAIP (2014). Efficient land use based integrated farming system for rural livelihood security in Aurangabad, Dhule and Gondia district of Maharashtra. Report.

Database Development in SOTER for Land Use Planning

P. Chandran
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

Information on natural resources is one of the most important requirements for resource planning of any country. It is well known that the most important link between farming practices and sustainable agriculture is health of soils that needs regular monitoring. A soil information system can provide a platform for monitoring the changes in soil properties induced by dynamic land use changes. A soil information system on SOTER framework has been developed for the two major food growing areas viz; Indo Gangetic Plains (IGP) and Black Soil Regions (BSR) of India. The database includes morphological, physical and chemical properties of soils. The information from this organized database can be retrieved for use and can be updated with recent and relevant data as and when they are available. The database has many application including land use planning. This warehouse of information in a structured format can be used as a databank for posterity

1. Introduction

It is well known that most important link between farming practices and sustainable agriculture is the health of soils that needs regular monitoring. This becomes very much important due to reports of declining trends of productivity in major production zones of India. The development of a systematic and organized information system on spatial variations and trends in condition of soils and landscape is necessary to have a clear view of the status of information on soils for land use planning. The soil information system can thus provide a platform for monitoring the changes in soil properties induced by dynamic land use systems. Such information system would not only provide datasets for posterity but also will improve our understanding of biophysical processes in terms of relationship among them in the pedo environment.

Though India has developed soil resource information in the form of maps and reports still we have not developed a soil information system which can be easily retrieved, updated, monitored and used for different purposes. International Soil Reference and Information Centre (ISRIC), The Netherlands in collaboration with FAO, UNEP under the aegis of International Union of Soil Science(IUSS) has developed a methodology for updating the soil information "World Soils and Terrain Digital Database Project" in SOTER environment.

2. Aims and Objectives of Soter

Global and National Soils and Terrain Digital Databases (SOTER) are used to create and maintain the digitized map units and their attributes. SOTER also intends to the establishment of national and regional soil and terrain databases, founded to further facilitate the exchange of land resource information and ultimate incorporation into a global database (van Engelen and Wen, 1995).The SOTER database has the following characteristics:

1. It is a framework for the storage and retrieval of soil and terrain data that can be used for a wide range of applications at different scales,
2. Allows information extraction at a resolution of 1:1 million, both in the form of maps and tables,
3. It is compatible with global databases.
4. It allows periodic updating and removing of obsolete and/or irrelevant data, and
5. It can be accessible to a broad array of international,

regional and national users through the provision of standardized resource maps, interpretative maps and tabular information essential for the development, management and conservation of resources.

There is no universally accepted system for world-wide classification of terrain, and therefore SOTER has designed a system, which is partly based on earlier FAO work. A Procedures Manual (van Engelen and Wen, 1995) is also available for selection, standardization, coding and storing of soil and terrain data.The inputs of soil and terrain data into the SOTER database depend upon the availability of sufficient detailed information. The SOTER approach is not intended to replace traditional soil surveys, but to provide data in universally acceptable form to monitor the changes of world soil and terrain resources. SOTER helps linking non-spatial data with the spatial data thereby creating a relationship between the map features and the non-spatial data.

2.1 Mapping Approach and Database Construction for SOTER

The SOTER mapping: In SOTER, areas of land with a distinctive, often repetitive, pattern of landform, lithology, surface form, slope, parent material, and soil were identified. Tracts of land distinguished in this manner are named SOTER units. Each SOTER unit thus represents one unique combination of terrain and soil characteristics.

SOTER Resource Material: Basic data sources for the construction of SOTER units are topographic, geo-morphological, geological and soil maps at a scale of 1:1 million or larger (mostly exploratory and reconnaissance maps). In principle all soil maps that are accompanied by sufficient analytical data for soil characterization can be used for mapping according to the SOTER approach.

Associated and Miscellaneous Data: SOTER is a land resource database. SOTER data can only be used in conjunction with data on other land-related characteristics for many of its applications. Therefore, the databases also include files on land characteristics such as climate, vegetation and land use. The climate file is in the form of point data that can be linked to SOTER units through GIS software. Vegetation and land use information, on the other hand, is provided at the level of SOTER units. The SOTER framework also stores information on map resource material, laboratory methods, and soil databases from which profile information has been extracted.

2.1.1 Differentiating Criteria for SOTER

The major differentiating criteria are applied in a step-by-step manner, each step leading to a closer identification of the land area under consideration. SOTER unit can be defined progressively into terrain, terrain component and soil component. Thus an area can be characterized by its terrain, its consisting terrain components and their soil components as below.

Terrain : Physiography and parent material are the two important criteria used for differentiating terrain. Thus the terrain, in the SOTER context, is a particular combination of landform and lithology which characterizes an area.

Terrain Components: The second step is the identification of areas, within each terrain, with a particular (pattern of) surface form, slope, meso-relief, areas with unconsolidated material and texture of parent material This result in further partitioning of the terrain into terrain components.

Soil Components: Further differentiation of terrain is made by identifying soil components within the terrain component. Soil components can be mapable or non-mapable at the considered scale. In the case of mapable soil components, each soil component represents a single soil within a SOTER unit.

Soil profiles: Each soil component must have at least one, but preferably more, fully described and analyzed reference profiles available from existing soil information sources. One of these reference profiles will be designated as the representative profile and the data must be entered into the SOTER database in accordance with the format.

Soil horizons :General information on the profile, including landscape position and drainage, each horizon has to be fully characterized in the database by two sets of attributes based on chemical and physical properties.

Optional and Mandatory data : The horizon data consist of mandatory and optional data. If mandatory data are missing, the SOTER database will accept expert estimates for such values. They will be flagged as such in the database. Optional data should only be entered where the information is reliable.

2.1.2 SOTER Database Structure

Data base structure: In mapping of spatial phenomena, two types of data can be distinguished as (i) geometric data, i.e. the location and extent of an object represented by a point, line or surface and topology and (ii) attribute data, i.e. characteristics of the object.

Geometric Database: The geometric database contains information on the delineations of the SOTER unit apart from data of base map.

Attribute database : The attribute database (RDBMS) of the terrain and terrain component should be available during the compilation of the database. But for horizon data, two types of attributes can be distinguished as mandatory and optional.

Thus, the terrain component information is split into two tables:

(i) The terrain component table which indicates the SOTER unit to which the terrain component belongs and the proportion that it occupies within that unit.

(ii) The terrain component data table which holds all specific attributes data for the terrain component.

In the same way the soil component information is stored in three tables:

(i) The soil component table holds the proportion of each soil component within a SOTER unit/terrain component combination and its position within the terrain component.

(ii) The profile table holds all attribute data for the soil profile as a whole.

(iii) The horizon table holds the data for each individual soil horizon. It consists of four sets of attribute values.

The horizon table must contain all mandatory measured data. In case data is not available for some of the quantifiable attributes, SOTER will allow expert estimates to be used for attributes of the representative profile. Measured and estimated values of the representative profile will be stored separately. All mandatory and optional attributes for the soil component, as well as all other non-spatial attributes of the SOTER units, are listed in Table 1.

Table 1. Non-spatial attributes of a SOTER unit

TERRAIN 1 SOTER unit_ID 2 year of data collection 3 map_ID 4 minimum elevation 5 maximum elevation	6 slope gradient 7 relief intensity 8 major landform 9 regional slope 10 hypsometry	11 dissection 12 general lithology 13 permanent water surface
TERRAIN COMPONENT 14 SOTER unit_ID 15 terrain component number 16 proportion of SOTER unit 17 terrain component data_ID	TERRAIN COMPONENT DATA 18 terrain component data_ID 19 dominant slope 20 length of slope 21 form of slope 22 local surface form 23 average height 24 coverage 25 surface lithology	26 texture group non-consolidated parent material 27 depth of bedrock 28 surface drainage 29 depth to groundwater 30 frequency of flooding 31 duration of flooding 32 start of flooding

SOIL COMPONENT 33 SOTER unit_ID 34 terrain component number 35 soil component number 36 proportion of SOTER unit 37 profile ID 38 no. of reference profiles 39 position in terrain component 40 surface rockiness 41 surface stoniness 42 types of erosion/deposition 43 area affected 44 degree of erosion 45 sensitivity to capping 46 rootable depth 47 relation with other soil components	PROFILE 48 profile_ID 49 profile database_ID 50 latitude 51 longitude 52 elevation 53 sampling data 54 lab_ID 55 drainage 56 infiltration rate 57 surface organic matter 58 classification FAO 59 classification version 60 national classification 61 Soil Taxonomy 62 phase	HORIZON (* = mandatory) 63 profile_ID* 64 horizon number* 65 diagnostic horizon* 66 diagnostic property* 67 horizon designation 68 lower depth* 69 distinctness of transition 70 moist colour* 71 dry colour 72 grade of structure 73 size of structure 74 type of structure* 75 abundance of coarse fragments*
76 size of coarse fragments 77 very coarse sand 78 coarse sand 79 medium sand 80 fine sand	81 very fine sand 82 total sand* 83 silt* 84 clay* 85 particle size class 86 bulk density*	87 moisture content at various tensions 88 hydraulic conductivity 89 infiltration rate 90 pH H2O* 91 pH KCl

Source : Van Engelen and Wen (1995).

Updating procedures :Updating the attribute database could become necessary because of missing data, incorrect data or obsolete data in the database. If there are some data gaps, the voids can be filled when additional data becomes available. Incorrect data, which include data that is being replaced by (a set of) more reliable data (e.g. a representative profile is substituted by another, more representative profile) can be replaced by new data.

2.1.3 SOTER database and their relationship

SOTER database is created by entering data for each terrain unit. These terrain units serve as Soter Unit IDs (SUID). Given below is an Entity- Relation Diagram for SOTER. There are seven entities which are interdependent to each other. These are listed below:

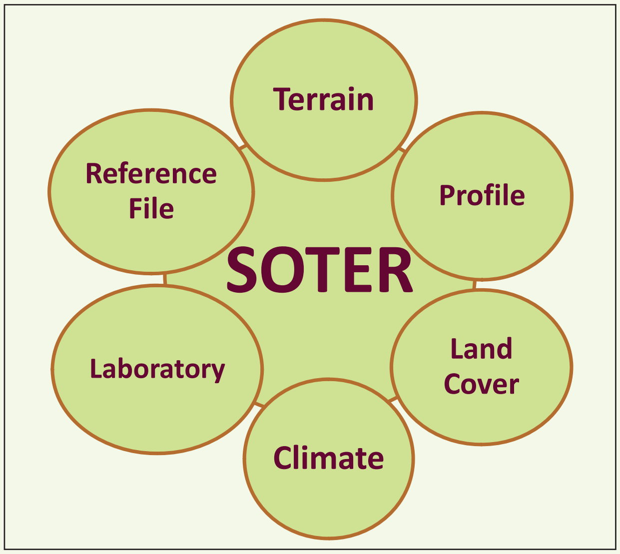


Fig.1. SOTER, its Entity-Relationship (ERDS) diagrams

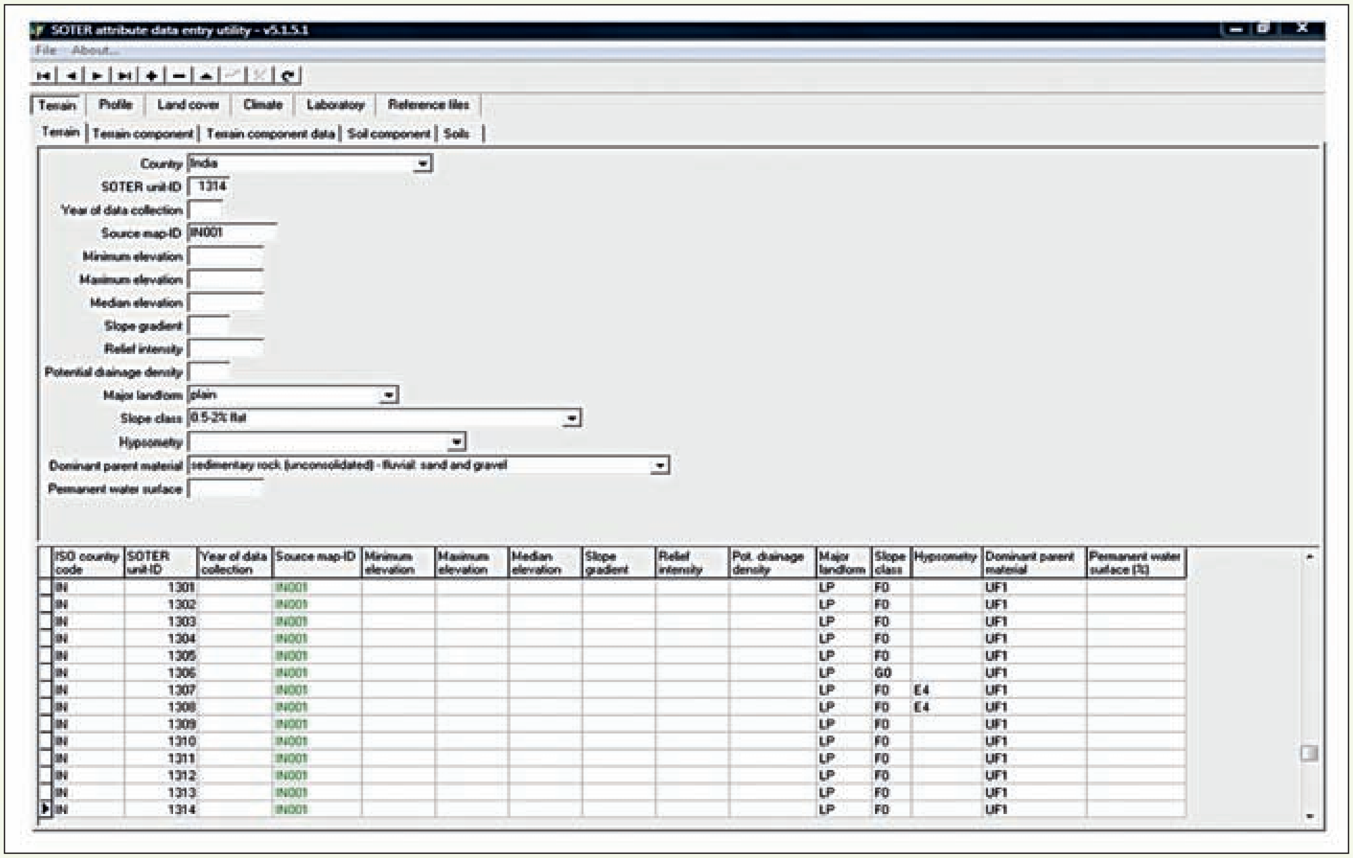


Fig.2. The Screen view of terrain table format of the SOTER

A database structure has a link with each table in the database using the primary keys. The primary keys help in linking of tables in the SOTER attribute database with each other and help in entering the data of common fields of each attribute table.

2.1.4 Development of SOTER database for India

India has developed a map on 1:1 m scale published by NBSS &LUP (Staff, NBSS&LUP, 2002) with distinct map units taking into consideration the pattern of landforms, lithology, surface form, parent materials and soils. The map units are soil associations at Great Group level with description of textural class, drainage class and the dominant soil characteristics. From this map Indo-Gangetic Plain (IGP) and black soil region (BSR) area was carved out and this soil map is used as base material for developing SOTER - India.

The IGP is situated between Gurdaspur (Punjab) in the west to Jalpaiguri (West Bengal) in the east and is extending to Morigaon (Tripura) in the north-east and covers an area of 52.1 m ha (Mandal et al., 2010). Soil map of IGP carved out from the 1:1 m map is used as a geographic database for developing SOTER-IGP (Fig. 3). The IGP is subdivided into 8 agro-ecoregion and 17 agro-eco-subregions depending upon major physiography, climate and length of growing period (Velayutham *et al*., 1999; Bhattacharyya *et al*., 2014).

Similarly the BSR region was also carved out from the soil map of India and the revised total area of BSR is 76.4 mha covering 36 AESRs of the country.. Thus SOTER-BSR has 290 separate map units mainly distributed in 8 states of Peninsular India with sporadic occurrences in the states of Bihar, West Bengal, Punjab, Jammu & Kashmir and Kerala. The attribute data for SOTER has been developed from the 431 geo-referenced profile information distributed throughout the region (Fig. 4).

Development of attribute tables

Information on the attribute tables for Terrain, Terrain component, Terrain component data and

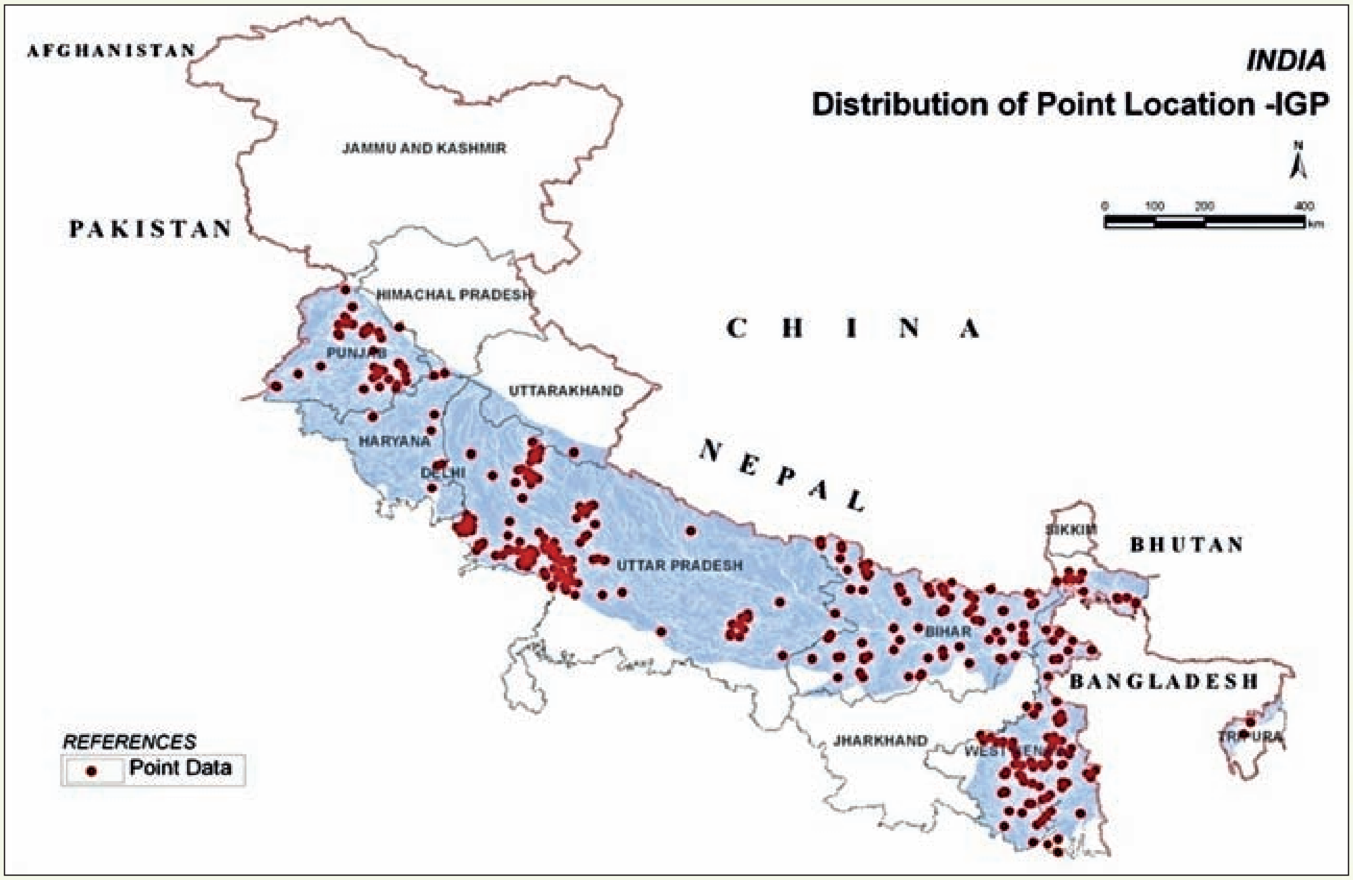


Fig. 3. Geo-referenced location points of IGP

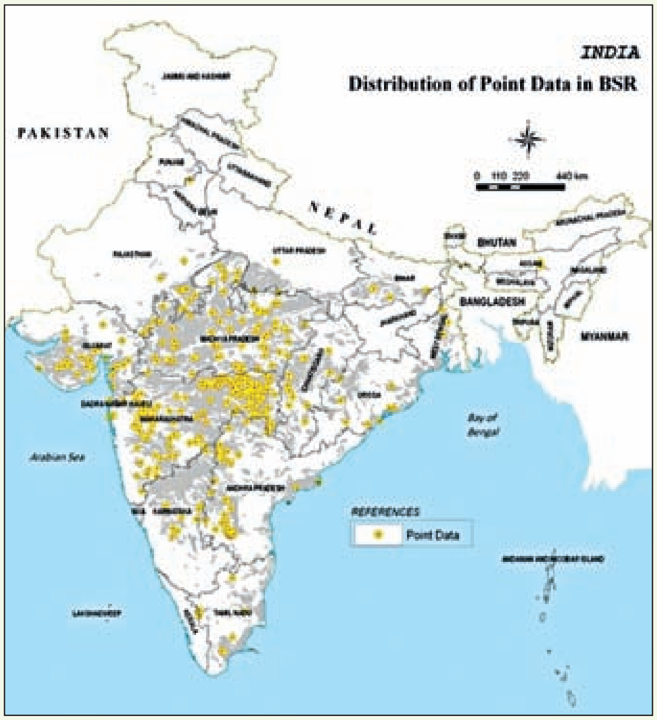


Fig. 4. Geo-referenced location points of BSR

soil component were developed from the soil map information and alsofrom the soil series information. The series information has been collected from different sources mostly from the information generated during the soil resource mapping programme and published by NBSS&LUP. Information on some of the laboratory parameters like bulk density and saturated hydraulic conductivity were not available in most of the earlier published soil survey reports. Therefore, pedo-transfer function (PTF) were developed for generating this information (Tiwari*et al.*, 2014) and validated.

Thus all the attribute tables has been developed as per SOTER procedure. It is to be noted that though we have collated 417 and 431 geo-referenced profile information for IGP and BSR respectively, each map unit can be attached with one profile information. Therefore, one profile was selected from the whole database for linking. Each profile has been given an profile-id for identification (e.g. IN UP 21_216: IN represents the country code India, UP represents the state Uttar Pradesh, 21 represents the profile number of that particularstate and 216 represents the profile number in the master dataset) (Chandran et al., 2013).

Selection of Reference profile and development of Soil Information System

One of the most important aspects of the database construction is selection of most representative profile for the SOTER unit. This is very important because from the information of the representative profile all other interpretative tables and maps are developed.

Reference profiles were selected for each SOTER unit, and information were filled in the corresponding tables for terrain, terrain component and soil component. The link field for this table to other components was prepared as a combination of country code and the SOTER unit. Suitability of the reference point data for representing that SOTER unit was checked from the profile and horizon data table by considering the properties of the profiles. After finding out the properties of the profile and matching with the SOTER unit characteristics the profiles were selected as representative profile for that unit of the map.

Linking of data with the map

The updated information in the SOTER database tables are linked with the map to prepare theme maps. This linking is done by joining the attribute tables of maps and the database through common fields ie: primary keys. In the attribute data tables of SOTER, a link field has been generated by considering each SOTER unit id. This primary key is also an attribute data of the .shp files of the IGP map.

Development of Theme Maps

One of the advantages of the database development is its linking with GIS to prepare interpretative maps. Using the base map of the IGP and BSR, SOTER database, a number of thematic maps were generated (Chandran *et al.*, 2014, Bhattacharyya *et al.*, 2014). The soil reaction map of IGP indicates that about 10% of the area is acidic particularly in the lower IGP where rainfall is high (Fig. 5). These soils may need liming for growing crops sensitive to acidity or can be utilized for crops which can tolerate acidity. However, efforts should be made to arrest further acidification of these soils by better soil and crop management. The map shows 40 per cent of the soils are neutral to slightly alkaline particularly in the lower and middle part of the IGP. However, about 23 per cent of the IGP is moderately to strongly alkaline. These soils are occurring particularly in the upper part of the IGP wherein semi-arid climate and intensive agriculture are followed. These areas need special attention for reclamation programme.

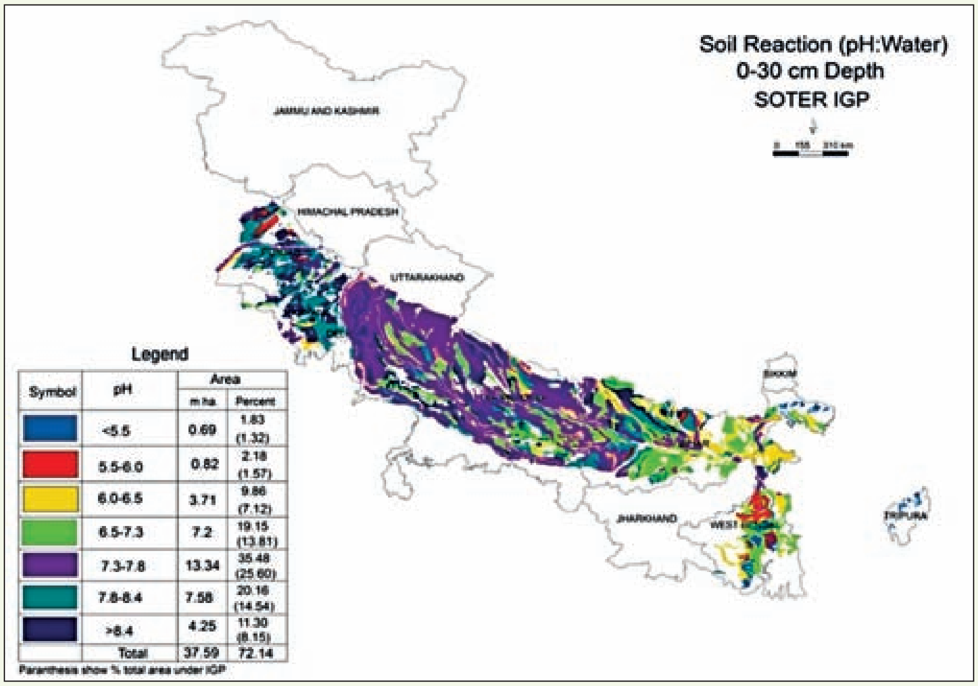


Fig. 5. Soil reaction map of IGP

3. CONCLUSION

The SOTER-IGP and SOTER-BSR are expected to expand knowledge in the study of many functions of land and also as input data for different simulation models and environmental studies. It is also expected to meet the demand of spatially referenced soil information system to be used by policy makers, researchers, modellers and farmers for sustainable agricultural production.

REFERENCES

Bhattacharyya, T., Sarkar, D., Ray, S.K., Chandran, P., Pal, D.K., Mandal, D.K., Prasad, J., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S. and Mandal, C. (2014). Soil information system : use and potentials in humid and Semi-Arid Tropics, *Current Science.* **107**(9):1550-1564.

Chandran, P., Bhattacharya, T., Ray, S.K., Durge, S.L., Mandal, C., Sarkar, D., Sahoo, A.K.,Singh, S.P., Jagat Ram, Ram Gopal, Pal, D.K., Gajbhiye, K.S., Aurangabadkar, B., Mendhekar,P. and Singh, B. (2005). **"***SOTER (Soil and Terrain Digital Databases) IGP, India***"**. Special publication for "Assessment of Soil Organic Carbon Stock and Change at National Scale."NBSS & LUP, India, p.101.

Chandran, P., Tiwary, P., Bhattacharyya, T., Sarkar, D., Pal, D.K., Mandal, D.K., Prasad, J., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Mandal, C. (2013). *Soil and Terrain Database for Georeferenced Soil Information System (GeoSIS) for Indo-Gangetic Plains & Black Soil Region*, Working Report No.8, NAIP Component - 4 Project on "Georeferenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture" NBSS Publ 1069, NBSS&LUP, Nagpur. p.68+ *Annexure.*

Chandran, P., Tiwary, P., Bhattacharyya, T., Mandal, C., Prasad, J., Ray, S.K., Sarkar, D., Pal, D.K., Mandal, D.K., Sidhu, G.S. and Nair, K.M. (2013). Development of SOTER database for major food growing regions of India for resource planning, Current *Science.* **107**(9):1420-1430.

Mandal, *et. al.* (2011). Soil map of Indo-Gangetic plains(IGP), India (unpublished).

Ray, S.K., Bhattacharyya, T., Sarkar, D., Mandal, C., Sidhu, G.S., Sahoo, A.K., Nair, K.M.,Singh, R.S., Dutta, D., Chandran, P., Pal, D.K., Tiwary, P., Mandal, D.K. and Prasad, J. (2012).**"***Georeferenced Soil Information System for Land Use Planning and Monitoring soil and landquality for Agriculture*" Baseline Data for the Indo-Gangetic Plains and the Black Soil Region**,**Vol- I and II Division of Soil Resource Studies, NBSS&LUP, Nagpur, .

Staff, NBSS&LUP (2002). *Soils of India*, NBSS Publ. No 94, National Bureau of Soil Survey & Land Use Planning, Nagpur, India, pp130+11 sheet maps.

Tiwary, P , Patil, N.G., Bhattacharyya, T., Chandran, P., Ray, S.K., Karthikeyan, K., Sarkar, D. , Pal, D.K., Prasad, J., Mandal, C., Mandal, D.K., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H (2014). Pedo-Transfer Functions: A tool for estimating hydraulic properties of two major soil types of India *Current Science.* **107(9):** 1431-1439

van Engelen, V.W.P. and Wan, T.T. (Eds.) (1995). *Global and National Terrain digital Database (SOTER) Procedure Manual* (revised edition) International Soil Reference and Information Centre, Wageningen, The Netherlands.

Velayutham, M., Mandal, D.K., Mandal, C. and Sehgal, J.L. (1999). *Agro-ecological sub-regions of India for development and planning*, NBSS Publ. No. 235, National Bureau of Soil Survey and Land Use Planning, Nagpur, India, 450pp.

Socio-Economic Assessment for Land Use Planning

S.C. Ramesh Kumar, Rajendra Hegde and S.K. Singh
ICAR-National Bureau of Soil Survey and Land Use Planning
Regional Center, Hebbal Bangalore 560024

ABSTRACT

The objective of this paper is to demonstrate how to integrate the biophysical and socio-economic data and use the integrated information for sustainable land use planning. Detailed soil survey at 1:10,000 scales was carried out for biophysical characterization and farm household survey was conducted for assessing the socio-economic evaluation during 1999-2000. The cost of land degradation was quantified about Rs 111per ha per year. The per hectare value of misapplication in nitrogen is Rs. 169, phosphorus Rs. 134 and potash Rs.142. The results of linear programming demonstrate that if farmers choose to implement land use plan suggested in model-I (maximization of net income) it can increase their existing net income of Rs 2921 ha^{-1} to Rs 4515 ha^{-1} with an increase of Rs 1594 ha^{-1}.The study conclusively proved that land use plans can improve land productivity, net income and overall sustainability of land resources.

1. Introduction

Socio-economic assessment is a tool used to predict the future effects of policy decisions upon people and can be used to assist people in dealing with change. It provides a better understanding of the scale and distribution of costs and benefits of change and seeks to maximize positive effects and minimize negative effects resulting from this change. Economic and social analyses are important features of the land use planning process. A land use project, like many other projects, can be implemented only if the total benefits exceed the total costs. Therefore, sustainable land use planning should meet two basis considerations, namely economic viability and social acceptability. Comparisons of social with economic analysis can highlight the need for policy changes. A great many land use planning projects in the past have failed due to the inadequate attention given to social and economic aspects in their design and implementation. Application of appropriate socio-economic analysis in all phases of the planning process is urgently required in the development of land use projects. In this regard it is recommended that effort should be made to incorporate economic and social analyses in land use planning methodologies.

Socio-economic assessments measure the broad range of effects which may arise from changes in policy or practice. These effects may be broken into three key categories - economic, social and environmental. Economic effects refer to changes in well-being, regardless of whether these changes are reflected in monetary flows. Social impacts refer to changes in community cohesion, vitality, confidence, and the demographic makeup of local and regional communities. Environmental effects refer to changes in environmental quality. Balanced decision making requires the integration and explicit recognition of social, economic and environmental impacts. There is a range of methods available to assess the socioeconomic effects of the change. It is not possible, however, to establish a single method to apply in all situations because nature and impact of natural resource management decisions will vary from place to place. Although the fourth principle of the FAO (1976) Framework did emphasize the importance of economic land evaluation, there are hardly any published economic land evaluations. Rossiter (1995) attributed this to three causes: historical, institutional and practical. First, land evaluation is mostly carried out by natural resource specialists with little or no economics training. Second, institutional barriers may also be significant: natural resource scientists and economists may be located in different organizations or in different sections of the same organization, with little motivation or support for interdisciplinary projects. Third, many land evaluations were used to attract financial support for development projects, but not to help guide their implementation. Therefore the fact that a recommended land use option might not have been economically feasible is not exposed.

The major obstacle to quantitative land evaluation and land use planning is the difficulty of obtaining reliable data on the input use patterns and economics of production and how these are affected by land qualities. The difficulty can be handled in several ways (Rossiter 1995). First, since land evaluation is a strategic rather than tactical planning tool, its predictions do not need to be excessively precise. Second, sensitivity analysis can be used to see how wrong estimates of economic or land data must be before there is a change in predicted land allocation or economic suitability. Third, a variety of techniques can be used to estimate 'S1' yields and input levels and how these change with increasing limitations. The examples are rural surveys, expert judgement, statistical modelling and simulation modelling. When several different techniques give similar results, it is likely that the economic predictions are close enough for land evaluation purposes. Economic land evaluation is not excessively difficult. When due attention is paid to details, it can provide a more useful prediction of land performance than a purely physical evaluation, because it can better reflect the decision-making criteria of land users.

1.1 Land Use Planning

Land-use planning (LUP) is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future (FAO,1996).

1.1.1 *Different planning levels and linkages*: Land use planning is a partially integrating and sector overlapping process. The planning objects are the land resources. Therefore, LUP is not suitable for solving all local problems, nor can it replace the overall planning for an area. The basic technical strategy in LUP is to plan land use according to the suitability and the various needs in the area to be taken in to account. National and regional objectives constitute important general conditions for the preparation of the planning process (Table 1).

Land use planning at the regional or district level has a kind of "linking function" between implementation and national strategic planning. One of its major tasks is to provide information for subordinate and superior planning levels. It is impossible to achieve direct participation by all individuals taking part at regional and district level. Interest groups therefore need representation structures and recognized organizations. With respect to the plan implementation at local level, district planning has the following tasks: 1. To provide information on national development objectives and guidelines; 2. To determine the need at local level and to provide appropriate proposals; 3. To mediate in conflicts between stakeholders; 4. To identify land use objectives of regional interest ; 5. To identify and promote nonfarm enterprises for landless and agricultural labours which are not sufficiently integrated into local planning.

Table 1. Planning level, stakeholders and their priorities

Planning Levels	Stakeholders	Priorities/Concerns
National/ State/ District/ Panchayat/ village Micro watershed (*Planning unit is for an administrative boundary*)	Policy makers in the relevant ministries, planning /technical authorities, administrative committees and organizations.	Identifying potential areas for meeting regional food requirement. Identifying potential areas for meeting export targets Identifying potential areas for conservation of natural resources Identifying employment potential of opportunities in the proposed land use plan/system. Identifying potential developmental schemes in the proposed land use plan/system. Preparation of annual budgetary requirement for implementing agricultural LUP. Allocation of budget for Implementing the proposed plan
Farm household (*Planning unit is for an household group*)	Farmers (Small, Medium and Large farmer)	Maximizing /assured food security Maximizing profitability Minimizing purchased inputs Minimizing seasonal labour constraints Minimizing yield and prices risk

1.1.2 Land Evaluation

Land evaluation is the assessment of land performance when used for specific purposes (Sys *et al.*, 1991). There is today a high and worldwide demand for information in the suitability and productivity of land for a wide range of land uses. Connections have been made between land evaluation and sustainability, ecological, and environmental issues (FAO, 1993; 1996) and human development. The purpose of land evaluation is primarily to provide the information necessary to achieving sustainable land management (SLM). Land management combines land administration (cadastre, land rights), land allocation and use, and natural resource management. In its broadest sense, therefore, SLM can be as described as seeking to achieve a balance of agricultural, economic and environmental benefits through the productive use of soil, water, and biological resources. SLM strives to combine production (crops and livestock) and environmental management such that the combined social and economic benefits are greater than those from production alone. The benefits to the land user can be improved yields, reduced risks of production, reduced input costs, reduced labour, and improved social and economic well being.

1.1.3 Data needs of land use planners: The authors' experience of working with watershed department in Karnataka suggests that planners need information that will assist them to: (1) Identify production constraints in agriculture and demonstrate the improved technology to bridge the yield gap in agricultural crops and livestock enterprises. (2) Identify priority areas for soil and water conservation and implementing soil and water conservation measures to increase productive potential of land and (3) Targeting the investment for potential to implement agro-horticulture, agro-forestry and silvi-pastoral systems on private lands and common property resources to increase the biomass, yield and income.

Data on socio-economic factors play an important role in determining constraints on resource management (Ramesh Kumar, *et al* 2002). The Farm Household (FHH) survey is conducted for each soil type for geo-referencing the farm households data. The data collection includes (i) demographic profiles (ii) resource endowments (iii) land use and management (vi) economic viability of different LUT (v) marketing constraints (vi) farming constraints and (vii) farmers priorities for LUP. The important socioeconomic data collection modules and factors considered in land use planning are listed in Table 1.

1.1.4 *Methodology for socio-economic data collection and analysis*: The number of farm households in each planning area (block/watershed) may be too large to survey every household. We must pick representative sample farm households. In each planning area, list the soil types and for each soil (series) type list the survey numbers and the name of the farmers. Thirty per cent of number of farmers (survey numbers) in each soil group is taken and summed up to arrive at sample size. Simple random sampling is followed to select 30 per cent of farmers in each soil type.

Land use planners require information from farmers /private landholders about their: human capital, social capital, natural capital, physical capital and financial capital; livelihood strategies and the livelihood outcome/impact. The framework for data analysis and land use planning given in Table 2 and 3 and Fig. 1, 2.

Table 2. Socio-economic data collection modules and indicators used in land use planning.

Modules	Important Indicators
1. Household Identification	The farm household data (FHH-point data) can be linked to spatial unit. District, taluk, village, survey number, soil map unit number/ profile number/series/phase and questionnaire number.
2. Household Particulars	The household characteristics influence type of land use and management are age group, education, gender, member of community based organization, adequacy of drinking water, type of house, sanitation, electricity connection, and fuel for cooking.
3. Migration Details	Number of family member available for farming and migration influences the type & intensity of land use, total migration, wages per day, type of work, farm and non form employment.
4. Land Holdings	The extent of land resources that can support rural livelihoods, area cultivated, ownership, land rent, fallow lands and access to land resources
5. Water Resources Use	The source of irrigation at the farm indicates what kind of crops that we can recommend in the land use plan. Ownership and access to water resources, sources of irrigation, method of conveyance of water, type of irrigation, extent of adoption and awareness about subsidies for micro irrigation influence water related decisions.
6. Details of Cropping Pattern	The suggested land use plan should be based on farmers preferences in a specific region, past and present cropping pattern and reasons for present cropping pattern
7. Cost of Cultivation	Understanding present farming practices and potential for bridging yield gap in the proposed land use decisions, estimation of investment required for given land use type, evaluation of profitability for given land use type and generating input-output coefficients for each soil types
8, 9 and 10. Economics of Livestock,. Fishery	The relative cost and returns from livestock and fisheries are essential for suggesting integrated land use plans. Types of animals owned (cows/ buffaloes /goat /sheep /goat/ poultry) amount spent on fodder, disease curing and others, net income from livestock, dependency of people on common property resources influences economics of land use
11.Marketing, Constraints	Types of market, Distance to the market, transportation cost, constraints in marketing of farm produce influence marketing decisions
12.Credit Requirement	Farmers credit needs, dependency on non institutional credit, interest rate and repayment pattern. Income distribution, percent of households in poverty influence credit requirement

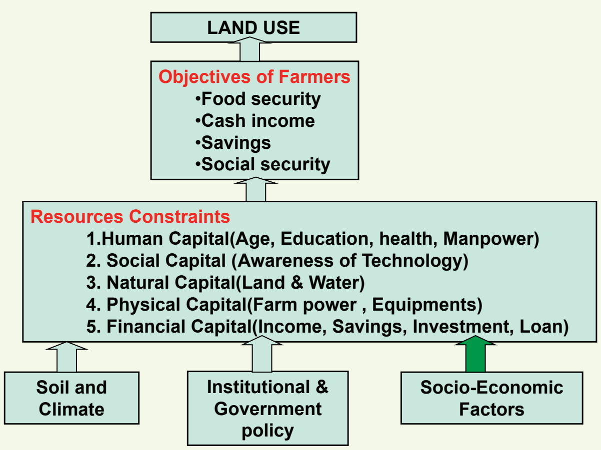


Fig 1. Factors influencing land use

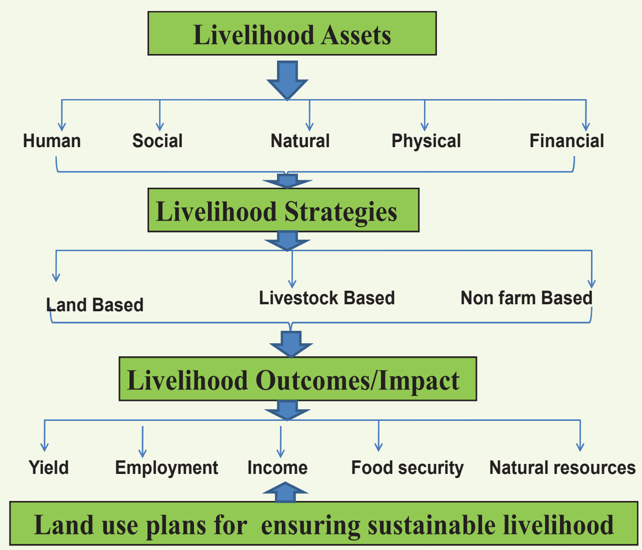


Fig. 2. Framework for socioeconomic data analysis

Table 3. Socio-economic data analysis for Land Use Planning

Livelihood assets	Indicators	Livelihood Strategies	Livelihood Outcomes/ Impact (Baseline situation)	Suggesting integrated land use plans (conservation + production of crops and livestock)
Human capital	Human capital comprises education, age skills, knowledge, health and ability to work for various livelihood pursuits	Land based activates	Yield	Goal -1. Bridging yield gap
Social capital	Social capital includes the social resources, such as networks, group memberships, and trust relationships, upon which individuals and households draw in pursuit of livelihoods		Employment	Goal -2. Increasing labour employment
Natural capital	Natural capital includes access to land, soil, water, forests fisheries and wildlife, from which households engage in agricultural pursuits and/ or resource collection for both sustenance and income generation.	Livestock based activates	Income	Goal -3. Deceasing cost of production and/ or Increasing farm income
Physical capital	Physical capital represents basic infrastructure, such as roads, water & sanitation, schools, ICT; and producer goods, including tools, livestock and equipment enabling the pursuit of various livelihood strategies		Food security	Goal -4. Increasing food security
Financial capital	Financial capital represents the financial resources available to individuals and households (e.g., savings, supplies of credit, or regular remittances or pensions) that provide opportunity for the pursuit of different livelihood options	Non farm based activates	Natural resources	Goal- 5. Decreasing natural resources degradation

1.1.4.1 *Economic evaluation of Land use types:* The economic analysis necessitated proper valuation or estimation of the cost of inputs and output as follows.

Variable costs: Variable costs include the cost of seed, farmyard manure, fertilisers, plant-protection chemicals, human and bullock labour charges and interest on working capital. The measure and definition of variable-cost components are as follows:

1. ***Seed***: The cost of seed, both purchased and farm-produced are computed based on the actual price paid by the respondents in the locality.
2. ***Farmyard manure***: The cost of farmyard manure produced on the farm as well as purchased is taken on the basis of the rate that prevailed when it was purchased by the farmers; other incidental charges paid are also considered.
3. ***Fertilisers and plant-protection chemicals***: The cost of fertilisers and-plant protection chemicals was computed at the actual price paid by the respondents including transportation cost.
4. ***Human labour***: Actual days worked were recorded separately for male, female and hired labour. They were then converted into productive man-days. Based on the wage rates for male and female labour, wages paid in cash or kind or in combination of both were computed in rupees equivalent. Valuation of family labour was done by adopting the prevailing wage rates of the casual labour engaged for similar operations in the study area. It was assumed that each man-day consists of eight hours of work.
5. ***Bullock labour***: Bullock labour in bullock-pair-days, both owned and hired, was charged at the prevailing rates in the locality per day of eight hours of work.
6. ***Farmer's net price***: The net price refers to the price per unit that the farmer realises after deducting the marketing costs from the gross price, which is the price that he receives from the market intermediary to whom he sells his produce.

The cost of inputs such as seed, manure and fertilizers, plant-protection chemicals, and payment towards human and bullock labour were included under variable costs. The value of main product and by-product from the crop enterprise at the market rates are the gross returns of the crop. Net returns are worked out by deducting variable costs from gross returns (Fig 3).

1.1.4.2 ***Assessment of adoption and yield gap of different land use*****:** The difference between the quantity of inputs used by the farmers and those recommended in the package of practices is the input or adoption gap. The yield difference between the output obtained and that is recommended (potential) is the yield gap.

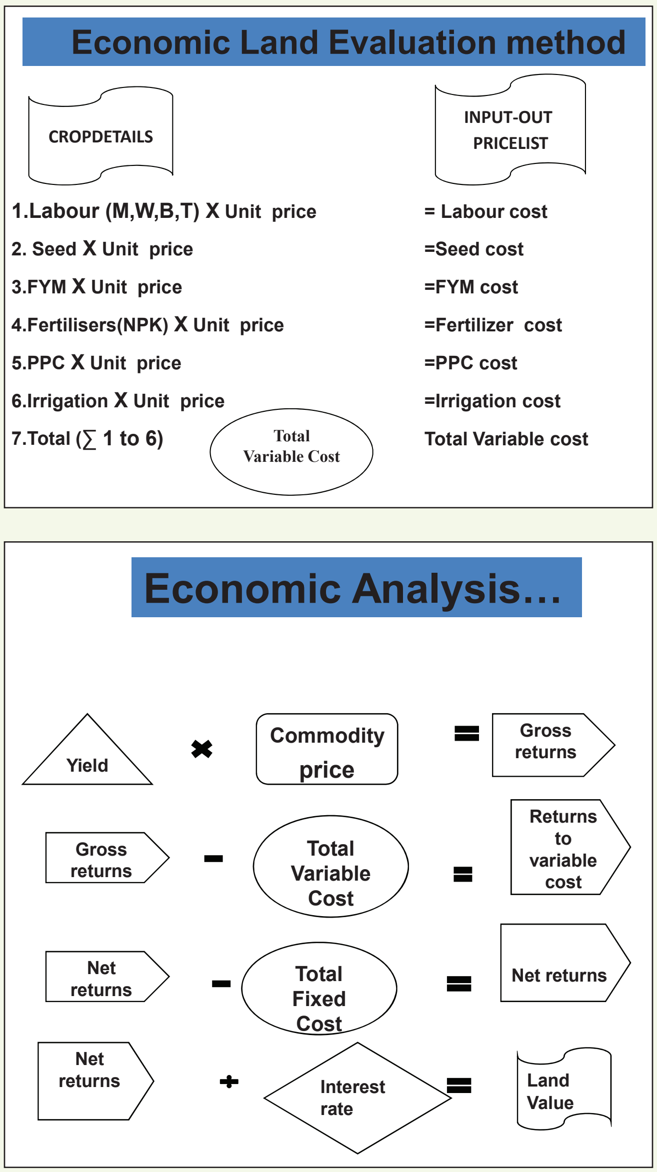


Fig 3 Steps in economic land evaluation

1.2 Estimation Cost of Land Degradation

Replacement cost approach provides an alternative method for estimating the cost of land degradation. The replacement cost method assumes that the productivity of a soil can be maintained if the lost nutrients and organic matter are replaced artificially (Hufschmidt *et al*., 1983; Dixon and Hufschmidt, 1986; Dixon *et al*., 1994). The basic premise of the replacement cost method is that the cost incurred in replacing productive assets damaged by an economic activity can be measured and interpreted as benefits if the damage were prevented. The data requirements for this method are estimates of soil erosion rates, nutrient analysis of eroded soil, and nutrient prices. The soil nutrients (N, P, K and micronutrients) and organic matter lost through erosion are quantified using erosion rate and soil nutrient level. These quantities were then valued using the market prices.

The approach is defined mathematically as

$$RC_i = (S_t - S_{t+1}) \mathop{S}_{j=1}^{k} N_{ij}P_j + C_{il}$$

where i = 1.....n, j = 1.....k,

RC_i = replacement cost of nutrients in i^{th} category soil unit (Rs/ha),

$S_t - S_{t+1}$ = soil loss from year t to year t+1 in i^{th} category soil unit (t/ha),

N_{ij} = quantity of j^{th} nutrient in the i^{th} category soil unit per ton of soil lost (kg/ha),

P_j= price of j^{th} nutrient (Rs/kg),

C_{il} = cost of labour in spreading fertilizers in i^{th} category soil erosion unit (Rs/ha).

1.3 ESTIMATION OF MISAPPLICATION OF FERTILIZER NUTRIENTS:

The present general fertilizer recommendations are compared with soil test based recommendation for specific yield target (balanced fertilizer application). A linear relationship between grain yield and nutrient uptake by a crop was assumed, that is, for a particular yield, a definite amount of nutrients is taken up by the plant. This requirement minus the contribution of soil nutrients gives the amount of fertilizer nutrient needed.

Type I misapplication

This type of misapplication is the potential loss if farmers follow the Agriculture Department's blanket regional recommendations of nutrients for optimum yields instead of the dose calculated by applying the STCR formula for those yields. The cost of such misapplication was calculated from the excess or deficit of nutrient applied.

Type II misapplication

Taking into account the nutrients available in each soil unit, fertilizer nutrients needed to produce the yield obtained by each category of farmer (marginal, small and large) are computed using the fertilizer-response equations for targeted yields given by Veerabhadraiah *et al.* (2001) for the various agroclimatic zones of Karnataka. The nutrient dose actually applied by farmers was compared with the calculated dose to quantify type II misapplication of fertilizer nutrient. Positive and negative differences were both considered harmful, for excess nutrient is wasted in the former, and the shortfall in nutrient in the latter leads to depletion of the soil. The cost of the misapplication was calculated from the market value of the nutrients N, P and K.

1.4 Method for Preparing Optimum Land Use Plans

Linear programming is the basis for multi-objective programming. This technique has been widely used because of its several advantages over functional analysis. Programmes involving changes in resource levels cannot be easily handled by functional analysis and determination of normative plans with resource inequalities appears to be impossible through functional analysis. Hence, linear programming technique that overcomes the above lacunae of functional analysis was chosen for analysis.

The mathematical form of linear programming used in this study can be written as

$$\text{Maximize} \quad Z_j = \sum_{j=1}^{n} C_{jk} X_{jk} \quad (1)$$

subject to

1. $$\sum_{j=1}^{n} a_{ijk} X_{jk} > b_i \quad (i = 1.....l) \quad (2)$$
2. $$\sum_{j=1}^{n} a_{ij\,k} X_{jk} < b_i \quad (i = m......n) \quad (3)$$
3. $$\sum_{j=1}^{n} a_{ij\,k} X_{jk} = b_i \quad (i = p.......r) \quad (4)$$
4. $$X_{jk} \geq 0 \quad (5)$$

where

Z_j = objective function to be maximized,
C_{jk} = value of the jk[th] activity in Rs/ha,
K = kind of soil,
X_{jk} = level of jk[th] activity per hectare,
a_{ijk} = coefficient that reflects either absorption of ($a > 0$) or contri bution to ($a < 0$) a constrained resource,
b_i = available quantity of i[th] resource or the requirement to be met.

1.4.1 *Objective function*: The objective function represents maximization of the 'annual net returns' per hectare from crop enterprises subject to the resource constraints specified in the model. The general basic economic objective is maximization of welfare of the watershed. This concept is subjective and difficult to quantify. Hence the annual net returns in the watershed for the resources committed to the farming system were used as a proxy for maximizing welfare of the farmers.

The net returns per hectare were calculated by deducting total variable costs of seeds, human and bullock labour, fertilizer, FYM and plant protection chemicals from gross returns.

1.4.2 *Input coefficients* (a_{ijk}): Input coefficient is the average quantity of the i^{th} input used per unit of the j^{th} activity on the k^{th} type of soil (soil series). It was calculated per hectare for each crop. The input coefficients for men, women and bullock labour, FYM, fertilizers (N, P, K), plant-protection chemicals and seed for different crops on different soil series were derived by totalling and averaging the corresponding input-output coefficients of different soil series and crops, and formed elements of the matrix.

1.4.3 *Constraints and requirements*: These are the elements in the matrix. The activities (row vectors), which were the important constraints considered in the study, were land, labour, manure (FYM). fertilizers (N, P, K), plant-protection chemicals, available own funds, borrowing and non-resource constraints such as food requirements. A constraining resource was specified as maximum resource available with a relation £, while b_i referred to the requirement. They are generally found as RHS values in the linear programming model.

Land: The kinds of soil mapped at series level were considered for each crop season (*kharif, rabi* and summer). The area under perennial crops and soils not suitable for certain crops were excluded from the model. All the resource requirements were considered at macrolevel to reflect the total watershed area.

Labour: The availability of family labour was estimated taking into consideration the number of persons aged >15 years and <60 years (both male and female) fully or partially engaged in farm business. Men labour and women labour, expressed in days, were treated as separate activities since there was gender segmentation in the various activities. The wages of own labour and hired labour were considered in calculating the total cost and returns per hectare. The availability was indicated in days for each category in a year or season and the hiring facility was accommodated in the model. Availability of bullock labour in bullock-pair days was also estimated.

Manures (FYM): Available FYM among the farm households in the watershed was estimated and considered in the model along with a provision for purchase.

***Fertilizers and plant-protection chemicals**:* The fertilizer inputs were converted to nutrient units and the requirements for different crop activities were worked out. The level of plant-protection chemicals used was also incorporated in the model as input coefficient. The availability of fertilizers (N, P, K) was assumed to be unlimited (0).

Working capital: The working capital available with the farmers sometimes might not be sufficient to meet the requirements of the different agricultural operations. Capital thus acted as a constraint in the study area, and farmers had taken to subsistence agriculture owing to inadequacy of working capital. Working capital includes funds required to meet the cost of seeds, FYM, fertilizers, plant-protection chemicals and wages of human and bullock labour. Family savings were estimated for available capital in the model, the constraint being specified by the '£' relation.

Borrowing: Borrowing activity was provided to encompass only short-term credit needs. Interest rate was reflected as the cost of borrowing in the objective function. The amount borrowed was to supplement the cash available with the farmers during the crop season.

***Non-resource constraints**:* These constraints arise not because of lack of resources but from customs and psychoogical reasons affecting the decisions of the farmers.

***Minimum cereal requirement of family**:* This constraint ensures that the minimum cereal needs of the households are met from the farm itself. The area required to meet the requirement of the commonly consumed cereal of the watershed population was incorporated as a constraint in the model.

***Maximum area constraint**:* Factors such as risk, uncertainties, high input costs, self-dependence on farm-grown food, supervision and marketing problems, and environmental degradation associated with crops might prevent farmers from growing them beyond certain limits. In allocating resources it is important to see that resources allocated to these crops do not cross the limits set by the farmers.

1.4.4 *Activities in the model* : These activities (column vectors) specify the crop and/or livestock activities that could be put to various alternative uses. The various activities incorporated in the model, namely, crop-production activities, livestock activities, labour-hiring activities, borrowing activities, and purchase of FYM and fertilizers were categorized according to soil (soil series) in each watershed.

1.5 Generation and evaluation of land-use plans

To represent the multiple and partially conflicting views of different stake-holders, various socio-economic and biophysical (environmental) objectives were identified for evaluation. The classification of these objectives is not unequivocal; for instance, some of the objectives included in the socio-economic realm might have a biophysical dimension as well. However, this classification has no effect on the programming for optimization. The planning objectives used in the evaluation procedure are given below.

Realm of objective	Objectives
Socio-economic	Maximization of net farm income Minimization of total variable cost Minimization of total seasonal employment of men labour Minimization of total seasonal employment of women labour Minimization of total seasonal employment of bullock labour
Biophysical (environmental)	Maximization of FYM application Minimization of N fertilizer application Minimization of P fertilizer application Minimization of K fertilizer application

To achieve policy objectives, instruments that influence farmers' decision on land use and allocation of other resources need to be identified. These measures or instruments are represented in the model in accordance with relevance of the measures.

The total economic costs involved for soil and water conservation and correcting soil degradation and the benefits in terms of increasing land productivity, employment and income can be quantified following standard methods. The different between additional benefits minus the cost will be the impact of the land use planning.

1.6 Case study of Nalatwad Micro-watershed in Karnataka

Nalatwad microwatershed having an area of 560 ha located in Muddebihal taluk of Bijapur district, Karnataka was selected as a cast study. The microwatershed falls in agroclimatic zone 3 (northern dry zone) of the state, having the length of growing period of 115 to 120 days (Ramesh Kumar *et al.* 2002). This area has been categorized as severely drought prone with frequency of occurrence of 4 drought years in each of the decades during 1970-1990. The microwatershed has alluvial black soils derived from the basalt. The area consists of gently sloping plain lands with elevation ranging from 515 m to 530 m above MSL. The slope ranges from less than 1 per cent to about 5 per cent and is generally up to 3 per cent. The general slope is north to south. The micro watershed area is drained by the Arehalla stream, which joins the Krishna river further south.

1.6.1 *Status of soil and land resources* : During the detailed soil survey of the microwatershed, six soil series (A to F) were identified and the details of soils classification up to subgroup level are presented (Table 3). These series were mapped as 19 phases on the basis of variations of slope (symbol A for slope class of 0-1 %, B for slope class of 1-3 per cent and C for slope class of 3-5 percent) and erosion status symbol 1 (slight erosion class < 15 t/ha), 2 (moderate erosion class 15- 40 t/ha) and 3 (severe erosion class > 40 t/ha) as determined at the profile site locations.

Shallow (< 75 cm), deep (76- 100 cm) and very deep (>150 cm) soils occupy 20, 36 and 44 per cent, respectively to the total area of microwatershed. Most of the area was covered by very gently sloping (1–3% slope) or nearly level (<1% slope) lands and very small area had gently sloping (3–5% slope) lands. Larger areas are under slight (35 %) and moderate erosion (61%) and small area under severe erosion (2.3 %).

The soil phases map for the watershed is presented in Figure 4. Surface soil samples collected at 80-m grid intervals were analysed for available macro and micro nutrients to generate fertility maps for each nutrient.

Table 3. Soil and site characteristics of Nalatwad microwatershed

Sl. No.	Soil map unit (SMU)	Area (ha)	Slope (%)	Erosion class	Est. AWC (mm/m)	Soil depth (cm)	Soil texture	Soil reaction (pH)	
								Surface soil	Subsoil
1	AmB2	40.74	1–3	e2	70	25–50	c	8.7	8.6
2	AmC2	13.70	3–5	e2	70	25–50	c	8.7	8.6
3	AmC3	2.50	3–5	e3	70	25–50	c	8.7	8.6
4	BmB2	37.72	1–3	e2	120	51–75	c	8.9	8.0
5	BmC2	17.12	3–5	e2	120	51–75	c	8.9	8.0
6	BmC3	1.29	3–5	e3	120	51–75	c	8.9	8.0
7	CmB2	68.10	1–3	e2	120	76–100	c	9.3	9.0
8	CmC2	11.87	3–5	e2	120	76–100	c	9.3	9.0
9	CmC3	1.64	3–5	e3	120	76–100	c	9.3	9.0
10	DmA1	6.08	0–1	e1	170	101–150	c	9.2	8.0
11	DmB2	47.28	1–3	e2	170	101–150	c	9.2	8.0
12	DmC2	19.13	3–5	e2	170	101–150	c	9.2	8.0
13	DmC3	6.66	3–5	e3	170	101–150	c	9.2	8.0
14	EmB2	31.59	1–3	e2	170	101–150	c	8.4	8.2
15	EmC2	5.56	3–5	e2	170	101–150	c	8.4	8.2
16	FmA1	192.10	0–1	e1	170	>150	c	8.8	8.9
17	FmB2	41.88	1–3	e2	170	>150	c	8.8	8.9
18	FmC2	6.94	3–5	e2	170	>150	c	8.8	8.9
19	FmC3	0.79	3–5	e3	170	>150	c	8.8	8.9

Soil classification : Soil series A : Lithic Haplustept, Soil series B:Vertic Haplustept, Soil series C : Typic Haplustert, Soil series D : Typic Haplustert , Soil series E : Typic Haplustert , Soil series F : Typic Haplustert

The entire area of the watershed showed low level of nitrogen (<280 kg ha^{-1}). Phosphorus level is low to medium (<57 kg P_2O_5 ha^{-1}) in about 74 per cent and potassium level was high (>337 kg K_2O ha^{-1}) in almost 94 per cent of the area (Table 4).

Table 4. Soil phase wise distribution of soil fertility

Sl. No.	SMU	Total No. grids	Avalable nutriments status (kg/ha)			Organic Carbon (%)
			Nitrogen	Phosphorus	Potash	
1	AmB2	58	134	34	641	0.60
2	AmC2	22	135	37	468	0.60
3	AmC3	4	184	43	669	0.60
4	BmB2	56	121	17	619	0.59
5	BmC2	29	123	14	559	0.59
6	BmC3	1	79	15	366	0.59
7	CmB2	100	127	21	603	0.59
8	CmC2	16	127	14	489	0.59
9	CmC3	4	106	9	331	0.59
10	DmA1	9	160	10	694	0.54
11	DmB2	74	136	20	638	0.54

12	DmC2	31	118	24	523	0.54
13	DmC3	9	135	17	493	0.54
14	EmB2	51	131	19	661	0.74
15	EmC2	9	122	24	485	0.74
16	FmA1	293	125	14	581	0.67
17	FmB2	70	125	16	1085	0.67
18	FmC2	10	183	25	680	0.67
19	FmC3	1	136	4	637	0.67
Watershed		847	132	20	591	0.61

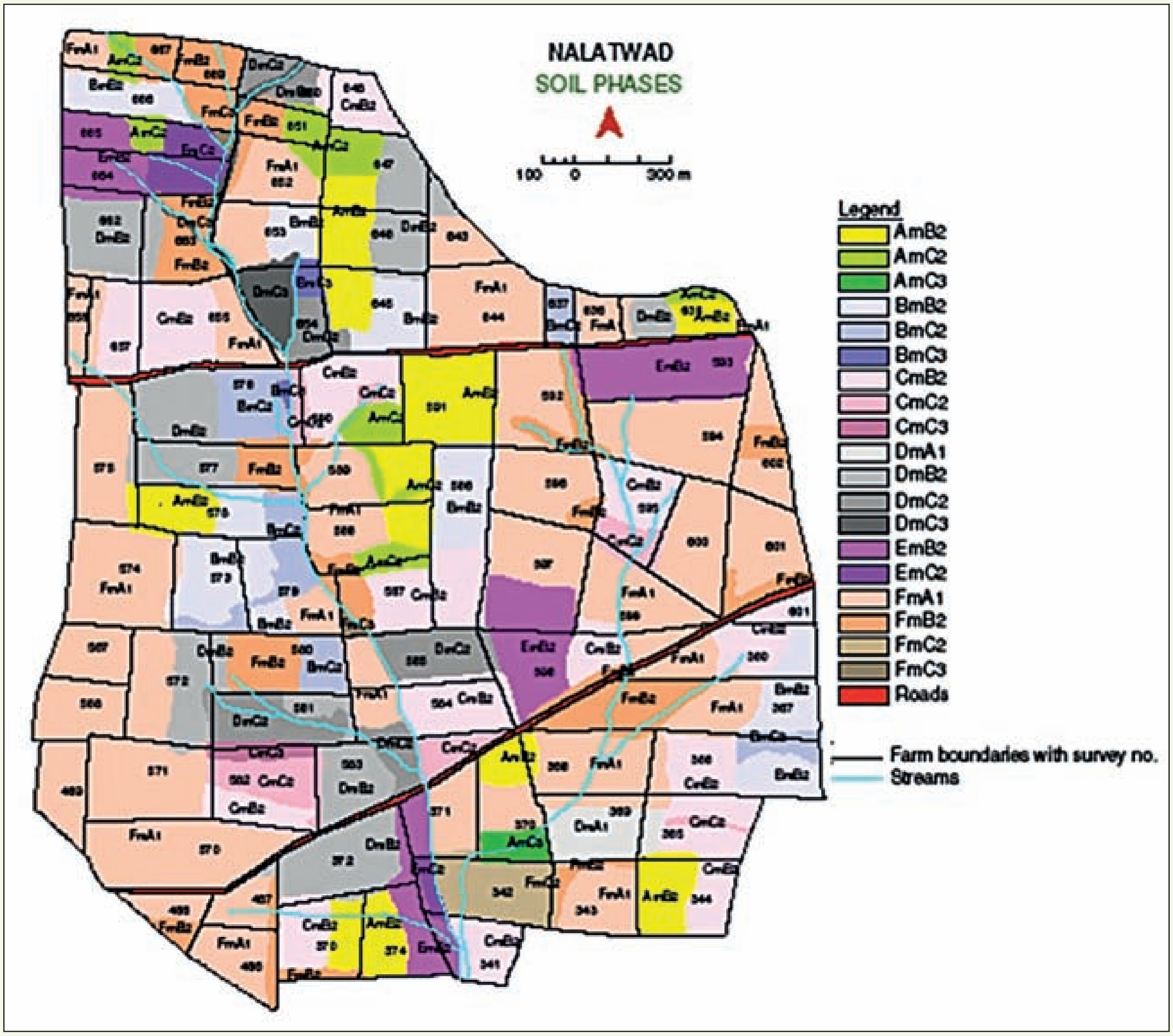


Fig. 4. Soil phases in Nalathwad microwatershed, Karnataka

The soils of the watershed were almost all deficient in available zinc (< 0.6 ppm) (Takkar *et al*. 1990). The levels of available iron were deficient (<4.5 ppm) in about 57 per cent of the area. For economic analysis, the available-nutrient levels for the soil units of the watershed (soil phases) were calculated by averaging the data from the points falling in each soil map unit.

The 553ha of Nalatwad watershed housed 135 farm house-holds, having 993 human and 361 animal populations. The average land holdings is 0.75 , 1.81 and 5.54 ha, respectively among the marginal, small and large farmers. The population density was highest among marginal farmers (10/ha), followed by small farmers (3.5/ha) and large farmers (1.42/ha). The same order is observed in the livestock population density (3.0/ha, 1.0 /ha, and 0.55/ha, respectively, among marginal, small and large farmers). The marginal farmers occupied the smallest proportion of land with highest human and livestock population.

Sorghum covered 73.5 per cent of the total cultivable area. The other important crops were sunflower (15.9%), bengal gram (5.2%) and wheat (3.2%). The minor crops were pearl millet *(bajra)* (0.9%) and green gram (0.2%). About 1.1 per cent of land was left fallow. Marginal and small farmers had their lands exclusively under sorghum, whereas large farmers cultivated *bajra*, bengal gram, sunflower, wheat and green gram as well. The cropping pattern indicated that crop diversification was low.

1.6.2 *Economic Land Evaluation*: The economic valuation of sorghum on different soil units is presented in Table 5. The cost of cultivation of sorghum ranged from a minimum of Rs 3363 in CmB2 to a maximum of Rs 4376 in BmB2 with a mean cost of cultivation of Rs 3783 ha^{-1}. Net returns ranged from a low of Rs 2841 ha^{-1} on soil unit AmC2 (shallow soil on 3 to 5% slope, with moderate erosion) to a high of Rs 5810 on soil unit EmB2 (deep soil on 1–3 % slope, moderate erosion). The land value ranged from Rs 27879 $ha^{-1}$to Rs 52819 ha^{-1} (Table 5); the average was about Rs 37566 ha^{-1}. Net returns from sorghum and soil depth were positively correlated. Shallow soils (AmB2) fetched net returns of Rs 3067 ha^{-1}compared to a maximum of Rs 5810 ha^{-1}on deep soils (EmB2) with a difference in net returns of Rs 2440 ha^{-1}. Soil erosion and net returns indicated inverse relationship.

Table 5. Economic evaluation of sorghum productivity (net income) on different soils

Soil Phases	TCC/ha	TGR/ ha	NR/ha	Value (11%)	B:C Ratio
AmB2	3701	6768	3067	27880	1.8
AmC2	4435	7277	2841	25827	1.6
BmB2	4376	8760	4384	39854	2.0
BmC2	3699	6972	3273	29756	1.9
CmB2	3363	7742	4379	39807	2.3
CmC2	3605	7086	3481	31645	2.0
DmB2	3554	8265	4711	42831	2.3
DmC2	3578	7470	3892	35384	2.1
DmC3	3750	6912	3162	28743	1.8
EmB2	3866	9676	5810	52820	2.5
FmA1	3929	9216	5287	48065	2.3
FmB2	3992	8856	4864	44215	2.2
FmC2	3860	7900	4040	36731	2.0
Mean	3783	7915	4092	37566	2.1
Min	3363	6768	3067	27880	1.6
Max	4376	9676	5810	52820	2.5
SD	252	960	868	7887	0.2
CV	7	12	21	21	10.7

TCC= Total Cost of Cultivation, TGR= Total Gross Returns, NR= Net Returns,

Value= Capitalised value at 11 per cent, B:C Ratio= Benefit Cost Ratio

Net returns from sorghum on slightly eroded soils (soil loss <5 t ha^{-1} y^{-1}) were Rs 5287 ha^{-1}compared to Rs 3161 ha^{-1} on severely eroded soils (soil loss 15–40 t ha^{-1} y^{-1}), the difference being Rs 2125 ha^{-1}.

The productive capacity and the economic value of the soil/ land depends on two factors, allocation of land for different types of use and the level of land/ crop management followed in each crop. The influence of soil depth, slope and soil erosion influences on the productivity of different crops. The comparative analysis of different land use types across the soils are given in Table 6. On shallow soils (series A and B with a depth of 25-75 cm) the average net returns per hectare is more in sorghum (Rs. 3391) compared to sunflower (Rs. 2318), bengalgram (Rs. 2026) and wheat (Rs. 1060). On deep soils (series C, D and E with a depth of 76-150 cm) the average net returns per hectare is more in sunflower (Rs. 5503) compared to sorghum (Rs. 4239), bengal gram (Rs. 3607) and wheat (Rs. 2587). On very deep soils (series F with a depth of >150 cm) the average net returns per hectare is more in sunflower (Rs. 6742) compared to sorghum (Rs. 4730), wheat (Rs. 4447) and bengal gram (Rs. 4427). The productivity is influenced by soil depth and erosion and slope of the land.

Table 6. Productivity (net returns in Rs./ha) of different land use types

Soil phases	Sorghum	Sunflower	Wheat	Bengalgram
AmB2	3067	2293	1230	2026
AmC2	2841	1208	890	Not grown
BmB2	4384	3455	Not grown	Not grown
BmC2	3273	Not grown	Not grown	Not grown
CmB2	4379	4863	2146	3424
CmC2	3481	4733	Not grown	Not grown
DmB2	4711	5877	2361	Not grown
DmC2	3892	5500	2159	2849
DmC3	3162	Not grown	Not grown	Not grown
EmB2	5810	6543	3684	4550
FmA1	5287	6967	4447	4862
FmB2	4864	6517	Not grown	3993
FmC2	4040	Not grown	Not grown	Not grown
Average	4092	4796	2417	3617

1.6.3 *Estimation of cost of land degradation*: The annual losses of nutrients through soil erosion estimated for each soil unit and the entire watershed are presented in Table 7. The total annual soil-nutrient loss due to erosion from the entire watershed as a whole was 72945 kg, with a value of Rs 61294. The annual soil organic matter loss for the watershed was 70302 kg, worth of Rs 35151. The total loss of nitrogen from the watershed was 384 kg, worth of Rs 4005. Total annual loss of phosphorus estimated was 61.49 kg, worth of Rs 984. The total annual potash loss estimated was 1890.55 kg worth of Rs 15124.Apart from macronutrients loss of micronutrients also estimated and given in the Table 7.

Table 7. Estimation of annual loss of major soil nutrients due to soil erosion

Particulars		Quantity (Kg)	Value(Rs)
Organic matter, kg	ha^{-1}	127	64
	Total	70302	35151
Nitrogen, kg	ha^{-1}	0.69	7
	Total	384	4005
Phosphorus, kg	ha^{-1}	0.11	2
	Total	61	984
Potash, kg	ha^{-1}	3	27
	Total	1891	15124
Iron, kg	ha^{-1}	0.11	4
	Total	63	2080
Manganese, kg	ha^{-1}	0.4	6
	Total	220.38	3252
Copper, kg	ha^{-1}	0.03	0.5
	Total	19	278
Zinc, kg	ha^{-1}	0.01	0.76
	Total	4	419

1.6.4 *Estimating the Cost of Misapplication of fertiliser nutrients*: The estimated cost of fertilizer misapplication for sorghum cultivation in Nalatwad microwatershed is given in Table 8. In sorghum cultivation the present level of fertilizer use by the farmers is 21.8 kg/ha of N, 21.7 kg/ha of P and 1.06 of K kg/ha. The fertilizer requirement based on soil test was assessed for sorghum (81.3, 46.8 and 30.5 kg of N, P, K, respectively) and compared with regional recommendation (65, 40 and 40 kg of N, P, K, respectively). The difference between the regional

Table 8. Misapplication of soil nutrients

Particulars	Fertilizers misapplication (kg/ha) by following blanket recommendation		
	N	P	K
Average quantity (kg/ha)	-16.2	-8.4	10.0
Average Value (Rs/ha)	-169.5	-134.4	142.7
Total quantity in kg	-8980.9	-4641.1	5510.3
Total value in Rs	-93671.2	-74258.2	78853.0

N=Nitrogen, P=Phosphorus= Potash, (-) indicates deficit application (+) indicates excess application

recommendation and soil test based fertilizer requirement is arrived as misapplication. If extension agencies recommend blanket regional recommendation of fertilizer application (65, 40 and 40 kg/ha of NPK) without considering soil fertility status, there is likely to lesser application of nitrogen (-16.2 kg/ha) and phosphorus (-8.4 kg/ha) and excess application of potash (+10 kg/ha) in sorghum cultivation. The per hectare value of misapplication in nitrogen is Rs. 169, phosphorus Rs. 134 and potash Rs.142. If extension agencies use soil fertility information for prescribing fertilizer, there is possibility to avoid this kind of misapplication. The per hectare/ farm soil testing cost worked out to Rs 100/ which is less than the per hectare fertilizer misapplication cost of Rs 446 for NPK.

1.6.5 Optimum Land-Use Plans for Nalatwad micro watershed

Present cropping and input-use pattern: In the existing cropping pattern in Nalatwad watershed the farm households were growing sorghum (406 ha), sunflower (88 ha), wheat (17 ha), bengal gram (29 ha) and pearl millet (5 ha), which accounted for 74, 16, 3, 5 and less than 1 per cent, respectively, of the total cultivated area of the watershed (553 ha).

The data collected from the watershed farmers were analysed using linear programming technique to draw inferences on the multiple objectives (nine) set forth in the study. The results of the analysis are presented in Table 9 in the form of normative land-use plans for the watershed. Table 10 gives data on input use and net income under the different models.

Table 9. Normative land-use plans for Nalatwad watershed

Plan type	Crop	Soil series A	Soil series B	Soil series C	Soil series D	Soil series E	Soil series F	Total area, ha
Model I Maximization of net income	Sorghum	56.93	56.12	81.61	79.15	37.16	179.71	490.68
	Sunflower	Not suitable	0	Not suitable	Not suitable	0	55.00	55.00
	Wheat	0	0	0	0	0	7.00	7.00
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model II Minimization of cost	Sorghum	56.93	56.12	74.61	79.15	37.16	241.71	545.68
	Wheat	0	0	7.00	7.00	0	0	7.00
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model III Minimization of bullock labour	Sorghum	0	0	0	79.15	0	140.85	220.00
	Sunflower	Not suitable	0	Not suitable	Not suitable	37.16	0	37.16
	Wheat	0	0	81.61	0	0	0	81.61
	Bengal gram	56.93	56.12	0	Not suitable	Not suitable	100.86	213.91
	Total	56.93	56.12	81.61	79.51	37.16	241.71	552.68

Plan type	Crop	Soil series A	Soil series B	Soil series C	Soil series D	Soil series E	Soil series F	Total area, ha
Model IV Minimization of men labour	Sorghum	0	0	0	79.15	37.16	103.69	220.00
	Sunflower	Not suitable	0	Not suitable	Not suitable	0	55.00	55.00
	Wheat	0	56.12	81.61	0	0	0	137.73
	Bengal gram	56.93	0	0	Not suitable	Not suitable	83.02	139.95
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model V Minimization of women labour	Sorghum	56.93	49.12	81.61	79.15	37.10	241.71	545.68
	Wheat	0	7.00	0	0	0	0	7.00
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model VI Maximization of FYM	Sorghum	0	0	81.61	79.15	37.16	22.08	220.00
	Sunflower	Not suitable	55.00	Not suitable	Not suitable	0	0	55.00
	Wheat	56.93	1.12	0	0	0	0	58.05
	Bengal gram	0	0	0	Not suitable	Not suitable	219.63	219.63
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model VII Minimization of nitrogen	Sorghum	0	0	81.61	79.15	37.16	22.08	220.00
	Sunflower	Not suitable	55.00	Not suitable	Not suitable	0	0	55.00
	Wheat	56.93	1.12	0	0	0	219.63	277.68
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model VIII Minimization of phosphorus	Sorghum	56.93	0	46.76	79.15	37.16	0	220.00
	Wheat	0	56.12	34.85	0	0	241.71	332.68
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68
Model IX Minimization of potash	Sorghum	56.93	56.12	81.61	79.15	0	241.71	515.52
	Wheat	0	0	0	0	37.16	0	37.16
	Total	56.93	56.12	81.61	79.15	37.16	241.71	552.68

Table 10. Per hectare input use and net income in different models

Item	Existing	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII	Model VIII	Model IX
Total men labour (md)	6.4	9.1	8.0	7.1	6.4	9.4	7.5	8.2	7.8	9.5
Total women labour (wd)	27.1	25.4	29.7	33.1	32.8	23.8	33.1	31.7	30.7	25.2
Total bullock labour (pd)	8.5	11.5	9.4	1.1	8.7	11.4	8.8	9.4	9.6	8.2
Total FYM (ql)	21.1	19.3	17.7	20.0	20.7	19.4	21.6	19.3	17.5	18.8
Total nitrogen (kg)	20.2	24.0	16.7	22.0	21.2	24.7	20.5	15.6	16.7	24.1
Total phosphorus (kg)	23.1	24.2	22.1	24.5	22.4	24.2	23.9	21.7	21.1	24.4
Total potash (kg)	0.5	0.4	1.7	1.5	1.8	0.2	2.3	1.4	1.6	0.0
Total cost (Rs)	4452.3	3864.1	3600.4	3965.7	3909.6	3808.9	4139.6	3760.3	3612.8	3789.8
Net returns (Rs)	2921.3	4515.5	3592.5	3888.2	3968.0	4286.0	3934.5	3942.0	3819.2	4176.1

Model I: maximization of net income

The optimum plan under maximization of net income as objective recommended cultivation of sorghum on a larger area of 490.68 ha, on different soil units of all the series. The area recommended for sorghum on series A was 56.93 ha, on B 56.12 ha, on C 81.61 ha, on D 79.15 ha, on E 37.16 ha and on F 179.17 ha (Table 9). From table 10 it can be seen that the recommended cropping pattern under this optimization model would enable the farmers to realize a net income of Rs 4515 ha^{-1}, which in turn would require a cost of Rs 3864 ha^{-1} for the purpose of input purchase.

Model II: minimization of cost

The optimum plan with minimization of cost as objective did not recommend changes in the area under sorghum on soil series A, B, D and E. However, the decrease recommended in sorghum area on soil series C by 7 ha has been transferred to wheat, while the entire area of 55 ha under sunflower on series F has been recommended to be under sorghum. This optimization model with cost minimization as main focus allotted 545 ha under sorghum and, 7 ha under wheat with no area under sunflower or bengalgram (Table 9). This cropping pattern under cost-minimization objective would provide a net income of Rs 3592 ha^{-1} (lower than that under maximization of income) with a cost of Rs 3600 ha^{-1} (Table 10).

Similarly when the objectives are minimization of bullock, men or women labour, use of nitrogen, phosphorous, potash and maximization of FYM, the optimum land-use plans call for significant changes in the crops and area on the six soil series (Table 9). Obviously, these will be reflected in the level of net income and cost associated with the types of crop grown (Table 10).

All nine optimization models clearly recommend larger area under cereals, particularly sorghum, as farmers of Nalatwad watershed are presently following subsistence agriculture, that is, self-dependence for food requirement from their own farm land. The optimum land use plans clearly demonstrate the potential to increase the per hectare net income compared to existing situation (Table 10).

All the optimum models are superior in terms of net income ha^{-1} as well as total cash needs compared to existing situation. Farmers can choose any of the models according to their goals. The results of linear programming demonstrate that if farmers choose to implement land use plan suggested in model-I (maximization of net income) it can increase their existing net income of Rs 2921 ha^{-1} to Rs 4515 ha^{-1} with an increase of Rs 1594 ha^{-1}.

REFERENCES

Dixon, J.A. and Hufschmidt M.M. (1986). *Economic Valuation Techniques for the Environment: A Case Study Workbook.* Environment and Policy Institute, East-West Center, Honolulu HI, U.S.A.

Dixon J.A., Scura L.F., Carpenter R.A. and Sherman P.B. (1994). *Economic Analysis of the Environmental Impacts.* Earthscan Publications Ltd, London, U.K.

FAO (1976). *A framework for land evaluation.* Soils Bulletin 32. FAO, Rome.

FAO (1991). *Guidelines on land evaluation for extensive grazing.* FAO Soils Bulletin n. 58. Rome.

FAO (1993). *Guidelines for land-use planning.* FAO Development Series 1. FAO, Rome.

FAO (1993). *Guidelines for land use planning*. Rome.

FAO (1995). *Planning for a sustainable use of land resources. Towards a new approach.* Rome.

FAO (1996). *Agro-ecological zoning – Guidelines.* Soils Bulletin 73. FAO, Rome.

Hufschmidt M.M., James D.E., Meister A.D., Bower B.T. and Dixon J.A. (1983). *Environment, Natural Systems, and Development: An Evaluation Guide.* Environmental Policy Program, East-West Center, Honolulu HI, U.S.A.

Ramesh Kumar, S.C., Krishnan, P., Velayutham, M. and Gajbhiye, K.S. (2002). Economic land evaluation for sustainable land management of watershed in different agro-clmatic zones of Karnataka. Volume - I (Summary report) and Vol -II (Database) NBSS&LUP Technical Report no.582, NBSS&LUP, Nagpur.

Rossiter, D.G. (1995). Economic land evaluation: why and how. *Soil Use and Management* **11**: 132–140.

Sys, C., Van Ranst, E. & Debaveye, J. (1991a). *Land evaluation. Part 1: Principles in land evaluation and crop production calculations*. Agricultural publications 7,1. General Administration of Development Cooperation of Belgium, Brussels. 273 p

Takkar, P.N., Chhibha, I.M. and Mehta, S.K. (1990). *Twenty years of coordinated research on micronutrients in soils and plants*, Bulletin 1, Indian Institute of Soil Science, pp 1-313.

Veerabhadraiah, A.M., Thippeswamy, Narasimha Reddy P.N. and Siddaramappa R. (2001). Status of Soil Testing and Fertilizer Recommendations in Karnataka. (In) A. Subba Rao and San-jay Srivastava (Eds.). *Soil Test Based Fertilizer Recommendations for Targeted Yields of Crops*. All India Coordinated Research Project for Investigations on Soil Test Crop Response Correlation, Indian Institute of Soil Science, Bhopal. pp. 238–266.

Causes, Assessment and Control of Land Degradation for Effective Land Use Planning

Dipak Sarkar, Ex-Director
ICAR-National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

Land degradation and the associated loss of soil productivity and quality are of great concern both from food production perspective and environmental conservation. Global land degradation status reveal that about 2 billion hectares in the world is affected by various forms of human induced land degradation with erosion by water being the chief contributor, followed by wind erosion, chemical degradation and physical degradation. Land degradation is steadily increasing due to the growing pressure on land and unsustainable land use in India. The revised estimate on land degradation in India is 120.72 m ha, of which land degradation due to water erosion is the most widespread; the extent of the area affected is to the tune of 82.5 m ha. Data revealed that nearly 8.4 m ha of the irrigated lands in India are affected by soil salinity and alkalinity; of which about 5.5 mha suffers from waterlogging. The present article reports the impact of land degradation on agricultural productivity in the country and also discusses various strategies/effective technologies for mitigating land degradation towards efficient land use planning.

1. INTRODUCTION

The term "land", in land evaluation and land use planning, etc., has a wider meaning than just soil. It refers to all natural resources, which contribute to agricultural production, including livestock production and forestry. Land thus covers climate and water resources, landform, soils and vegetation, including both grassland resources and forests (FAO, 1976; UNEP, 1992b).The way and extent to which land resources are utilized decide the socio-economic development of a country. Hence, proper utilization of the land resource according to its use potential is important not only for producing food materials (cereals, fruits and vegetables) but also for developing industrial sector, transport and communication network, and other social needs and public amenities. Improper use of land should be avoided since it may lead to a considerable wastage and progressive decline in production and productivity.

The Green Revolution in mid sixties ensured food security in the developing world through adoption of novel seed and production technologies. However, indiscriminate exploitation of natural resources with least regard to their carrying capacity and non-judicious use of agricultural chemicals are the factors responsible for post-green revolution problems. Degradation of land and water resources, loss of plant biodiversity, shift of agricultural land for non-agricultural uses, environmental pollution and resultant climate change are the important post-green revolution consequences leading to fatigue in agricultural production thereby threatening food security (Paroda, 2003).

India with geographical area of 329 M ha, constitutes 2.3 per cent of world's land resources supporting about 17 per cent human population and 15 per cent livestock population, 4.2 per cent of water resources, 1 per cent of forests and 0.5 per cent of pastures. The net cultivated area of about 140 M ha has remained static for about last three decades, and many prime farm lands are being diverted to non-agricultural purposes such as industries, mining and urbanization, etc (Yadav and Sarkar, 2009). It is also a matter of serious concern that about 43 M ha is not available for cultivation, of which about 6 per cent is barren and unculturable land and about 8 per cent is used for non-agricultural practices which also is on the increasing trend GOI (2011), Sarkar *et al* (2009).

Agricultural production in India has increased through green renaissance, growing high-yielding varieties of crops and adopting scientifically improved soil fertility management, water management, plant protection and crop husbandry technologies during the past three decades (Basu 2012). Because of such integrated approach, we have been able to increase the agricultural production manifold, particularly in case of food grain crops from about 82 million tons in 1960-61 to about 255 Mt currently (http:// www.icar.org.in).

Notwithstanding such impressive developments, food grain demand is estimated to increase to about 300 Mt by 2025 with a projected decrease in *per capita* land availability to about 0.10 ha from 0.14 ha at present (ICAR 2008). Further the target has to be achieved against several constraints viz. soil health deterioration (soil erosion, depletion of soil organic matter, soil nutrient mining, soil acidity/salinity, soil contamination by As, Se etc.), shrinking water resources, climate change affecting mostly the marginal and small farmers constituting about 80 per cent of the Indian farming community and unabated land degradation (ICAR & NAAS 2010; Rawat 2012).

Therefore, considering all such factors and also in view of present global crisis on food, progressive conversion of good lands for non-agricultural uses, unabated land degradation, proper conservation of land resources is of paramount importance for maintaining the much needed tempo of growth in agricultural production.

2. LAND DEGRADATION

Soil erosion and land degradation are among the glaring environmental problems posing a big threat to the natural resources adversely affecting soil productivity (Singh 2008). "Land degradation" refers to a temporary or permanent decline in the productive capacity of the land (UNEP, 1992b). It covers various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of rangelands and is one of the most important global issues for the 21st century because of its adverse impact on agronomic productivity, environment, security and overall quality of life.

Principal processes of land degradation include erosion by water and wind, chemical degradation (comprising acidification, salinization and nutrient loss, waterlogging, leaching etc.) and physical degradation (crusting, compaction, hard pan setting etc.). Some lands or landscape units are affected by more than one process, of water and wind erosion, salinization, and crusting or compaction. Other types of degradation includes deforestation, rangeland degradation, acid sulphate formation, soil contamination, soil destruction through mining and quarrying activities, urban and industrial encroachment onto agricultural land, potential effects of global climatic change etc.

Estimate suggests that about 2 billion hectares of land in the world is affected by various forms of human induced land degradation with erosion by water being the chief contributor (1.1 billion hectares), followed by wind erosion (0.55 billion hectares), chemical

Table 1. Harmonized area statistics of degraded lands/ wastelands of India (Mha)

S. No.	Type of degradation	Arable land (Mha)	Open forest (<40% canopy) (Mha)
1.	Water erosion (>10 t ha^{-1} yr^{-1})	73.27	9.30
2.	Wind erosion (Aeolian)	12.40	-
	Sub-total	85.67	9.30
3.	Chemical degradation		
	a) Exclusively salt-affected soils	5.44	-
	b) Salt-affected and water-eroded soils	1.20	0.10
	c) Exclusively acidic soils (pH <5.5)	5.09	-
	d) Acidic (pH <5.5) and water-eroded soils	5.72	7.13
	Sub-total	17.45	7.23
4.	Physical degradation		
	a) Mining and industrial waste	0.19	-
	b) Water-logging (permanent) (water table within 2 m depth)	0.88	-
	Sub-total	1.07	-
	Total	104.19	16.53
	Grand total (arable land and open forest)	120.72	

Source: ICAR & NAAS (2010)

degradation (0.24 billion hectares) and physical degradation (0.08 billion hectares) (Oldeman, 1991, 1994). About 5-7 million hectares of arable land of the world is lost annually through land degradation (Lal and Stewart, 1990). The latest figure for land degradation in India is about 121 m ha of which water erosion alone accounts for about 68 per cent followed by chemical degradation (20.5 per cent), wind erosion (10.3 per cent) and physical degradation (0.9 per cent) (Table 1) (ICAR & NAAS, 2010).

Desertification, a form of land degradation occurring particularly in arid, semi-arid and dry sub-humid areas, resulting from various factors including climatic variations and human activities (UNCED, 1992), is experienced on 33 per cent of the global land surface and affects about more than one billion people. In India, about 38 per cent of the total land area is vulnerable to moderate to very high degree of desertification. (Eswaran *et al*., 2001).

2.1 Causes and consequences of land degradation

The driving energy for land degradation include population and poverty, climate change and natural disasters, globalization of agriculture, overgrazing and livestock and inappropriate land use and management resulting in acidification, nutrient stock depletion, soil organic carbon depletion, salinity and sodicity, truncation of surface horizon, sand dune reactivation, densification of sub-soils etc. Degradation of land is a consequence of either natural hazards or direct causes or underlying causes. Natural hazards are the environmental conditions which lead to high susceptibility to erosion such as high intensity storms , soils having less resistance to water erosion, high speed winds, soil fertility decline due to strong leaching in humid climate, acidity or loss of nutrients, water logging etc. The direct causes are human induced which result from unsustainable land use and inappropriate land management practices such as deforestation, overgrazing, cultivation on steep slopes and marginal/fragile lands without adoption of soil conservation measures, shifting cultivation, improper crop rotations, imbalanced fertilizer use or excessive use of agro-chemicals, over-exploitation of ground water and improper management of canal water.

2.2 Land degradation and its impact on agricultural productivity

The land degradation has both on-site and off-site impacts. On-site impacts are lowering of land productivity mainly due to nutrients losses, causing either reduced outputs or increased input needs. India loses nearly 0.8 Mt of nitrogen, 1.8 Mt of phosphorus and 26.3 Mt of potassium annually; constituting 0.2 per cent of total reserves (TERI, 1998).

Off-site effects include changes in water regime, decline in water quality, sedimentation of river bodies and reservoirs, loss of biodiversity and natural disasters like floods and droughts. Besides, irrigated agriculture, especially through canal systems, has resulted in degradation due to water-logging and salinization. It is estimated that nearly 8.4 million hectares of the irrigated lands are affected by soil salinity and alkalinity; of which about 5.5 million hectares is also waterlogged (IDNP, 2002). Impacts of the degradation are more landlessness, lower and less reliable food production, increased labour requirements and lower incomes.

2.2.1 *Soil erosion and its impact upon agriculture and environment:* Soil erosion occurs through surface water flow, high-velocity winds, shifting cultivation and deforestation. About 5,334 Mt of soil is lost annually that works out to over 16 t ha^{-1} (Dhruva Narayana and Ram Babu, 1983). Out of this, 29 per cent is lost permanently, to sea, 10 per cent is deposited in reservoirs decreasing their capacity by 1-2per cent every year, and remaining 61 per cent is again distributed on land (Deb 1995). Among different land resource regions, highest erosion occurs in black soils (24-112 t ha^{-1}) followed by Shiwalik region (80 t/ha), north-eastern region with shifting cultivation (27-40 t ha^{-1}), and the least in North Himalayan Forest region (2 t ha^{-1}) (NAAS 2009). Permissible soil loss in India varies from 2.5 to 12.5 t ha^{-1} yr^{-1} depending upon the soil order and soil depth (Mandal *et al*., 2008). About 70 per cent of land has soil loss tolerance limit of 10 t ha^{-1} yr^{-1} and it has been used for computation of degraded lands in the country covering 120.7 Mha. This analysis has revealed that about 39 per cent area has erosion of more than the permissible rate, thereby resulting in reduced agricultural productivity. About 11 per cent of area falls in very severe category with erosion rates of more than 40 t ha^{-1} yr^{-1}. Some of the states in the north-west and north-east Himalayas are worst affected with more than one third of their geographical area falling in very severe soil loss (40-80 t ha^{-1} yr^{-1}) category (NAAS, 2009) .

The lower Himalayan region has suffered a loss of 1 cm top soil. This has reduced maize-grain productivity by 76 kg ha^{-1} and that of maize-straw 236 kg ha^{-1} (Khybri *et al*., 1988). Maize grain productivity, on an average, decreased from 3.7 to 1.3 t with 30 cm removal of top soil (65 per cent reduction over control). In Alfisols, yield losses were 138, 84 and 51 kg ha^{-1} for sorghum, pearl millet and castor bean for every cm of loss of top soil (Vittal *et al*., 1990). Yadav *et al.* (1983) observed crop productivity losses on soils having different degrees (slight, moderate and strong) of erosion by water within 10, 10-35 and 60-75 per cent from the model yields. Sorghum suffered the most, followed by soybean and pigeon pea, with cotton being least affected.

2.3 Irrigation induced land degradation

Irrigation is a precondition for stable crop production in areas characterized by marked variability in rainfall distribution Secondary salinity results from human activities such as irrigation and land clearing in areas that are not irrigated (dry land salinity) (Ghossemi *et al.,* 1995). Both primary and secondary salinity affect plant growth by causing dehydration. Further soil salinity degrades land by making it unsuitable for agriculture. It changes the water potential and osmotic pressure within the soil itself, which makes it more difficult for roots to be in the position to take up water leading to development of alkalinity.

Irrigated agriculture, especially through canal systems, has resulted in degradation due to water-logging and salinization. It is estimated that nearly 8.4 Mha of the irrigated lands are affected by soil salinity and alkalinity; of which about 5.5 Mha is also waterlogged (IDNP, 2002). The development of salinization and water logging on the large-scale canal irrigation schemes of the Indo-Gangetic plains has been frequently reported where salinity-induced land degradation has increased steadily with concurrent reductions in agricultural productivity and sustainability Application of water in excess of natural rainfall has led to progressive rise in the water table and reaching close to the surface. Waterlogging led to salinization through evaporation processes leaving salt on the surface.

2.4 Mitigating Land degradation

Broadly, two-pronged strategies are needed to prevent land degradation and to bring water and wind erosions within permissible limits for sustained productivity. First is proper assessment of the degree, type, extent and severity of soil erosion and its effect on production and nutrient losses. The second is to check and reverse process of land degradation through appropriate technologies and conservation measures viz. integrated water management, integrated nutrient management, precision agriculture (site specific nutrient management), diversification of agriculture, conservation agriculture, gene mining for drought avoidance, inclusion of legumes in crop calendar, silvipasture and silviculture based agriculture agro-forestry etc.

2.5 Strategies for Arresting Land Degradation

For solving very complex problem like degradation, which has cascading effect on natural resources and mankind, a holistic approach is needed. The essence of holistic approach is the selection of right type of cultivars and appropriate technologies at right place depending on the specificity of problem. Execution of the programme may be done at appropriate scale. It may be at watershed, district or region depending on problem and client requirement. Use of GPS, RS, GIS and decision support system may be very handy for the execution and monitoring of preventing/ correcting land degradation programme.

For evolving effective strategies to check land degradation, it is imperative to assess, characterize and classify different types of degradation problems and develop appropriate technologies to reclaim the degraded areas for their productive utilization. In India, participatory watershed management has been accepted as a tool for all developmental activities with a focus on socio-economic aspects apart from biophysical attributes following ‘bottom up’ participatory approaches. It involves adoption of appropriate resource conserving technologies on arable and non-arable lands for holistic development of rainfed areas and wastelands for sustained productivity and environmental security.

The following issues need to be addressed on high priority for efficient management of natural resources (Sharda, 2011),

Generation of natural resource database [specially on landform, soil, water, climate, biota (vegetation) etc] and precise delineation of degraded Lands using geospatial techniques (RS, GPS & GIS).

For sustainable land use management, methodologies need to be developed for optimal land use planning at different scales using modern tools and procedures.

There is a need to develop and evaluate integrated farming systems in different agroecological regions of the country to maximize productivity and profitability, input use efficiency, cropping intensity, resource conservation, employment generation, environmental security and poverty alleviation. It would encompass optimal combination of various enterprises, viz; agriculture, horticulture, livestock, fishery, forestry etc. for different categories of farmers and farming situations to achieve efficient utilization of land and water resources and prevent over exploitation of land.

For productive utilization of degraded lands, location specific alternate land use systems, viz; agri-horti, horti-pastoral, agri-horti-silvi, agri-silvi-medicinal and silvipastoral need to be developed for scientific planning of land resources following watershed approach.

Soil quality deterioration is attributed to wide gap between nutrient demand and supply, imbalanced fertilizer use and emerging deficiencies of secondary and micronutrients in soils. The nutrient-use efficiency can be increased by integrating and balancing the nutrient dose in relation to nutrient status and crop requirements to achieve higher partial and total productivity. Soil health cards should be prepared based upon geo-referenced soil nutrient mapping depicting fertility status of agricultural lands for input based land use planning.

The problem soils such as saline and alkali soils should be managed by leaching of excess salts, improving drainage systems, application of gypsum, growing green manures or mulches and tolerant crops and trees as per packages developed and recommended by research organizations. Judicious liming should be practiced for ameliorating soil acidity.

Soils polluted by heavy metals or toxic substances and excessive use of agrochemicals can be ameliorated through phytoremediation and/ or bioremediation, and growing resistant crops.

To prevent land degradation, conservation agriculture should be promoted to ensure minimum disturbance to the soil, provide permanent cover to the land surface and select appropriate cropping systems and rotation to achieve higher profitability and environmental security. It would include zero-tillage, residue management, mulching, cover crops and various soil and water conservation measures.

Soil management practices like residue incorporation, manuring, reduced tillage and mulching play a vital role in sequestering carbon in the soil and check CO_2 emissions. Reclamation of degraded soils and ecosystems following watershed approach can enhance the terrestrial C pool, microbial population and soils net C sinks for higher and sustained productivity.

Suitable soil quality indicators need to be developed to sustain hydrological, biological and production functions of the soil and to prevent deterioration of land resource due to physical, chemical and biological factors.

Enabling policy framework is essentially required by enacting suitable legislations to provide remediation of damaged soils, trans-boundary impact of pollution and cost of land degradation to tax-payers. The polluters must pay for abuse of the land resource through dumping of industrial or domestic wastes, irrigation with poor quality water, excessive use of agro-chemicals; intensive use and over-exploitation of land especially the marginal and fragile ecosystems and non-adoption of appropriate conservation measures during mining and related activities.

3. Way Forward

- Generating authentic inventory of land resources based on nationally accepted reliable methodologies.
- Periodic monitoring of soil health.
- Timely adoption of corrective measures according

to local site and socio-economic conditions.

- Preventive measures for soil degradation through adoption of technically sound, economically viable and eco-friendly practices.
- Balanced, adequate and timely application of nutrients in site-specific mode, with minimum use of chemicals.
- Enhancement of nutrient-use efficiency with higher factor productivity.
- Soil Nutrient Mapping towards Site-Specific Nutrient Management (SSNM) .This is a step forward towards precision agriculture.
- Development of suitable models to predict adverse changes in soil health consequent to land uses, management techniques, climate changes and strategies for mitigation.
- Alternate land use planning in conformity with location-specific biophysical and socio-economic environment based upon land capability, irrigation potential, detailed soil characteristics, agro-ecological set up etc viz. agro-forestry based land use, agro-horti forestry, silviculture, silvi-pasture based agriculture etc.
- Developing land use models incorporating both natural and human-induced factors that contribute to land degradation for land use planning and management.
- Creating mass awareness by conducting appropriate training programmes, demonstrations through participatory approach etc. among the farmers, extension workers, policy makers, administrators, technical personnel and other stakeholders regarding the value of soil health and disastrous damages arising from its misuse eventually leading to land degradation.

4. Conclusion

In the 21st century, agricultural professionals have to play an increasingly important role in crop production for ensuring food security to the teeming millions in the face of widespread land degradation, water scarcity and climate change. This calls for knowledge based management of land resources using latest scientific and technological advancements.

A holistic approach dealing with the selection of right land use at right place in terms of cropping system and /or combination of crops, along with agro techniques viz. alternate land use, intercropping, agro-forestry, agro horticulture, silvipasture, integrated nutrient, water and pest management, conservation tillage, water harvesting, etc. are some of the most viable options for managing degraded land towards optimizing agricultural production.

We are aware that where land remains neglected, people remain poor. We also recognize that land cannot expand. Population is rising and exerting pressure on land beyond its carrying capacity. This results in land degradation of various types – soil erosion through run off and gullying, landslides, soil acidity, water logging, salinity, wind erosion and finally desertification. The land base per person is shrinking posing the challenge of maintaining the soil health while obtaining more and more crop from less and less quantity and quality of the land. So Land Degradation is unacceptable and has to be handled with a very strict hand to sustain our existence.

REFERENCES

Basu, P.K. (2012). *Future of agriculture to be science based.* Convocation Address, Convocation and Prize distribution Ceremony, PAU, Ludhiana, March 1, 2012.

Deb, D.L. (1995). *Natural Resource Management for Sustainable Agriculture and Environment* (Ed), Angkor Publishers Pvt. Ltd., New Delhi.

Dhruvanarayana, V.V. and Ram Babu (1983). Estimation of soil erosion in India. *J. Irrig.Drainage Engg.* **109**:419-34.

Eswaran, H., Lal, R., and Reich, P.F. (2001). Land degradation: An overview. (In): Bridges, E.M., I.D. Hannam, L.R. Oldeman, F.W.T. Pening de Vries, S.J. Scherr, and S. Sompatpanit (Eds.), *Responses to Land Degradation*. Proc. 2nd. International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.

FAO (1976). *A framework for land evaluation*. FAO Soils Bulletin 32. FAO, Rome.

Gajbhiye, K.S. and Sohan Lal (2006). Land Utilization (In): Handbook of Agriculture, 5th Edition, Directorate of Information and Publications of Agriculture, Indian Council of Agricultural Research, New Delhi – 110012.

Ghossemi, F., A. J. Jakerman, and H. A. Nix (1995). *Salinisation of Land and Water Resources,Human Causes, Extent, Management and Case Studies.* Canberra Act 0200: Centre for Resources and Environmental Studies, The Australian National University, Australia.

GOI (2011). *Agricultural Statistics at a Glance*. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi.

ICAR & NAAS (2010). *Degraded and Wastelands of India, Status and Spatial Distribution*, ICAR, New Delhi.

ICAR (2008). From the DG's Desk. News reporter , April-June 2008, pp 1-2.

IDNP (2002). *Recommendations on waterlogging and salinity control based on pilot area drainage research*, p.100. Indo-Dutch Network Project, CSSRI, Karnal, India.

Khybri, M.L., Prasad, S.N. and Sewa Ram. (1988). Effect of top soil removal on the growth and yield of rained maize. *Indian J. Soil Conserv*. **8**:164-69.

Lal, R. and Stewart, B.A. (1990). Soil degradation: A global threat. *Advances in Soil Science* **11:**XIII-XVII.

Mandal, D., Sharda, V.N. and Tiwari, A. (2008). *Soil Loss Tolerance Limits in Planning Conservation Measures in Different Districts of India*, pp. 112. CSWCRTI, Dehra Dun, India.

NAAS (2009). *State of Indian Agriculture.* National Academy of Agricultural Sciences, New Delhi.

Oldeman, L.R. (1991). Global extent of soil degradation, pp.19-35, *Bi-annual Report, ISRIC*, Wageningen, The Netherlands.

Oldeman, L.R. (1994). The global extent of land degradation. In: *Land Resilience and Sustainable Land Use,*eds. D.J. Greenland and I. Szabolcs, 99–118. Wallingford: CABI.

Paroda, R.S. (2003). *Sustaining our food security.* Konark Publishers Limited, Delhi, (India).

Rawat, H. (2012). Developmental programme needed for addressing climate change issues (In): Inaugural address, International Conference on Climate Change, Sustainable Agriculture and Public Leadership, New Delhi, February 07, 2012.

Sarkar, Dipak, Gajbhiye, K.S. and Sohan Lal (2009). Land Utilization (In): Handbook of Agriculture, Sixth (Revised) Edition, Directorate of Information and Publications of Agriculture, Indian Council of Agricultural Research, New Delhi.

Sharda, V.N. (2011) Strategies for arresting land degradation in India (In): Sarkar et al. (Eds) Strategies for Arresting Land Degradation in South Asian Countries, SAARC Agriculture Centre, BARC Complex, Farmgate, Dhaka – 1215, Bangladesh, p. 264.

Singh, A.K. (2008). Soil resource management – Key to food and health security, *Journal of the Indian Society of Soil Science* **56:** 348-357.

TERI (1998). *Looking Back to Think Ahead.* Tata Energy Research Institute New Delhi.

UNCED (1992). Earth Summit '92. The UN Conference on Environment and Development Rio de Janeiro, Brazil.

UNEP. (1992b). Desertification, land degradation [definitions]. Desertification Control Bulletin 21.

Vittal, K.P.R., Vijayalakshmi, K. and Rao, U.M.B. (1990). The effect of cumulative erosion and rainfall on sorghum, pearl millet and castorbean yields under dry farming conditions in Andhra Pradesh, *Experimental Agriculture* **26**:429-39.

Yadav, J.S.P. and Sarkar, D.(2009). Soil Degradation with special reference to India, (In): *Souvenir*, pp. 15-21, Platinum Jubilee Celebration, Indian Society of Soil Science, New Delhi.

Yadav, S.C., Sehgal, J.L. and Vadivelu, S. (1983). UNDP Terminal Tech. Report on Study of Factors of Land Evaluation System, pp. 73-100. NBSS Publ. (unpublished).

Soil Nutrient Mapping in West Bengal for Land Use Planning

Pradip Sen, Former Joint Director (Chemistry)
Government of West Bengal

ABSTRACT

Variations in soil nutrient contents represented in GIS environment provide synoptic view to planners for developing rational nutrient management policies and also aid in decisions making development strategies for integrated nutrient management that would aid in balanced and cost effective fertilizer application. This article reports development of a web and mobile based advisory for West Bengal built using 76000 sample (collected at 1 km interval) database in West Bengal.) A village level database on macro, major and micro nutrient status of soils of the state was developed and mapped. The findings indicate low balance of available potassium in the districts of Puruliya, Bankura, Birbhum, Maldah, Murshidabad, Dakshin Dinajpur and Bardhaman and low balance of available phosphorous in the districts of Puruliya, Bankura, Birbhum, Maldah, Haora, Bardhaman, Paschim Medinipur, Murshidabad, North 24 Parganas and South 24 Paraganas. Available sulphur content was found low in 18.7 per cent and medium in 17.1 per cent area of the state, whereas the problem of available iron, manganese and copper availability was not extensive in West Bengal. The area delineated as deficient in zinc and boron occupied 34.8 and 14.9 per cent area of the state, respectively. The nutrient maps also facilitated in finding the districts with varied combinations of nutrient deficiency for e.g. phosphorous, potassium and boron available the deficiency in Dakshin Dinajpur. Such information combined with recommendations as Site-Specific Nutrient Management (SSNM) is expected to serve as an important link in land use planning.

1. Introduction

Managing soils is a formidable challenge to ensure productivity, profitability and national food security. The United Nations Millennium Development Task Force on hunger made "Soil Health Enhancement" as one of the five recommendations for increasing agricultural productivity and fight hunger in India as a component of Millennium Development Goals (MDGs) (Singh, 2008). Major issues of soil health under Indian context include: i) physical degradation caused by compaction, crusting, water logging and soil erosion, ii) chemical degradation caused by wide nutrient gap between nutrient demand and supply, low and imbalanced fertilizer use, emerging deficiencies of secondary and micro nutrients, poor nutrient use efficiency, soil acidity, salinity and alkalinity, iii) biological degradation due to organic matter depletion and loss of soil fauna and flora, and iv) soil pollution from industrial wastes, excessive use of pesticides and heavy metal contamination (Singh, 2008).

The growing concern about poor soil health and declining factor productivity or nutrient-use efficiency has raised concern on the productive capacity of agricultural systems in India. Major factors contributing to the low and declining crop responses to fertilizer nutrients are (a) continuous nutrient mining due to imbalanced nutrient use, which is leading to depletion of some of the major, secondary, and micro nutrients like P, K, S, Zn, Mn, Fe and B, and (b) mismanagement of irrigation systems leading to serious soil quality degradation. Furthermore, such low efficiency of resources and fertilizer inputs has impacted the production costs with serious environmental consequences (Johnston et al. 2009).

Imbalanced use of fertilizers without understanding the available nutrient balance and crop requirement has already resulted in widespread degradation and depletion of land and environmental quality with ultimate effect on crop yield. Due to intensive agriculture, degradation is more precarious and pronounced in West Bengal, where the increase of soil acidity, contamination of ground water with toxic elements like arsenic, and nutrient imbalance including multi-nutrient deficiencies have been reported. Erosion on Darjiling hills and Chotanagpur plateau together with the problem of soil acidity are the major factors of soil degradation. Recurrent drought in the region of Chotanagpur plateau, devastating flood and salinity in the coastal area further intensified the problems. Intensity of problems is expected to increase in future because of rising human and animal population, lack of education, shrinking per capita availability of land and water resources and ignorance of the farmers about the improved technologies. Predicted change in the climate is another threat to preserving land quality and preventing land degradation.

Intensification of agriculture in the state of West Bengal during last fifty to sixty years has resulted in heavy mining of nutrients and created a number of soil related problems. Excessive use of nitrogenous fertilizers shovels the stock of phosphorus, potassium and other micro-nutrients. The areas under low balance of multi-nutrients have increased out of proportion. The extent and severity of acidity and erosion has increased in the rice bowl alluvial plains of West Bengal. Apart from zinc, the deficiency of micro-nutrients like boron and molybdenum has been reported in many parts of the state. However, low balance of nutrients did not uniformly appear across the state or region. It varied between and within physiographic regions depending upon the geology and land uses. In general, 25 to 60 per cent of the analyzed samples in West Bengal are deficient in zinc, whereas 50 to 90 per cent samples showed boron deficiency. Molybdenum deficiency was observed in 25-50 per cent of the samples. Extent and intensity of the deficiency is high in the eastern plateau and in Tista-Mahananda alluvial plains as compared to other parts of the state. Therefore, the response of crops to the applied fertilizers based on blanket recommendations is not uniform.

The reason for blanket fertilization is perhaps due to inadequate database on available nutrient stock in soils in the site-specific mode, nutrient requirement of the crops and the factors governing the nutrient availability and dynamics under a given set of conditions. Therefore, right fertilizer policy could not be framed for the state that could have ensured the application of fertilizer and ameliorant in the right quantity, at right time and in the right place. Further, consequences of such blanket recommendations pose severe threat to future food security, agricultural sustainability, soil health, inter-generational equity as well as environmental quality.

Site-Specific Nutrient Management (SSNM) based on the soil test value is one of the logical steps to overcome the above problems. It takes into account spatial variations in nutrient status, cutting down the possibilities of overuse or underuse of the costly inputs. A systems approach with well developed analytical framework, database and powerful simulation models aids in further improvement of SSNM.

However, for defining the area of nutrient sufficiency/deficiency, a systematic scientific method of survey is lacking. Soil nutrient mapping based on geo-referenced soil samples, laboratory analysis, database structuring in GIS and subsequent interpolation spun off new dimensions in the field of SSNM. Nutrient sufficiency/deficiency zones of single and multiple nutrients could be prepared by using logical algorithms in GIS. This is one step forward towards practicing precision agriculture in the state of West Bengal. The application of such maps as a fertilizer decision support tool to guide nutrient application in a site-specific mode may open new vista in attaining the maximum fertilizer-use efficiency. Repetitive survey using these maps can give a clear visual indication of the changing fertility scenario at block/ village/ district level on real time scale. The information generated during the course of survey can also be utilized in structuring the farm planning with a view to restricting degradation and depletion of natural resources. The maps can further serve as guide to develop site-specific fertilizer and crop planning with targeted yield. As a matter of fact, this is the much needed information for the well defined farming system of West Bengal.

Value addition in such database could be made possible if fertilizer recommendations for different land uses and crops are made available along with the soil test values. The utility of such database and recommendations is enhanced further if these are directly made available to the farmers residing in the remotest and farthest village of the state. In such context, web and mobile based farmers' advisory which can guide the farmers for effective utilization of inputs by allocating right type of fertilizers, in right quantity, in right combination, at right place, can certainly serve as one of the promising tools for increasing fertilizer-use efficiency. The information is not only useful for the farmers but also for the administrators and planners for formulating appropriate fertilizer policy by allocating right type and amount of fertilizers and/or ameliorant in different parts of the state based on soil test values.

Recently soil nutrient mapping of West Bengal using geoinformatics has been completed on 1:50,000 scale and district wise soil nutrient maps (organic carbon, available N, P, K, S and available Fe, Mn, Zn, Cu, B and Mo) along with soil pH and surface texture maps were generated towards agricultural development and crop planning of the state. Such information are useful for developing fertilizer recommendations for important crops of the region accounting for the factors affecting the nutrient status and dynamics in soils as well as developing farmers' advisory based on web server and mobile cell phone for fertilizer and crop planning.

2. West Bengal: Generalities

West Bengal, lying between 21°33′ to 27°14′ N latitude and 86°35′ to 89°53′ E longitude, is one of the most important agriculturally developed states in the country. It stretches from Himalayas in the north to the Bay of Bengal in the South; Assam, Sikkim and Bhutan in the northeast, and Odisha in the Southwest. The state of Jharkhand bounds the western border. The entire stretch of eastern part is bounded by Bangladesh. The state covers an area of 8.87 M ha representing 2.7 % of the total geographical area (TGA) of the country and produces food, fibre and timber for 7.77 per cent of the country's population. The state is administered through three divisions, Barddhaman, Presidency and Jalpaiguri and has eighteen districts. The state capital, Kolkata is a premier city with a population of more than ten millions.

Physiographically, the state is divided into three broad regions viz. Eastern Himalaya (in the north), Eastern plateau and Indo-Gangetic plains. The Eastern Himalaya in the north, comprises the mountainous terrain of Darjiling (except Siliguri sub-division) and northern fringes of Jalpaiguri district.Eastern plateau or Chotanagpur plateau-a tertiary and post tertiary peneplain surface in the west and south-west, encompasses western part of Barddhaman, Paschim Medinipur, Bankura, Birbhum and whole of Puruliya district. Indo-Gangetic alluvial plain is the other physiographic region, which is further sub-divided into Tista-Mahananda alluvial plains covering Jalpaiguri, Koch Behar, north and south Dinajpur and Maldah district; Bengal basin including Murshidabad, Nadia, Hugli, eastern part of Barddhaman, Birbhum, Bankura, Purba Medinipur, North 24 Parganas and South 24 Parganas excepting coastal areas of Sundarbans and south eastern part of Purba Medinipur district and coastal areas of North 24 Parganas and South 24 Parganas. Each physiographic region shows different types of soil related constraints. The problem of severe erosion on high hill slopes is very extensive; whereas acidity related problem is very common in Tista-Mahananda alluvial plains. Nutrient deficiency, poor soil fertility and soil acidity are the major constraints in Eastern Plateau. Drainage congestion in low lying area in Bengal basin; salinity, acidity and water logging in the coastal plains are the major bottlenecks for agriculture in the state.

The state exhibits very distinct climatic variations. It is per-humid in the Eastern Himalaya, humid to sub-humid in the Tista alluvial plains (*Terai* and *Dooars*), moist sub-humid in the Indo-Gangetic and Deltaic plain and dry sub-humid in the western part of the state. The rainfall varies from 1300 mm in the rainfed zones of western part to 3500 mm or more in the Himalayan region. The main seasons are summer, rainy season, a short autumn, and winter. Summer season in the delta region is noted for excessive humidity; the western highlands experience a dry summer. Monsoons bring rain to the whole state from June to September. Winter (December–January) is mild over the plains. However, the Darjiling hill region experiences a harsh winter with occasional snowfall at places.

Agriculture is the primary occupation of nearly two third of the working population in the state. The net cropped area is about 54.63 lakh hectare, representing 62 per cent of the area of the state. The gross cropped area is about 97 lakh hectare indicating cropping intensity of 170 per cent. In the kharif season, 90 per cent of the cropped area is under rice and the remaining area is cultivated for Jute, vegetables, maize, sugarcane, pulses and oil seeds.

The cropping system in the state is diversified depending upon the soil type, climate, water resources and socio-economic conditions. The northern hilly regions are dominantly under tea and other plantations such as orange, pineapple, citrus, pear and plum. Field crops in the region include potato, maize, winter vegetables, rice and wheat. The *Terai* region is mostly under tropical horticultural crops, such as jackfruit, mango, betel-nut, pineapple and root crops. The common cropping patterns are Jute-rice-wheat, rice-rice (short duration)-pulses, vegetables-oilseeds (mustard). Important cash crops like tobacco are grown in the upper alluvial region. The western plateau, dominantly lateritic in nature is under rice-potato, pulses-mustard (under irrigated agriculture) and maize/sorghum, pulses/groundnut (under rainfed agriculture). Rice-potato and rice-vegetables are the dominant cropping sequences of the Bengal basin.

The area and production of all principal crops increased manifold from 1947-48 to 2009-10. During the period, the area for rice and wheat increased by 43 and 900 per cent, respectively. The production of rice increased by 308 per cent. Similarly, production of wheat has gone up manifold. Area under potato increased from 0.31 to 3.87 lakh hectares and production has increased from 2.71 to 138.38 lakh tonnes. The area and production of jute also went up from 1.08 to 6.14 lakh hectares and from 6.54 to 93.25 lakh bales respectively. Before independence, during 1938-39, the number of tea growing estates of West Bengal was 316, which increased to 453 in 2009-10. Area and production were 82,120.15 hectares and 49.57 lakh kg, respectively in 1938-39 which increased to 1,15,100 hectare and 2,233.33 lakh kg, respectively in the year 2009-10 (Banerjee *et al.* 2013).

3. Soil Nutrient Mapping Programme - the Approach and Methodology

The steps involved in nutrient mapping programme are base map preparation, soil sampling, laboratory analysis, database preparation, development of thematic maps of soil nutrients (macro, major and micro), organic carbon, soil acidity and surface soil texture, identification of the area having more than one nutritional problem, and finally issuing web and mobile based farmers advisory.

3.1 Base Map

For sampling, grids on one km interval were organized on the base map of 1:50,000 scale using Survey of India toposheets for each district. Total 76000 sample grid points have been located in the state and marked on the toposheet for collection. Number of samples collected in the different districts is shown in Table 1. The highest number of samples (6329) has been collected from Barddhaman district and the lowest number of sample (1187) from Haora district.

3.2 Soil sampling and laboratory analysis

Soil samples from 0-25 cm depths at each grid point along with the information on land use and management practices were collected simultaneously. Four additional soil samples were also collected about 200 m apart around each grid point (Fig. 1).

Table 1. Number of samples collected in the different districts of West Bengal

Sl.No.	District	No of samples
	Barddhaman	6329
	Birbhum	4276
	Hugli	2873
	Howrah	1187
	Nadia	3228
	North 24-Parganas	2911
	South 24-Parganas	4018
	Darjiling	1733
	Jalpaiguri	3590
	Koch Behar	2761
	Uttar Dinajpur	2281
	Dakshin Dinajpur	1766
	Maldah	3202
	Murshidabad	4625
	Purba Medinipur	3489
	Paschim Medinipur	5322
	Bankura	6240
	Puruliya	5863

Thus total five samples were mixed thoroughly to have one composite sample for subsequent laboratory analysis. The collected samples were analyzed for soil pH, organic carbon, available nitrogen, phosphorus, potassium and sulphur, DTPA extractable iron, manganese, zinc, copper, available boron and molybdenum . The soil texture was determined in the field by feel method. The methods used for the analysis of soil samples are shown in Table 2.

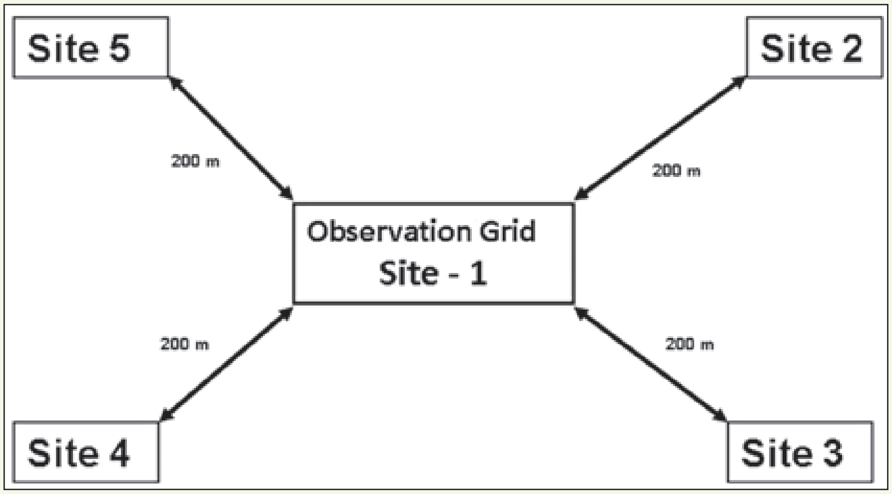


Fig.1. Sampling scheme for collecting the composite soil samples in West Bengal

Table 2: Methods used for analysis of soil samples

Parameters	Methods	References
pH, EC	1:2.5 (soil:water)	Jackson (1973)
Organic Carbon	Wet digestion (1N $K_2Cr_2O_7$)	Walkley & Black. (1934)
Available N	Alkaline $KMnO_4$ Extractable -N	Subbaiah & Asija (1956)
Olsen P	$NaHCO_3$ extractable P (pH 8.5)	Olsen et al. (1954)
Bray P	NH_4F extractable P	Bray et al. (1945)
Available K	NH_4OAc extractable K	Jackson (1973)
Available S	0.15% $CaCl_2$ extractable S	Williams & Stienbergs (1969)
Available B	Hot water extractable B	Berger & Truog (1939)
Available Mo	Ammonium oxalate (pH 8.3) extractable Mo	Grig (1953)
Av. Fe, Mn, Zn, Cu	DTPA extractable	Lindsay & Norvel (1978)

3.3 Organization of database in GIS

Relational database was prepared in Arc-info GIS environment. Districtwise soil nutrient status maps on 1:50,000 scales were prepared using Inverse Weighted Distance method of Interpolation.

The database consisting of macro, major and micro-nutrients, texture, organic carbon and pH for each grid point is developed in ARC GIS version 9.2. The database has location co-ordinates of each geo-referenced sampling point (latitude and longitude), and also the name of village, block and district. The same is also structured in EXCEL format for statistical analysis. A part of the database of Hugli district is shown in Table 3. Macro, major and micro nutrients analyzed for each grid point are ranked as low, medium and high; micro-nutrients as sufficient and deficient; and pH class from strongly acidic to alkaline based on the scheme given in Tables 4a-d (Govt. of West Bengal, 2005).

Table 3. Part of soil database of Hugli district in GIS

ID	Longitude	Latitude	Topo No.	Grid No.	Dist. Name	Block Name	pH	OC (%)	N ($kg ha^{-1}$)
11916	87.6813	22.99145	73N/9	19	Hugli	Goghat II	4.6	0.24	197
11918	87.7009	22.99145	73N/9	21	Hugli	Goghat II	5.4	0.37	205
11919	87.7107	22.99145	73N/9	22	Hugli	Goghat II	5.1	0.75	592
11920	87.7205	22.99145	73N/9	23	Hugli	Goghat II	5.3	0.91	675
11921	87.7303	22.99145	73N/9	24	Hugli	Goghat II	5.5	0.73	586
11939	87.6519	22.98245	73N/9	42	Hugli	Goghat II	4.5	0.53	366
11940	87.6617	22.98245	73N/9	43	Hugli	Goghat II	4.8	0.69	421
11941	87.6715	22.98245	73N/9	44	Hugli	Goghat II	4.8	0.56	335
11942	87.6813	22.98245	73N/9	45	Hugli	Goghat II	6.0	0.67	422
11943	87.6911	22.98245	73N/9	46	Hugli	Goghat II	6.0	0.40	236
11944	87.7009	22.98245	73N/9	47	Hugli	Goghat II	5.7	0.65	401
11945	87.7107	22.98245	73N/9	48	Hugli	Goghat II	5.4	0.85	690
11946	87.7205	22.98245	73N/9	49	Hugli	Goghat II	5.6	0.83	620
11947	87.7303	22.98245	73N/9	50	Hugli	Goghat II	5.1	0.88	736
11948	87.7401	22.98245	73N/9	51	Hugli	Goghat II	5.1	0.54	328
11965	87.6519	22.97345	73N/9	68	Hugli	Goghat II	5.2	0.83	615
11966	87.6617	22.97345	73N/9	69	Hugli	Goghat II	5.2	0.85	651
11967	87.6715	22.97345	73N/9	70	Hugli	Goghat II	4.5	0.40	250
11968	87.6813	22.97345	73N/9	71	Hugli	Goghat II	4.8	0.73	446
11969	87.6911	22.97345	73N/9	72	Hugli	Goghat II	4.6	0.63	400
11970	87.7009	22.97345	73N/9	73	Hugli	Goghat II	5.2	0.59	386
11971	87.7107	22.97345	73N/9	74	Hugli	Goghat II	4.8	0.46	210
11972	87.7205	22.97345	73N/9	75	Hugli	Goghat II	5.2	0.44	201
11973	87.7303	22.97345	73N/9	76	Hugli	Goghat II	5.4	0.37	182
11974	87.7401	22.97345	73N/9	77	Hugli	Goghat II	5.3	0.62	390

ID	Longitude	Latitude	Topo No.	Grid No.	Dist. Name	Block Name	pH	OC (%)	N ($kgha^{-1}$)
11992	87.6617	22.96445	73N/9	95	Hugli	Goghat II	5.4	0.43	260
11993	87.6715	22.96445	73N/9	96	Hugli	Goghat II	4.9	0.73	457
11994	87.6813	22.96445	73N/9	97	Hugli	Goghat II	5.1	0.74	652
11995	87.6911	22.96445	73N/9	98	Hugli	Goghat II	5.4	0.76	965
11996	87.7009	22.96445	73N/9	99	Hugli	Goghat II	5.5	0.83	972
11997	87.7107	22.96445	73N/9	100	Hugli	Goghat I	5.8	0.72	460
11998	87.7205	22.96445	73N/9	101	Hugli	Goghat I	5.2	0.62	360
11999	87.7303	22.96445	73N/9	102	Hugli	Goghat I	5.8	0.90	670
12000	87.7401	22.96445	73N/9	103	Hugli	Goghat II	5.1	1.05	785
12018	87.6617	22.95545	73N/9	121	Hugli	Goghat II	5.0	0.75	456
12019	87.6715	22.95545	73N/9	122	Hugli	Goghat II	4.7	0.72	435
12020	87.6813	22.95545	73N/9	123	Hugli	Goghat II	5.3	1.03	746
12021	87.6911	22.95545	73N/9	124	Hugli	Goghat II	5.4	1.05	690
12022	87.7009	22.95545	73N/9	125	Hugli	Goghat II	5.2	0.90	773
12023	87.7107	22.95545	73N/9	126	Hugli	Goghat I	5.4	0.73	476

Table 4a. Rating scale for macro and major nutrient

Nutrients	Low	Medium	High
Av. N($kgha^{-1}$)	<280	280-450	>450
Av. P_2O_5 ($kgha^{-1}$)	<45	45-90	>90
Av.K_2O ($kgha^{-1}$)	<200	200-350	>350
Av.S (μgg^{-1})	<10	10-15	>15

Table 4b. Rating scale for pH

Classes	pH
Strongly acidic	<4.5
Moderately acidic	4.5-5.5
Slightly acidic	5.5-6.5
Neutral	6.5-7.5
Slightly alkaline	7.5-8.5
Alkaline	>8.5

Table 4c. Rating scale for organic carbon

Organic Carbon Class	Organic carbon (%)
Low	<0.5
Medium	0.5 – 0.75
High	>0.75

Table 4d. Rating scale for micro-nutrient

Micronutrient	Critical levels ($mgkg^{-1}$)
Zinc	0.60 (DTPA extractable)
Copper	0.20 (DTPA extractable)
Iron	4.50 (DTPA extractable)
Manganese	1.00 (DTPA extractable)
Boron	0.36 (Hot $CaCl_2$ extractable)
Molybdenum	0.05 (Ammonium Oxalate extractable)

3.4 Soil nutrient maps

Inverse weighted distance (IWD); a GIS based interpolation technique was used to develop individual maps of macro, major and micro nutrients for each district of West Bengal on 1:50,000 scale.

Farmers' advisory

Web and mobile based farmers' advisory is hosted on www.wbagrisnet.gov.in keeping village as a unit of recommendation. It is primarily based on the soil test values of 76000 grid points and the recommendations developed thereon. By using the advisory, farmers of village can get information on range of soil pH, macro, major and micro-nutrient status, nutrient requirement, type and amount of fertilizers, organic matter and soil ameliorant for given crop/varieties/land uses of a village in different seasons. Advisory also suggests method and time of fertilizer application. Soil health card is generated in Pdf format. The farmers' advisory can be effectively utilized by the farmers of villages growing rice, vegetables and other crops.

4. Salient outcome

The results indicated that fine loamy, fine and coarse loamy soils occupied 34.6, 24.6 and 24.9 per cent area of the state respectively. The soils affected with the acidity were marked on 63.3 per cent area of West Bengal. Majority of the soils of Darjeeling, Jalpaiguri, Cooch Behar, Uttar and Dakshin Dinajpur, Puruliya, Paschim Medinipur and Bankura were classified in the pH range of 4.5 to 5.5, whereas the soils of Barddhaman, Birbhum, Hugli, Purba Medinipur, North 24 Parganas and South 24 Parganas were classified in the pH range of 5.5 to 6.5. The soils of Maldah, Murshidabad and Nadia dominantly belonged to the pH range of 6.5 to 7.5.

Organic carbon content was marked as low, medium and high on 29.4, 27.4 and 29.7 per cent area of the state, respectively whereas availability of available nitrogen was delineated as low, medium and high in 24.3, 31.1 and 30.7 per cent area of West Bengal, respectively. Low content of available phosphorus and potassium covered 44.5 per cent and 46.1 per cent area of the state, respectively, whereas medium content of available phosphorus and potassium occurred on 20.4 per cent and 23.1 per cent area of the state, respectively. Extensive area affected with low balance of available potassium was mapped in the districts of Puruliya, Bankura, Birbhum, Maldah, Murshidabad, Uttar and Dakshin Dinajpur and Barddhaman, whereas low balance of phosphorus extensively occurred in Puruliya, Bankura, Birbhum, Maldah, Haora, Barddhaman, Paschim Medinipur, Murshidabad, North 24 Parganas and South 24 Parganas. Available sulphur content was found low in 18.7 per cent and medium in 17.1 per cent area of the state, whereas the problem of available iron, manganese and copper availability was not extensive in West Bengal. The area delineated as deficient in zinc and boron occupied 34.8 and 14.9 per cent area of the state, respectively.

The database and the map in GIS was further analyzed using union and integration command in GIS for knowing the deficiency/low balance of nutrients occurring individually or in combination. The results indicated that apart from nitrogen and acidity, soils of West Bengal suffer from the low balance of multiple nutrients. The low balance of phosphorus, potassium, boron and zinc occurred together dominantly in the districts of Jalpaiguri, Murshidabad, Birbhum, Bankura, Nadia and Paschim Medinipur districts. The nutrient balance sheet suggested that low balance of phosphorus; potassium and zinc together were found to occur in the districts of Maldah and Howrah. The low balance of phosphorus, potassium and boron in combination was mapped in the district of Dakshin Dinajpur, whereas the Koch Behar district was affected with inadequate level of phosphorus and potassium. The study also revealed the occurrence of low balance of phosphorus, potassium and boron together in the districts of Hugli, Barddhaman and Puruliya districts. The problems of low balance of phosphorus and zinc in association were noted in the district of Purba Medinipur, North 24 Parganas and South 24 Parganas. Further, low balance of potassium and zinc in union was marked in the districts of Uttar Dinajpur, whereas the soils of Darjiling district have the problem of boron nutrition.

4.1 Launching of Web based Farmer's advisory for input based land use planning in West Bengal

Promoting Web-GIS venture is expected to improve information access and effective delivery of services to the farming community for their decision-making, thereby improving productivity and profitability of farmers through better advisory systems. Recently such type of Farmers' Advisory System has been developed based on the soil nutrient status database and agro-climatic situation generated by National Bureau of Soil Survey and Land Use Planning (ICAR) supported by the Department of Agriculture, Government of West Bengal and was hosted on www.wbagrisnet.gov.in of National Informatics Centre (NIC), Govt. of India server. Advisory was also linked with mobile cell phone services. Web application acts as a Decision Support System (DSS) that calculates number of alternate options, which could be selected by the farmers depending upon their requirement, availability of irrigation water and socio-economic conditions. The advisory offers service to the rice, vegetable, pulse and fruit growers of West Bengal, the requisite back up knowledge for fertilizer and crop planning (Sen et al.2012) (Fig .2) .

Fig.2 User interface for visualizing the database and selection of desired attributes

Farmers' advisory, based on knowledge base (information heuristises), inference engine (analyzes knowledge base) and end user interface (accepting inputs and generating outputs) has an open architect for addition/ deletion of soil test values and the new interest of farming likely to be arising in future. It generates information on ranges of soil pH, macro, major and micro-nutrient status and calculates nutrient requirement; recommends type and amount of fertilizers, organic matter and soil ameliorants for a given crop/ variety or land use of a village in the different seasons of a particular agricultural year following a justified crop cycle. Advisory also recommends methods and time of fertilizer applications. It therefore becomes evident that, SSNM practices not only help in maintaining the soil productivity and hence better crop, web based farmers' advisory and/or the mobile phone based service helps the farmers to receive information about nutrient management at timed intervals through personal cell phones as per the crop cycle and variety, hence helping in increasing farm yield (Sen *et al.*2012).

Thus soil nutrient mapping together with the recommendation package in farmers' advisory certainly opened a new corridor to reduce the risk of environmental contamination arising due to the misappropriation of fertilizers. It is expected that farming in the state will be more efficient and profitable by utilizing the information generated through soil nutrient mapping and dissemination of the generated knowledge through farmers' advisory towards input-based land use planning.

References

Banerjee, T., Sarkar, D., Mukhopadhyay, S., Mukhopadhyay, J., Mandal, C. and Singh, S.K. (2013). *Land Resource Atlas of West Bengal*. NBSS Publ.154, pp. 164.

Govt. of West Bengal (2005). *Fertilizer recommendation for principal crops and cropping sequences of West Bengal.* Jahangir Ali S.K. (Ed.), Deptt. of Agriculture, Govt. of West Bengal).

Johnston, A.M., Khurana, H.S., Majumdar, K. and Satyanarayana, T. (2009). Site-specific nutrient management - concept, current research and future challenges in Indian agriculture, *Journal of the Indian Society of Soil Science* **57:** 1-10.

Sen, P., Singh, S.K., Sarkar, D. and Majumdar, A. (2012). Farmers Advisory Services for Fertilizer and Crop Planning in the State of West Bengal – A Novel Approach to reach out to the farmers, *Fertilizer Marketing News* **43:** 1-7.

Singh, A.K. (2008). Soil resource management – Key to food and health security, *Journal of the Indian Society of Soil Science* **56:** 348-357.

Management of Salt Affected Soils for Sustainable Land Use Planning

V.K. Kharche
Associate Dean, College of Agriculture, Nagpur

ABSTRACT

Salt affected soils exist mostly under arid and semi arid climates, in more than 100 countries. Agricultural production in the arid and semi arid regions is limited by salinity, sodicity, poor water resources, limited rainfall and loss in soil fertility, constrained to a localized area or sometimes extending over the whole of the basin. The salt affected Vertisols have been reported to have saline, saline sodic and sodic characteristics. The main cause of salt problems to Vertisols reported include unscientific irrigation, topographic situation, aridity in climate, ground water rise due to canal seepage and poor drainability. The gypsum which was widely used amendment in these soils is also becoming scarce and needs to be supplemented with alternative amendments. Application of organic amendments in the form of green manures and crop residues is the simple practice which can prove as promising option. The application of dhaincha and sunhemp in situ green manuring showed highest potential to sequester carbon in soils.

1. Introduction

Soil degradation is antonymous of soil quality. It is causing a great threat to the sustainability of agricultural crop production. Soil degradation resulting from salinity, sodicity or a combination of both, is a major impediment to optimal utilization of land resources. Salt affected soils exist mostly under arid and semi arid climates, in more than 100 countries. In India chemical degradation by salinization and alkalization is reported to be extended to 10.1 Mha and the problem is further increasing at an alarming rate (Suri, 2007). Nearly 120 M ha area is under degraded soils in India (Maji *et al.* 2010). Agricultural production in the arid and semi arid regions of the world is limited by salinity, sodicity, poor water resources, limited rainfall and loss in soil fertility, constrained to a localized area or sometimes extending over the whole of the basin. Extension of irrigation to the arid and semi arid regions, however, usually had led to an increase in the area under shallow water tables and to intensify and expanding the hazards of salinity and sodicity. This is because irrigation water brings in additional salts and releases immobilized salts in the soil through evapotranspiration and concentrating dissolved salts in the soil solution. The relative significance of each source in contributing soluble salts depends on the natural drainage condition, soil properties, ground water quality, irrigation water quality, and management practices.

The input use efficiency is declining on such problem soils. It is therefore very necessary to restore these soils and arrest their further degradation. A number of technologies have been generated for reclamation and management of these soils. However, there are some constraints in their large scale adoption by the farmers either because they lack simplicity or the scarcity of materials like amendments etc. The reclamation of these soils must also be necessarily cost effective and durable. The present paper emphasizes particularly on the strategies for reclamation and management of degraded black swell shrink soils due to salinity/sodicity.

Kharche and Pharande (2010) in their studies on sodic black soils of Mula command area in Maharashtra observed that these soils with high sodium on the exchange complex (ESP>10) in association with high clay content of smectitic nature have restricted drainage. Farmers' experience and field observations show poor drainage especially at ESP above 10 necessitating lowering of ESP limit in black swell-shrink soils for categorizing them as sodic mainly because the sodification problem in these soils is further aggravated by high clay content causing the soils to be inherently slow in permeability. The threshold value of 15 ESP for a soil to be termed sodic is not sacrosanct and soil physical properties could deteriorate at values lower than this (Swarup 2004). An ESP limit of 5 has been suggested by Balpande *et al.* (1996) for alkali subgroup of Vertisols in central India that have high smectite content. Sharma *et al.* (1997) reported that an ESP of 5 and 6 in Vertisols could cause considerable deterioration in soil physical properties. However, further investigations on the extent of dispersion due to different degrees of sodium and its effect on soil quality in relation to crop yield reduction particularly in Vertisols are necessary.

2. Conventional Approaches for Amelioration of Salt Affected Soils

Amelioration of sodic soils through the provision of a readily available source of calcium (Ca^{2+}) to replace excess Na^{+} on the cation exchange complex and to leach out Na^{+} from the root zone through the water is an age old practice. However, cost of amendments have increased prohibitively over the past two decades due to competing demands and limited sources of availability. The high cost on the transport of these amendments needs attention as farmers are not in position to pay high cost for these inputs. However, the improved agronomic practices still have a promise to enhance the productivity on these lands. The choice of appropriate crops and cropping systems suitable and tolerant to these soils certainly helps to optimize the utilization of these soils.

The recommendations for application of amendments in the sodic black soils of Purna valley in Vidarbha region of Maharashtra have been made based on the increase in the crop yield and soil improvement. Broadcasting of gypsum in powder form @ 2.5 t ha^{-1} (50% GR) before sowing of crop and mixing it with surface soil is recommended for increasing the productivity of cotton, sorghum and green gram as well as improving the physical and chemical characteristics of sodic soils of Purna valley. It is also recommended to pass the alkali water through gypsum bed of 30 cm thickness for getting higher yield of irrigated cotton with improvement in characteristics of sodic Vertisols of Purnavalley. For improving the characteristics of soil and sustaining the yields of green gram –saffower on sodic Vertisols of Purna valley, it is recommended to incorporate crop stubbles @ 2 t ha^{1} + PSB @ 10 kg ha^{-1}alongwith 50 per cent recommended dose of fertilizers.

Alternative Management Options

3.1 Crop Residues and Green manuring

The effective alternatives to the conventional approaches are necessary to increase the potential of soil reclamation. Application of organic amendments in the form of green manures and crop residues is the simple practice which can prove as a promising option in this regard. These materials are locally available at the farm itself which can help in on-farm recycling of nutrients besides reclaiming the soils. This material reduces pH and ESP of the alkali soils due to production of organic acids and increase in availability of Ca^{2+} that exchange with Na^{+} of clay complex leading to creation of favorable environment for microbial activity which reflects in improvement of microbial activity (Rao and Pathak, 1996, Shirale, 2014).

The amendments which are easily available could probably be the most effective option for improving soil health, maintaining soil productivity and sustaining crop yields in salt-affected areas. A holistic approach should be to consider the cost and availability of the inputs. The potential of crop residues and green manuring in soil reclamation needs to be emphasized and the farmers should be motivated towards adoption of these practices. Application of green manure enhances the reclamation action of organic manures by improving physical and chemical properties of soil and by markedly decreasing soil pH. Plant litter incorporation improves aggregation and lead to better aeration and water relationship. Application of straw mulch had been found to curtail the evaporation from soil surface resulting in reduced salt concentration in the root zone profile (Kaur, 1994) that may help in arresting sub soil sodicity.

The plant roots of green manures increase the dissolution rate of calcite, by increasing levels of CO_2

and H^+ proton in the rhizosphere region of plant roots. Subsequent incorporation of green manures decomposes rapidly which contains calcium and acid juice which enhances solubility of native calcium carbonate and subsequent release of Ca^{2+}, which displaces Na^+ in soil exchange complex and displaced Na^+ subject to leaching. The application of organic amendments could be beneficial in several aspects ; reduction in soil pH, ESP, bulk density, improvement in exchangeable Ca and Mg, CEC, available nutrients, promotion of soil aggregate stability and creation of soil macro pores that improve soil hydraulic properties and root proliferation and environmental considerations in terms of soil carbon sequestration.

Field experiments conducted during 2011-12 and 2012-13 to study the effect of various organic amendments in comparison with gypsum on carbon dynamics and nutrient availability in calcareous sodic Vertisols of Purna valley in Vidarbha region of Maharashtra revealed that application of gypsum showed significant reduction in pH followed by dhaincha insitu green manuring. The application of organic amendments significantly enhanced the organic carbon, permanganate oxidizable carbon, soil microbial biomass carbon and SOC stock over the application of gypsum and control. The application of dhaincha and sunhemp insitu green manuring showed highest potential to sequester carbon in soils. The application of organic amendments showed slight reduction in calcium carbonate content of the soils. The availability of major and secondary nutrients were highest under the organic amendments as compared to gypsum and control. The potential of different organic amendments in alleviating the carbon and nutrient stress in sodic Vertisols under high pH and ESP stress situation besides reclamation has been documented (Shirale, 2014).

3.2 Biomulch:

Use of mulching as one of the important components of soil and water management approaches has potential to enhance soil quality over a long term, as well as increase production. This practice has specific significance in management of salt affected soils. Crop residues placed on soil surface shade the soil, serve as water vapour barrier against evaporation losses, slow surface runoff and increase infiltration (Mulumba and Lal, 2008). Duikar and Lal (1999) reported a positive and linear effect of mulch application rate on soil organic carbon thereby increasing carbon storage in soil. Deng *et al.* (2006) reported that mulching with crop residue improves water-use efficiency by 10-20 per cent as a result of reduced soil evaporation and increase plant transpiration. In case of winter wheat, straw mulching has been shown to increase water-use efficiency.

3.3 Carbon Sequestration in salt affected soils:

Incorporation of organic amendments into subsoil raises the possibility of storing carbon in the deeper soil layer. Clay soils due to presence of high proportion of small pores, have potential for sequestering carbon. Soil organic matter is the single soil property which influences the soil fertility, soil formation, profile development, soil structure, soil physical, organo-chemical and biotic characteristics in addition to serving as a source of food and energy for microorganisms. The complexity and content of soil organic matter depend upon the nature of organic material incorporated in soil, different cropping sequences and crop combinations, which decides the quantum of production of humic substance showing favourable effect on improving physical, chemical and biological characteristics of soil.

In India, more than 100 million hectares are classified as degraded and greatly depleted in SOM; 35 % of this area is classified as salt affected. It has been suggested that only by reclamation of salt affected lands in India; up to 2 Gt C should be sequestered. There is a considerable uncertainty in the estimates, concerning both C flux rates and soil C storage capacity. Since soils have a finite capacity to store additional C, the total amount of C sequestered and the estimates thereof depend on the time horizon considered. Further, permanence of C sequestered in soil depends on the continuation of the recommended management practices.

Technological options that have been found to be efficient for soil C sequestration in Indian agro-ecosystems include integrated nutrient management and manuring, soil crop residue incorporation, mulch farming and / conservation agriculture, agroforestry systems, grazing management, choice of cropping systems and intensification of agriculture. Incorporation of organic manures include decomposition of organic matter where roots, hyphae and polysaccharides bind mineral particles into micro aggregates and then these micro-aggregates bind to form C rich macro-aggregates. This type of C is physically protected within macro-aggregates. The free primary particles are cemented together into micro-aggregates by persistent binding agents characterized by humification of organic matter and stimulate accumulation of C in aggregates.

REFERENCES

Balpande, S.S., Deshpande, S.B. and Pal, D.K. (1996). Factors and processes of soil degradation in Vertisols of Purna valley, Maharashtra. India. *Land degradation and development* **7**:1-12.

Deng, L., M. Chen, Z. Liu, Q. Shen, H. Wang and J. Wang (2003). Effects of different ground covers on soil physical properties and crop growth on saline-alkaline soil. *Chinese J. of Soil Sci.* **34**(2):93-97.

Duikar, S.W., Lal, R. (1999). Crop residue and tillage effect on carbon sequestration in a Luvisol in central Ohio. *Soil and Tillage Res.* **52**:73-81.

Rao, D.L.N. and Pathak, H. (1996). Ameliorative influence of organic matter on biological activity of salt affected soils. *Arid Land Research and Management*, **10**(4): 311-319.

Kharche, V.K. and Pharande, A.L. (2010). Land degradation assessment and land evaluation in ula command of irrigated agrosystem. *J. Indian Soc. Soil Sci.* **58**(2):221-227.

Mulamba, L.N. and Lal, R. (2008). Mulching effects on selected soil physical properties. *Soil and Tillage Res.* 98, 106-111.

Sharma, O.P., Sharma, D.N. and Minhas, P.S. (1997). In 25 Years of Research and Management of Salt-affected Soils and Use of Saline Water in Agriculture. Central Soil Salinity Research Institute, Karnal, pp. 64-84

Swarup Anand (2004). *Chemistry of sodic soils and fertility management*. Proc. International Conference on Sustainable Management of Sodic Lands, February 9 – 14, 2004, UP Council of Agricultural Research, Lucknow, pp 27 – 52.

Shirale, A.O. (2014). Effect of crop residues and green manuring on soil properties and crop productivity in Purna valley of Vidarbha, Ph.D. Thesis Dr. PDKV, Akola.

Suri, V.K. (2007). Perspectives in soil health management- a looking glass. *J. Indian Soc. Soil Sci.* **55** (4):436-443.

Land and Land Use Policy Issues in India

Arun Chaturvedi, Pr. Scientist
ICAR- National Bureau of Soil Survey and Land Use Planning
Amravati Road, Nagpur-440033

ABSTRACT

Land resources are used for a variety of purposes which may have historical linkages and many compete with one another. Proper planning and management of these uses therefore becomes desirable for optimization of sustainable land use systems. This requires scientific land use planning backed by an objective acceptable land use policy.

Land use planning is the process of evaluating land and alternative patterns of land use and other physical, social and economic conditions for the purposes of selecting and adopting the kinds of land use and courses of action best calculated to achieve specified objectives. Land use planning may be at national, regional, state, district, watershed or village and also at farm level. It entails systematically evaluating land and alternative pattern of land use, choosing that use which meets specified goals, and the drawing up of policies and programmes for the use of the land (Gautam, 2002). The plans will need to be backed up with legislative support in form a policy within a legal framework. While the country has policies governing most land use systems there is no integrated land use policy even after nearly three and a half decades of discussions on the issue. In September, 2013 the Department of Land Resources, (Ministry of Rural Development; Government of India) has released the first draft of a National Land Utilisation Policy framework for land use planning & management. Each State Government shall prepare the State Land Utilisation Policy (SLUP) within a period of one year from the date of publication of the National Land Utilisation Policy, having due regard to the National Land Utilisation Policy and incorporating state-specific requirements.

1. Introduction

Land utilization manifests the man-environment relationship at any given time and place. In addition to the role of land and water, in terms of quantity as well as quality, the other important aspect in any Land Utilization is the management practices, the human dimension which influences and ultimately decides the success or efficiency of land use. As different people have different aspirations, a large number of conflicts like Singur are observed.

Resolving conflicts in natural resources management can best be achieved through participatory approach. Land is a finite and precious resource and planning its use has gained critical importance as the anticipated climate changes are causing anxieties and the scientists community is resetting the research agenda with a rigid emphasis on conservation of eco-systems. Agricultural eco-systems are no exception and in fact agricultural land use planning is now a multi-faceted exercise because of the interwoven issues of water resources development, power generation, metal and ore exploration and so on. Unfortunately, India as a country has no well defined land use policy. Ideally, each district should have a land use plan. The district environmental action plans in turn should integrate potential users and ecosystems for designated uses while conserving the resources. Environmental planning and land use planning are now becoming almost synonyms. Manpower development is the foremost requirement as currently lack of awareness and proactive role by the state agencies in synergistic mode has left this task to different agencies often working at cross with each other and thereby generating conflicts, causing delays in project implementation, cost over-runs. Combined effect of these factors is the stalled or slow paced development. An integrated land use policy and its effective implementation is therefore needed for balancing the act of development and conservation.

Land issues in india

India with a total geographical area of 329 m.ha. (Table-1), has the seventh largest land area in the world and is located between 8° 4′ 37° 6′ latitude and 68° 7′ E - 97°25′ E longitude. It spans 3,214 km from north to south, and 2,933 km from east to west. The coastline stretches for over 7516.6 km. It occupies 2.4% of the earth's surface It is endowed with a variety of pysiographic, edaphic, climatic and biological attributes ranging from the glacial undulating terrain to high rainfall level plains. Still nearly 265 m.ha. of the land has Potential for Biological Production.

The fact is that India has the seventh largest land area In the world, with second largest population in the world and higher population density (851/sq.miles). Theer has neen a perception that :

- There is no shortage of land
- Urban population of india can be settled in 2.5-3% of TGA.
- Indian agriculture can never be the base for total livelihood & economic development.
- The future of the country lies in the industrial and service sector

With more than 183 million ha. Lands categorized as cultivable lands and a population above a billion, India has less than 0.183125 ha. of cultivable land per person. This makes Land Use Planning a very crucial aspect for food security of the country. Assessment of soil and land resources is the first step in any land related planning process. With 65 % of its 110 crores population having farming as way of life and means of livelihood, agriculture has to be the mainstay of indian economic growth. Nearly 42% of total geographical area of the country being under agriculture, makes it the largest land utilisation category in the country. The irony is that agriculture contributes only 21% to the GDP. The highest growth rate is only 2.5% (in U.P.) inspite of our best efforts.

A major handicap in Land Use Planning has been an institutional support mechanism through policies and legislations for integrated land use systems. There are various policies which regulate individual land use systems. The list of central policies which have a bearing on land use, include

Table 1. Physiographic region/subregion

Physiographic region/subregion	Area m.ha.	% Area	Physiographic region/subregion	Area m.ha.	% Area
Indo-Gangetic Alluvial plain	37.94	11.54	Hill ranges (Ghats).	25.43	7.73
Bengal basin	7.85	2.39	Islands.	0.83	0.25
Central Highlands	41.05	12.49	Himalayas and other Mountain ranges.	34.15	10.39
Deccan Plateau	62.90	19.13	North Eastern Ranges, Eastern Himalayas and Brahmaputra valley.	25.51	7.76
Eastern Plateau	33.23	10.11	Coastal plain	23.96	7.29
Gujarat coastal plain	16.36	4.98	Western plains	19.52	5.94
				328.73	**100**

(Source - Soils of India, 2002)

- National Water Policy, 1987
- National Land Use Policy Outlines, 1988
- National Forest Policy (NFP) of 1988
- Policy Statement of Abatement of Pollution, 1992
- National Livestock Policy Perspective, 1996
- National Agricultural Policy 2000
- National Population Policy, 2000
- National Land Reforms Policy
- National Policy and Macro-level Strategy and Action Plan on Biodiversity, 2000

In addition, there are legislative frameworks which have to be conformed to by any state while planning a land use policy. These include:

- Forest (Conservation) Act, 1980
- Environment (Protection) Act, 1986

- Water (Prevention & Control of Pollution) Act, 1974 as amended in 1988
- Wildlife (Protection), 1972 as amended in 1988
- Constitutional Amendments (73rd and 74th Amendments) of 1992
- Municipality Act, 1992 (74th Amendment Act, 1992), and many more.

Developing land use policies for sustainable development while promoting environmental protection is a tough challenge especially in developing countries. Modern land use and changes in land use are mainly driven by economic interests though social interest could also be an influencing factor.

Land Use Policy

Indian still does not have a National Land Use Policy, the serious effort was made in 1985-86 when the Ministry of Agriculture decided after intensive deliberation with other agency to prepare a national land use policy guidelines and action plan. The "National Land Use Policy guideline and action points" prepared by the Government of India, Ministry of Agriculture, were placed before the 'National Land Use and Waste Land Development Council' under the chairmanship of Prime Minister and its first meeting was held on 6th February, 1986. The Council agreed to the adoption of policy and circulated the same throughout the country for adoption after suitable considerations at the state level. Of the nineteen points, some of the most important ones are:

1. Land Use Boards at the State level should be revitalized.
2. Land Use Policy must be evolved by all users of land within Government jointly and must be enforced on the basis of both legislation for enforcing land use as well as their promotional and preserving methods.
3. Urban Policy must be restructured so as to ensure that highly productive land is not taken away. Town planning should also provide for green belts.
4. A national campaign should be launched for educating the farmers and Government Departments about the need to conform to an integrated land use policy
5. Cropping pattern should be reviewed specially in drought prone/desert areas, so that maximum advantage is taken of improved soil and water management practices.
6. Land and soil surveys should be completed and inventory of land resources should be prepared in each State so that resources allocation is based on a reliable data base.
7. Heavy penalties should be imposed against those who interfere with land resources and its productivity. It must be recognized that environmental protection cannot succeed unless this is done.
8. The problems of water logging, salinity and alkalinity must be brought under control by the use of appropriate technologies and by the adoption of proper water management practices.
9. The management of Command Areas should be reviewed, restructured and revitalized within a specified time limit so that water is used efficiently. Necessary investments for treating the catchments must be met to prevent the collapse of irrigation system due to premature siltation.
10. Technologies relating to dry farming, land shaping and water harvesting must be propagated and adopted in the interest of moisture conservation and optimal use.
11. Land Use Planning should be integrated with rural employment programmes in such a manner that loans and subsidies are given only for those productive activities which represent efficient land use.
12. Rights of tribals and poorer sections on common land should be protected through legal and administrative structures.
13. Stall feeding should be popularized, especially in such areas where grazing land is already degraded.
14. Special Fodder Development Programme in selective blocks should be launched together with a Livestock Development Programme. The aim should be to limit the Livestock population to economically productive stock.
15. Plantations for meeting commercial and industrial needs should preferably be located far away from the habitat.
16. The policy of supplying forest raw materials on subsidized basis to users other than the rural poor should be reviewed so that raw material is supplied at the prevailing market price, with a view to

induce such users to go in for massive afforestation programmes, as also to motivate small and marginal farmers to grow forest based raw material for industry at remunerative prices.

17. The use of alternative packaging material, such as corrugated card boards etc. instead of wooden packaging, must be explored and encouraged.

The policy was finally adopted in 1988 but has not really been able to move things. The Policy has been circulated to all concerned for adoption and implementation through enactment of suitable legislation. The policy, however, did not make the desired impact, mainly due to the fragmented handling of different components of agriculture like water, land and soil.

Draft National Land Utilisation Policy (2013)

In September, 2013 the Department of Land Resources, (Ministry of Rural Development; Government of India) has released the first draft of a National Land Utilisation Policy framework for land use planning & management. The draft policy document examines the current land use planning and utilisation trends and the guiding principles for the National Land Utilization Policy. Emphasis has been laid on identification of Land Utilisation Zones (LUZ's) and Land-Use Management areas in addition to the implementation approach for the policy. It is also for the first time, land use has been considered as a holistic issue the policy document discusses the linkages between various land use types. The National Land Utilisation Policy also suggests an implementation strategy taking into consideration the fact that "land and its management" is a State subject.

The National Land Utilisation Policy has set its goal to ensure sustainable development of India and its main objective to ensure optimal utilisation of the limited land resources in India for achieving sustainable development, addressing social, economic and environmental considerations and to provide a framework for the States to formulate their respective land utilisation policies incorporating State- specific concerns and priorities.

Some specific objectives as outlined in the policy document are given below.

1. Protection of agricultural lands from land use conversions so as to ensure food security and to meet consumption needs of a growing population and to meet livelihood needs of the dependent population.
2. To identify and protect lands that are required to promote and support social development, particularly of tribal communities and poor section of society for their livelihood.
3. To preserve historic and cultural heritage by protecting, places/sites of religious, archaeological, scenic and tourist importance.
4. To preserve and conserve lands under important environmental functions such as those declared as National Parks, Wild Life Sanctuaries, Reserved Forests, Eco Sensitive Zones, etc. and guide land uses around such preserved and conserved areas so as not to have land use conflicts or negative environmental impacts.
5. To preserve the areas of natural environment and its resources that provide ecosystem services.
6. To promote properly guided and coordinated development in a sustainable manner of all developmental sectors including agriculture, urban, industrial, infrastructure and mining so as to minimise land use conflicts or negative environmental impacts.
7. To suggest a general implementation framework for implementing land utilisation policy by all concerned at different levels, viz. national, state, regional and local, and undertaking capacity building. (Anonymous, 2013).

It is expected that this policy will be implemented at the earliest to ensure Scientific land use planning in the country.

References

Anonymous, 2013. Draft National Land Utilisation Policy, Department of Land Resources, Ministry of Rural Development, New Delhi. July, 2013.

Soils of India. (2002). NBSS& LUP Publication 94, National Bureau of Soil Survey and Land Use Planning, Nagpur, India, pp134.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- +Soil Series of Chhatisgarh State, NBSS Publ.85, 2002. ISBN: 81-85460-61-2.
- +Soil Resource Atlas of Betul Dist. (M.P.), NBSS Publ.86, 2001, ISBN:81-85460-62-0.
- +Soil Based Agro-Technology Transfer in Sukli (Dist. Nagpur), NBSS Publ.87, 2002, ISBN: 81-85460-64-7.
- +Soils of Hugli District for Optimising Land Use, NBSS Publ.88, 2001, 91p. ISBN:81-85460-65-5.
- +Soil Series of West Bengal, NBSS Publ.89, 2001, 260p., ISBN:81-85460-66-3.
- +Soil Resource Atlas of Dhar Dist. (M.P.), NBSS Publ.90, 2001, 100p, ISBN:81-85460-68X.
- #Soil Series of Himachal Pradesh, NBSS Publ.91, ISBN:81-85460-69-8.
- +Soil Series of Goa, NBSS Publ.92, 2002, ISBN:81-85460-70-1.
- *Soil Resource Atlas of Ratlam Dist. (M.P.), NBSS Publ.93, 2002.ISBN: 81-85460-71-X.
- +Soils of India, (1:1 M Scale, 11 Sheets Maps) NBSS Publ.94, ISBN:81-85460-72-8.
- +Soil Resource Atlas of Bilaspur Dist. (Chhattisgarh), NBSS Publ.95. ISBN:81-85460-73-6.
- +Soil Series of Rajasthan,NBSS Publ.96, 2002,ISBN:81-85460-75-2.
- +Soil Erosion of Tripura: A model for soil conservation and crop performance, NBSS Publ.97,2002, ISBN:81-85460-76-0.
- +Soil Series of Bihar. NBSS Publ.98, 2004, ISBN:81-85460-77-9.
- +Soils of Ajmer district for optimising land use. NBSS Publ.99,2003, ISBN:81-85460-78-7.
- +Soil Resource Atlas of Chhindwara Dist. (M.P.), NBSS Publ.100,2003, ISBN:81-85460-79-5.
- +Soil Series of Assam. NBSS Publ.101,2004, ISBN:81-85460-90-6.
- +Soil Erosion of Rajasthan. NBSS Publ.102,2003, ISBN:81-85460-80-9
- +Soil Erosion of Chhattisgarh. NBSS Publ.103,2003, ISBN:81-85460-81-7
- +Soil Resource Atlas of Jadgalpur (Baster) Dist. (Chhattisgarh). NBSS Publ.104,2003, ISBN:81-85460-82-5.
- +Soil Series of Sikkim. NBSS Publ.105,2004,ISBN:81-85460-83-3
- +Soil Erosion: Madhya Pradesh. NBSS Publ.106,2003, ISBN:81-85460-84-1.
- +Soil Resource atlas of Jorhat Dist. (Assam), NBSS Publ.107,2004, ISBN:81-85460-85-X
- +Salt affected soils, Etah Dist. (UP). NBSS Publ.108,2004, .ISBN:81-85460-86-8
- +Soil Series of Nagaland NBSS Publ.109, 2004, ISBN:81-85460-87-6.
- #Soil Resource information and land use planning of Chhattisgarh. NBSS Publ.110.ISBN:81-85460-88-4
- +Soil Series of Tripura. NBSS Publ.111,2004,ISBN:81-85460-89-2
- +Soil Series of Delhi. NBSS Publ.112,2004,ISBN:81-85460-91-4.
- +Land use planning of Udaipur dist. Soil resource and agro-ecological assessment. NBSS Publ.113.2006,ISBN:81-85460-92-2
- +Soil erosion A.P. NBSS Publ. 114,2005,ISBN:81-85460-93-0
- #Economic land evaluation for sustainable land management of Rajanukunte watershed, Karnataka. NBSS Publ.115,2005, ISBN:81-85460-94-9
- +Soil resource atlas Wardha dist. (Maharashtra). NBSS Publ.116, 2005, ISBN:81-85460-95-7
- +Soil Erosion of West Bengal. NBSS Publ.117,2005, ISBN:81-85460-96-5
- +Soil Erosion: Assam. NBSS Publ.118,2005, ISBN:81-85460-97-3
- +Soil Series of Orissa. NBSS Publ.119, 2005,ISBN:81-85460-98-1.
- +Soil Series of Gujarat. NBSS Publ.120,2006,ISBN:81-85460-99-X
- +Soil Series of Meghalaya. NBSS Publ.121,2005, ISBN:81-89043-00-5
- +Soil Resources of Jalna district (Maharashtra) for optimising land use. NBSS Publ.122,2005, ISBN:81-89043-01-3.
- #Soil Resource for land use .planning, Meerut district (U.P.) NBSS Publ.123.ISBN:81-89043-02-1
- #Soil resource for land use planning, Etah district (U.P.) NBSS Publ.124.ISBN:81-89043-03-X
- +Soil Erosion of Bihar, NBSS Publ.125,2005, ISBN:81-89043-04-8.
- +Soil Erosion of Orissa, NBSS Publ.126,2005, ISBN:81-89043-05-6.
- +Soil Series of Medak district, Andhra Pradesh, NBSS Publ.127,2005, ISBN:81-89043-06-4.
- +Benchmark soils of Andhra Pradesh, NBSS Publ.128,2005. ISBN:81-89043-07-2.
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- *Soil Land Resources of Medak Distt. Andhra Pradesh for Land Use Planning. NBSS Publ.791(SSR), 2005.
- + Soil Resource data of Patiala Dist. of Punjab for perspective land use planning, NBSS Report No.795, 2004.
- +Soil Resource for Land Use Planning, Balaghat Distt. (M.P.). NBSS Publ.827(SSR), 2005.
- +Management of Acid Soils in NEH Region. NBSS Publ.909(SSR),2006.
- +Generation of Soil Database for Khulgad Watershed Development in Almora Dist. Uttarakhand, NBSS Report No.1043, 2013.
- +Georeferenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture, NBSS Report No. 1074, 2014.

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BOOKS

- *Murthy, R.S., Hirekerur, L.R., Deshpande, S.B. and Venkata Rao, B.V. eds. Benchmark Soils of India: Morphology, Characteristics, and Classification for Resource Management, 1982, 374p.
- *Soil Survey Staff, USDA. Soil Taxonomy, Indian Reprint, 1978.
- +Sehgal, J., Blum, W.E. and Gajbhiye, K.S. Red and Lateritic Soils. 1998. Vol.1, 453p., Vol.11: Oxford & IBH, New Delhi, 113p
- Sehgal, J., Gajbhiye, K.S., Batta, R.K. and Sarma, V.A.K., Eds. Swell-Shrink Soils (Vertisols) of India: Resource Appraisal and Management. Kalyani Publishers, New Delhi, 1999, 202p.

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RESEARCH BULLETINS

- *Glossary of Geomorphological Terms, Bull. No.1, 1980, 30p.
- *Soils of North Eastern Regions, Bull.No.2, 1981,72+XXIIIp.
- *Land Use Plan for Development of Bundelkhand Region based on Region Land and Soil Resources Survey, Bull.No.3, 1981, 33p.
- *Soils and Suggested Land Use of Maharashtra, Bull.No.4, 1980.
- *Soil-Physiographic Relationship in India, Bull. No.5,1982,106p.
- *Soil-based Agrotechnology Transfer under Lab-to-Land Programme, Bull.No.6, 1982,24p.
- *Bioclimatic Analysis of India, Bull.No.7, 1982,25p.+11maps.
- *Soil Survey of ICRISAT Farm and Type Area around Patancheru, AndhraPradesh,Bull.No.8(rev.ed.)1993,71p.ISBN:81-85460-08-6.
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- +Memorandum of Soil Correlation, Bull.No.10, 1984, 31p.
- *The Soils of Mondha Village (Nagpur) for Agrotechnology Transfer, Bull.No.11, 1986, 65p.
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- * Soil Resource Mapping of different States in India:Field Manual, Rev. ed. Bull.No.13, 1987, 73p.
- *Soil Resource Mapping of different States in India:Laboratory Methods, Bull.No.14, 1987, 49p.
- *Benchmark Soils of India: Mondha Series(Typic Chromustert) : Characteristics, classification and interpretation for land use planning. Bull.No.15, 1987, 24p.
- *Benchmark Soils of India: Pali Series(Lithic Calciorthid) :Characteristics, classification and interpretation for land use planning. Bull.No.16, 1987,32p.
- *Agroclimatic Environments and Moisture Regimes in North-West India - their application in soils and crop growth, Bull.No.17, 1987, 117p.
- *NBSS&LUP Publications: 1976-1988, Bull.No.18, 1988, 70p.
- *NBSS&LUP Publications: 1988-1999, Bull.No.18 (Supplement), 2000, 142p.
- +NBSSLUP Publications: 1976-2008, updated, NBSS Publ.18, 2009, 130p.
- *Benchmark Swell-Shrink Soils of India-their Morphology, Characteristics and Classification, Bull.No.19, 1988,116p.
- *The Soils of Kolar District (Karnataka) for Land Use Planning, Bull.No.20, 1988, 65p.+10 maps.
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- *Land Resource Atlas of Nagpur District, Bull.No.22, 1994. ISBN:81-85460-01-9.
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- *Agro-ecological Regions of India, 2nd ed. (with one colored map)Bull.No.24, 1990, 130p. ISBN:81-85460-15-9 (Contact for order: M/s Oxford & IBH; 66, Janpath, New Delhi-110 001)
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- +Soil Monoliths: Their Collection, Preparation and Display. Bull.No.64, 1995, 1995, ISBN: 81-85460-29-9.
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