Application of new science tools in integrated watershed management for enhancing impacts

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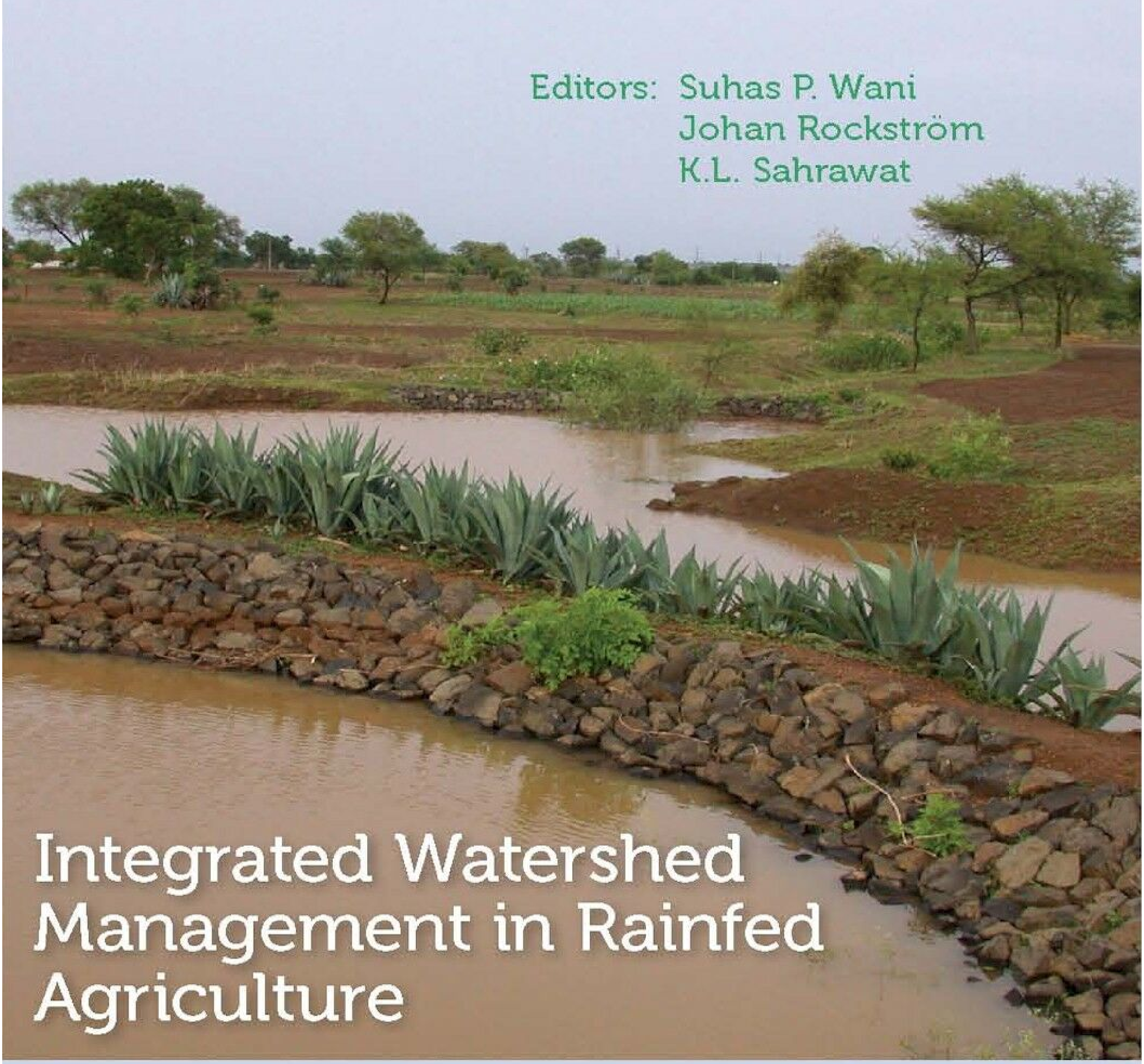

Integrated Watershed Management in Rainfed Agriculture

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Chapter 6

Application of new science tools in integrated watershed management for enhancing impacts

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6.1 INTRODUCTION

Insufficient scientific inputs in terms of research and development are responsible for low productivity of rainfed systems in the semi-arid tropics (SAT), in addition to biophysical and social constraints such as poor infrastructure, inherent low soil fertility, frequent occurrence of drought, severe degradation of natural resource base, and poor social and institutional networks (Wani *et al.*, 2003, 2009). Researchers and development workers apply high science tools mostly in well endowed areas as returns on the investments in terms of economic impact, successful experimentation, and adoption of new technologies are quick and assured. However, recent studies undertaken by the Asian Development Bank (ADB) have shown that the investments in rainfed areas are not as productive as in the well endowed areas but also more effective in reducing poverty in these hotspots of poverty. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in partnership with national agricultural research systems (NARSs) in Asia, for example, Central Research Institute for Dryland Agriculture (CRIDA), National Remote Sensing Centre (NRSC), State Agricultural Universities (SAUs) in India; Department of Agriculture (DoA) and Department of Land Development (DLD), Khon Kaen University (KKU), Thailand; Yunnan Academy of Agricultural Sciences (YAAS), The Guizhou Academy of Agricultural Sciences in China; Vietnam Academy of Agricultural Sciences (VAAS), Vietnam has applied new science tools such as simulation modeling, remote sensing, geographical information system (GIS), and information and communication technology (ICT) for enhancing the productivity of rainfed systems in the SAT through science-led development.

Watershed management is a process of formulating and carrying out a course of action involving manipulation of the natural system of a watershed to achieve objectives specific to the watershed such as control of soil erosion and land degradation, reclamation and rehabilitation of waste/degraded lands, land use changes consistent with land capability, or management of croplands, grasslands, and forests along with management of water resources. For a balanced participatory approach in the watershed development, all the stakeholders have to be involved at planning level itself for the smooth and efficient execution of the works in a timely manner. After understanding the requirements of the stakeholders, spatial technologies play a very crucial role in watershed planning. The tools along with spatial models help in visualizing the consequences of decisions taken before actually implementing them in the field. For example, computing runoff and sediment loads for locating a check-dam, efficiency of proposed soil conservation measures, location of industry and its non-point source pollution effects on various stakeholders, etc.

For executing any watershed program successfully without sacrificing the interests of stakeholders, the basic requirement is an account of natural resources, physiography, and socioeconomic data to assess the problems and prospects of the watershed. Role of modern technologies like remote sensing, GIS, internet, portable electronic devices, electronic sensors, and communication devices thus became vital in the gamut of total program planning, execution, monitoring, and evaluation.

In tropical rainfed areas, 80–85% farmers are small farm holders cultivating <2 ha each. To reach to the millions of small farm holders spread in the SAT across 3.65 million km^2 in Asia and 5 million km^2 in Africa to share knowledge and information about new technologies and products to improve productivity on their farms is indeed a gigantic task. Advances in space research enhanced the availability of spatial and temporal data. Processing of billions of data points to translate into knowledge and information to benefit policy makers, development investors, extension and development workers, and farmers has become feasible with the availability of advanced scientific tools, technologies, and combination of one or more of such tools (Diwakar and Jayaraman 2007; Wani *et al.*, 2008; Kaushalya Ramachandran *et al.*, 2009; Sreedevi *et al.*, 2009).

In this chapter, the availability of geospatial technologies, simulation modeling, and ICT application and the impacts are assessed. Other new science tools in the areas of plant biotechnology, genetic transformation, crop management, social and institutional innovations are not covered. Each of the tools is described briefly and its applications with examples in integrated watershed management program (IWMP) are discussed in detail and this shows how efficiency of integrated watershed management could be enhanced.

6.2 NEW SCIENCE TOOLS FOR WATERSHED MANAGEMENT

6.2.1 Geographical information system (GIS)

Watershed level planning requires a host of inter-related information to be generated and studied in relation to each other. Remotely sensed data provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. This is a very useful and essential tool in the planning and development of watersheds embracing all natural and socioeconomic facets. GIS is used in the development of digital database, in assessment of status and trends of the resources of an area/watershed, and to support and assess various resource management alternatives. Spectacular developments in the field of GIS to synthesize thematic information with collateral data have not only made this technology effective and economically viable but also an inevitable tool to arrive at sustainable development strategies for land and water resources management.

GIS is a tool that relates information to places. It stores spatial data in a topological framework defining the relationships between map elements (points, lines, polygons, and grid cells), facilitates convenient retrieval from the spatial database and supports analysis and modeling to be displayed as digital or hardcopy maps. By visualizing different types of data from different sources using digital maps, GIS cuts across communication boundaries and can become a medium for establishing a common language between otherwise contentious or disinterested groups. The ability of GIS to integrate and spatially analyze multiple layers of information is its core capability. During the initial phases of development, GIS was extensively used for data conversion/digitization of paper maps, storing and generating map prints with little focus on spatial analysis. Later, the scenario changed drastically wherein the spatial analysis took pivotal role in watershed planning. GIS also facilitates modelling to arrive at location specific solutions by integrating spatial and non-spatial data such as thematic layers and socio-economic data. With the simultaneous development of communication networks, the data storage boundaries were erased and new areas like collaborative mapping and web map services have been developed. The present GIS technology enables 'map anywhere and serve anywhere'. With recent developments, there is a leap in the development of spatial analysis tools and logical processing methods. This has enabled the development of numerous spatial algorithms, spatial modeling techniques, and better display and visualization of data. One such application that harnessed the benefits is watershed planning, wherein these techniques were efficiently used for land resources as well as water resources planning, watershed prioritization, and monitoring.

Multi-criteria spatial queries help us visualize the spatial patterns and spatial relationships to understand the phenomenon under study. With the progress in computing capabilities and availability of hardware, more functionality is added to the GIS and it became a very powerful tool for arranging and storing spatial and tabular data in a structured way. Spatial modeling is the application of analytical procedures with GIS. Models are coupled in different ways with GIS to produce spatial model outputs. Either spatial data is used as input to specific models or vice versa to understand spatial phenomenon. GIS has perhaps the best use in the field of agriculture, as it is the most widely prevalent activity on the earth. GIS is used to understand spatial dimensions of varied problems in agriculture especially when environmental variables such as climate, soil and water play a major role in production, constraints, and practices. Temporal data sets need to be analyzed, interpreted, and depicted suitably for better understanding of land related issues and this need can be fulfilled by GIS. Besides generation and spatial analysis of data, the important facet of this information is speedy real time public outreach. With the availability of RAID/BLADE servers that can serve data at faster rates, gigabit data transfer capabilities, and Mbps internet speeds, the outreach to outside world has improved tremendously. The spatial data with on-the-fly spatial analytical capabilities is now being served over internet. One such initiative by NRSC/ISRO is Bhoosampada, a portal wherein the natural resources information along with base details and very latest thematic information is being served through Web GIS. It has a provision to spatially analyze the data present, without the need for separate GIS package. Furthermore the output can be downloaded in a suitable output format also. The main aim of such attempts is to disseminate the information before the relevance is lost. Bhuvan is a Geoportal of ISRO showcasing the Indian imaging capabilities in a multi-sensor, multi-platform, and multi-temporal domain. It provides a gateway to explore and discover virtual earth in 3D space.

6.2.2 Remote sensing

Although remote sensing started during the 2nd World War, developments in satellite remote sensing started in early 1970s and have undergone significant improvements

Table 6.1 Suitability of various remote sensing sensors in watershed studies

Level of study	*Suitable spatial resolutions*	*Sensors*	*Application potential*
Basin level (1:250000 scale)	50 to 150 m	IRS-WiFS, AWiFS, LISS-I	Deriving overall base information on natural resources and land cover; large-scale monitoring of changes
Watershed level (1:50000 scale)	20 to 50 m	IRS-LISS-III, SPOT-MLA, TM, ETM	Deriving natural resources information for watershed prioritization, planning and monitoring
Sub-/Micro-watershed level (1:10000 or larger)	0.5 to 20 m	IRS-LISS-IV, SPOT-PLA, Cartosat-1/2, IKONOS, QuickBird, Worldview-2	Planning and execution, monitoring watershed developmental activities, detailed account of change occurrences, stereo data for DEM generation

in sensors and spatial, spectral, temporal, and radiometric resolutions. Satellite image resolutions increased from 80 m (coarse resolution: Landsat-MSS) in 1970s to 20–36 m (medium resolution: SPOT MLA/Landsat-TM/IRS-LISS II) in mid 1980s to 0.68–5.8 m during late 1990s (high resolution: QuickBird-PAN, MLA/IKONOS/IRS-PAN, LISS-IV, Cartosat-1/2). Corresponding with these developments, application of satellite data has extended from watershed level to sub-watershed and micro-watershed level (Table 6.1).

Simultaneously, stereo-satellite data was also made available from SPOT-PLA, IRS 1C/1D-PAN, IKONOS, and Cartosat-1/2. They enabled to develop digital elevation models (DEM) for the watersheds which is indispensable for topographic feature extraction, runoff analysis, slope stability analysis, landscape analysis, etc. DEM accuracy normally depends on base-height ratio and spatial resolution of the sensor. SPOT DEM accuracies generated from high resolution satellite imagery have absolute planimetric accuracy of 15 to 30 m and absolute elevation accuracy of 10 to 20 m (Anonymous 2004). In Cartosat-1, DEM of an accuracy of 3–4 m in height was achieved where spatial resolution is 2.5 m (Srivastava *et al.*, 2007). CartoDEM can be used as an input for planning developmental activities in watersheds. The geometric accuracy and information content of Ortho-images and DEM provided by the Cartosat-1 can be used for delineation of watershed boundaries at 1:25,000 and 1:50,000 scales, generation of contours at 10-m intervals, and generating thematic maps at 1:10,000 scale (Krishna Murthy *et al.*, 2008).

Besides, the latest developments in microwave interferometry from satellites like ERS-1/2 SAR, Radarsat and Envisat, and laser altimetry from aerial platforms enabled faster and precise generation of DEMs. Noteworthy developments in laser altimetry and its data processing capability enabled generation of DEM with centimeters accuracy under ideal condition. This sort of data is being used for canal, pipeline, road, and other fine spatial alignment planning works.

The high resolution (<6 m spatial resolution) satellite imagery (IRS-LISS IV, Cartosat-1/2, IKONOS, QuickBird) will be very useful for sub-watershed or micro-watershed level applications like mapping infrastructure (roads and drainage network), natural resources inventory (crops, soils, and groundwater potential), water resources (water bodies, natural springs, ponds), land use (single cropped areas, double cropped areas, wastelands, fallow lands, forest cover at level 4), etc. They can be employed at block or village level for management of disasters such as drought or flood damage, etc. and also for monitoring and impact assessment of developmental activities in the micro-watersheds. NRSA (2006) had demonstrated the utility of high resolution satellite data on the above mentioned activities in six micro-watersheds under crop production systems in different agroclimatic zones in India.

Advancements also took place in spectral resolutions, i.e., four spectral bands (Landsat MSS, IRS-1A/1B/1C/1D, SPOT) to seven bands (Landsat-TM) to 14 discrete spectral bands (ASTER). Simultaneous developments in ground-based observations helped to realize the importance of recording data in numerous narrow spectral bands and led to the development of satellite based hyperspectral remote sensing (Hyperion/HySI). Hyperspectral data provides unique capabilities to discern physical and chemical properties of natural resources which is not possible using broadband multispectral sensors. Some of the application areas in agriculture are crop stress (moisture, pest, nutrient) detection, yield prediction, soil quality, and agro-environmental health assessment.

6.3 CROP-GROWTH SIMULATION MODELING

Crop simulation models are mathematical, computer-based representations of crop growth and interaction with weather, soil, and other nutrients. They play an important role in scientific research and resource management, and have been used to understand, observe, and experiment with cropping systems. The strengths of models in general include the abilities to:

- Provide a framework for understanding a system
- Evaluate long-term impact of interventions
- Provide an analysis of the risks involved in adopting a strategy
- Provide answers quickly and more cheaply than is possible with traditional experimentation

The Decision Support System for Agrotechnology Transfer (DSSAT) is a software package integrating the effects of soil, crop phenotype, weather, and management options that allows users to ask "what if" questions and simulate results on a desktop computer. The DSSAT package incorporates models of 27 different crops with new tools to facilitate creation and management of experimental, soil, and weather data files. It also includes improved application programs for seasonal and sequence analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, and precision management. Crop growth modeling software such as Agricultural Production Systems Simulator (APSIM) and InfoCrop is also widely used by various researchers.

Singh *et al.* (2009) have studied the yield gaps of important crops in various countries by simulating potential yields of sorghum, pearl millet, maize, soybean, groundnut and chickpea using DSSAT. They used InfoCrop software for rice and cotton and APSIM for pigeonpea potential yield estimations. They showed that the actual yields of food and other crops obtained by the farmers are much below the potential yields that can be obtained with improved management. Crop yields can be at least doubled from their current levels by the promotion and adoption of existing 'on-the-shelf' technologies available with the national and international research institutes. The governments need to provide more suitable policy environments and institutional support to promote greater adoption of new and improved technologies to benefit the poor farmers of rainfed areas and to meet the challenge of greater food needs of future.

Singh *et al.* (2009) have analyzed yield gaps for several crops in various countries including India, Thailand, Northern Vietnam, and West Asia and North Africa (WANA) region. Estimation of potential rainfed yields and yield gaps in Northern Vietnam was based on simulated yields, experimental station yields, and province yields – all obtained under rainfed situation. Potential yields of soybean, groundnut, and maize were simulated using DSSAT v3.5 crop models. The models were tested and validated using data of three experiments conducted at Than Ha watershed site in Hoa Binh province (Chuc *et al.*, 2005). Rainfed potential yields of crops were simulated using weather data of 28 years for the five locations (Vinh Phuc, Ha Nam, Ninh Binh, Ha Tay, and Phu Tho) and 10 years for the Hoa Binh. Long-term yield data of yield maximization trials were also available for each crop and benchmark site. These data were averaged over the time period and compared with mean simulated yields and province level mean yields for the benchmark sites to quantify the yield gaps for each crop.

As groundnut is more drought resistant during initial stages of its growth under rainfed conditions, the spring season for groundnut starts earlier as compared to soybean and maize. During spring season, simulated potential yields of groundnut across six provinces ranged from 3740 to 4700 kg ha^{-1} with an overall mean of 4170 kg ha^{-1} whereas the experimental potential yields ranged from 2550 to 3400 kg ha^{-1} with an overall mean of 3010 kg ha^{-1} (Figure 6.1). This indicates that even the experimental yields are below the simulated potential yields by about 1100 kg ha^{-1} in the provinces. The province yields of groundnut ranged from 1180 to 2200 kg ha^{-1} with an overall mean of 1520 kg ha^{-1}. The yield gap was 2650 kg ha^{-1} between the simulated and province yield and 1490 kg ha^{-1} between experimental and province yield.

During autumn-winter season, simulated potential and experimental potential yields were lower than those obtained during the spring season (Figure 6.1). Simulated potential yields ranged from 2910 to 3920 kg ha^{-1} with an overall mean of 3530 kg ha^{-1} whereas the experimental yields ranged from 2300 to 2800 kg ha^{-1} with an overall mean of 2620 kg ha^{-1}. Yield gap was 2010 kg ha^{-1} between the simulated and province yield and 1100 kg ha^{-1} between experimental and province yield. These results indicate that the groundnut yields in the six provinces during the spring and autumn-winter seasons can be more than doubled with improved management practices.

Crop simulation models are also used to understand the impacts of climate change on crop growth and productivity. Cooper *et al.* (2009) have looked at a *factorial combination* of climate change of five different temperature increases (1, 2, 3, 4, and 5°C) and three different percentage changes in seasonal rainfall (0%, +10%, and −10%) and compared the crop simulation outputs with a 'control' of the current climate. Their study indicated that predicted temperature increases have greater negative impacts on

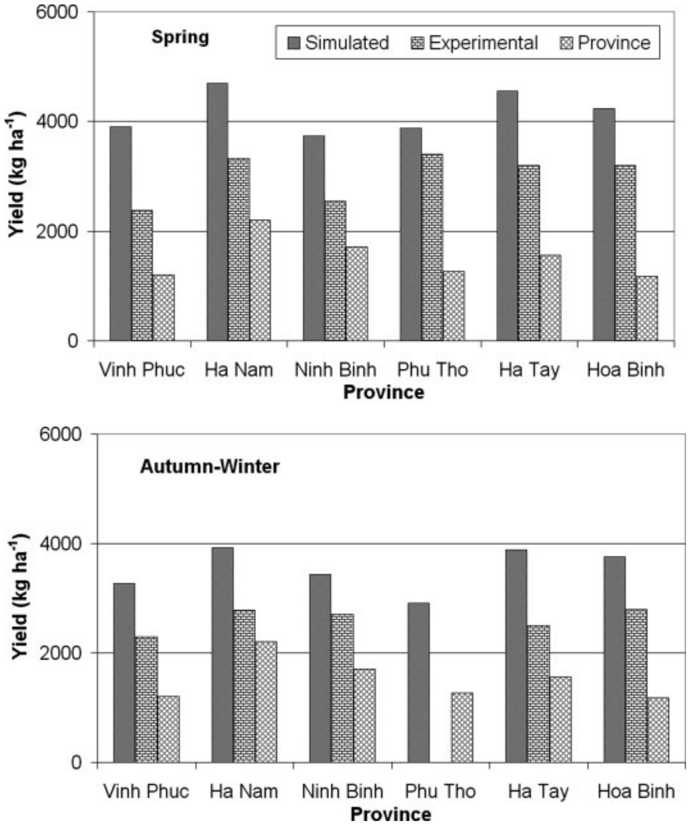


Figure 6.1 Simulated potential, experimental, and province mean pod yields and yield gap of rainfed groundnut in spring and autumn-winter seasons at selected sites in Northern Vietnam

crop production than relatively small changes in rainfall. They have shown that the ex ante analyses clearly illustrate both the challenges that climate risk poses as well as the opportunities that it can offer.

6.4 FIELD SENSORS AND DATA COMMUNICATION DEVICES

In watershed management, one important component is the collection and sharing of field data or ground information and integrating it into the processing and analysis of spatial data in real time, which helps in timely decision-making and taking up appropriate corrective measures. Field data collection typically consists of recording geographic location, photographs of the area at the sample points, notes on soils, crops, and land use and general details in a ground truth proforma. Collecting the data and putting it to use is normally done as a sequential process with a significant amount of time delay since the same scientists perform both the tasks and the entire ground truth data collection activity is normally allowed to be completed before starting the use of data.

Field data collection has undergone a number of changes from the days of hardcopy jottings on paper in the field to the use of laptops/palmtops in recent times. However, a combination of some of the recent technology trends promises to deliver significantly enhanced solutions in this area, which would benefit a wide range of users. The important technology areas impacting the field data collection process are described below.

6.4.1 Global Positioning System

Global Positioning System (GPS) is one of the important tools that brings location awareness to any application. While collecting and using any real time field data, the location from where it was collected is very important. GPS is a known electronic device to most of the tech-savvy people and has become an important tool for location awareness. Several location-based and location aware applications are being developed especially in emergency management, service and utility sectors. New developments and relaxations in security related matters have helped in improving the location accuracy to better than 15 m using ordinary code receivers. In differential mode, sub-meter accuracies are possible.

6.4.2 Automatic Weather Station

Collection of precise weather data at watershed level and transmission on real time basis is vital for resource management as well as for improving crop productivity. Automatic Weather Station (AWS) is an affordable way to get detailed weather information at the watershed areas. AWS records data on parameters such as rainfall, wind speed and direction, humidity, temperature, etc. Special sensors of particular interest can also be included in AWS, to measure soil temperature, leaf wetness, etc. AWS is a very compact, modular, rugged, powerful, and low-cost system. The AWS system consists of a compact datalogger, data transmitter, antenna, GPS, solar panel, and sensors. Power requirements are minimum and hence do not pose any operational problems. Sensors on AWS collect data at specified time interval and store the data in its memory. Logged weather data is transmitted at prescribed time slots through geostationary communication satellite systems. Datalogger, power supply, and battery are housed in a weather proof enclosure.

The AWS data finds extensive applications in agricultural monitoring (drought/crop condition assessment), crop management, disaster management (flood forecasting), and in other fields like transport. Near-real time information on weather and crops allows the calculation of water requirements of crops and hence invaluable for drought monitoring and management. Integration of relevant spatial and non-spatial information of natural resources and socioeconomic aspects related to agricultural drought is required for generation of a spatial decision support system and AWS data would be a value-addition for drought management.

6.4.3 Mobile devices

Mobile devices, which are of interest to field data collection process are Personal Digital Assistants (PDAs) and cell phones. PDAs are basically palm-size devices which originally started as high-end organizers, but quickly added a number of features like bigger LCD screens, color, keyboard, stylus, handwriting recognition, higher speed wired and wireless data connectivity to desktop systems, etc. With time, as processor power grew, their operating systems evolved and now compact Windows operating systems are adapted to these devices. Thus, desktop applications (word processing, spreadsheets, email clients, web browser, etc.) are made available on PDAs also. This forms a handy device to record and store field level information in an organized way.

Cellular phones, on the other hand, evolved from being primarily wireless voice communication devices to encompass various features like organizer, messaging, camera, music player, and Bluetooth connectivity. Over time these mobile phones became powerful tools with many other features like larger screen, deployment of custom applications, and web browser. Integrated mobile devices are also commonly equipped with a digital camera, which can be used to capture necessary field photographs for storing as well as sharing by email. Thus it forms an important component for communicating data wirelessly to any part of the world. Public wireless networks serving the common man like the cellular networks based on GSM and CDMA technologies have become widespread and ubiquitous in recent times.

PDA phone with GPS is the resultant of convergence of the PDA, cellular phone, and GPS technologies with a built-in camera. These PDA devices are becoming increasingly powerful with the deployment of powerful processors and larger memory. They also have bigger color touch screens and full QWERTY keypads for better inputting of data. With these powerful configurations, it is now possible to deploy rich Graphical User Interface (GUI) applications, which were considered to be difficult just a few years ago.

6.5 DATA STORAGE AND DISSEMINATION

Latest development in server technology has enabled availability of blade servers with RAID capabilities at a very cost effective price. These servers act as storehouses for storing the data in a safe and efficient way and can serve clients via network sharing and World Wide Web, in near-real time.

Internet is all pervasive and cost-effective technology where a number of applications are specifically designed to use the Internet and the related IP-based protocols to communicate and exchange data with one another, thereby optimizing the costs as well as ensuring widespread geographical reach. Internet connectivity on current PDA devices is easily ensured with an appropriate subscription to GPRS/EDGE feature from the wireless network service provider. Almost all present-day organizations have an Ethernet local area network in place for data communication among the various computer systems including servers, workstations, and desktop PCs. The same network is also invariably used to implement a number of intranet applications in addition to the traditional client-server based applications and databases on servers.

6.6 SPATIAL TECHNOLOGIES IN RAINFED AGRICULTURE AND WATERSHED MANAGEMENT

6.6.1 Characterization of production systems in India

Production systems (PSs) based approach to agricultural research was found to be more relevant at ICRISAT during the 1990s and the SAT was divided into 29 PSs.

A GIS database of PS maps consisting of soils, climate, crops and other socioeconomic variables was used. It was further proposed to refine these PSs using GIS to be able to compare with the national agroecological zones (AEZs) so that these PSs are useful for up-scaling and down-scaling of technologies (Johansen 1998).

Out of the 12 PSs in Asia, India has 10 types of PSs. Further, 12 were delineated in Latin America and 5 in Africa. A PS is defined by the environmental resources, geography, and important issues, or constraints to, and opportunities for improving productivity and sustainable agriculture (ICRISAT 1994).

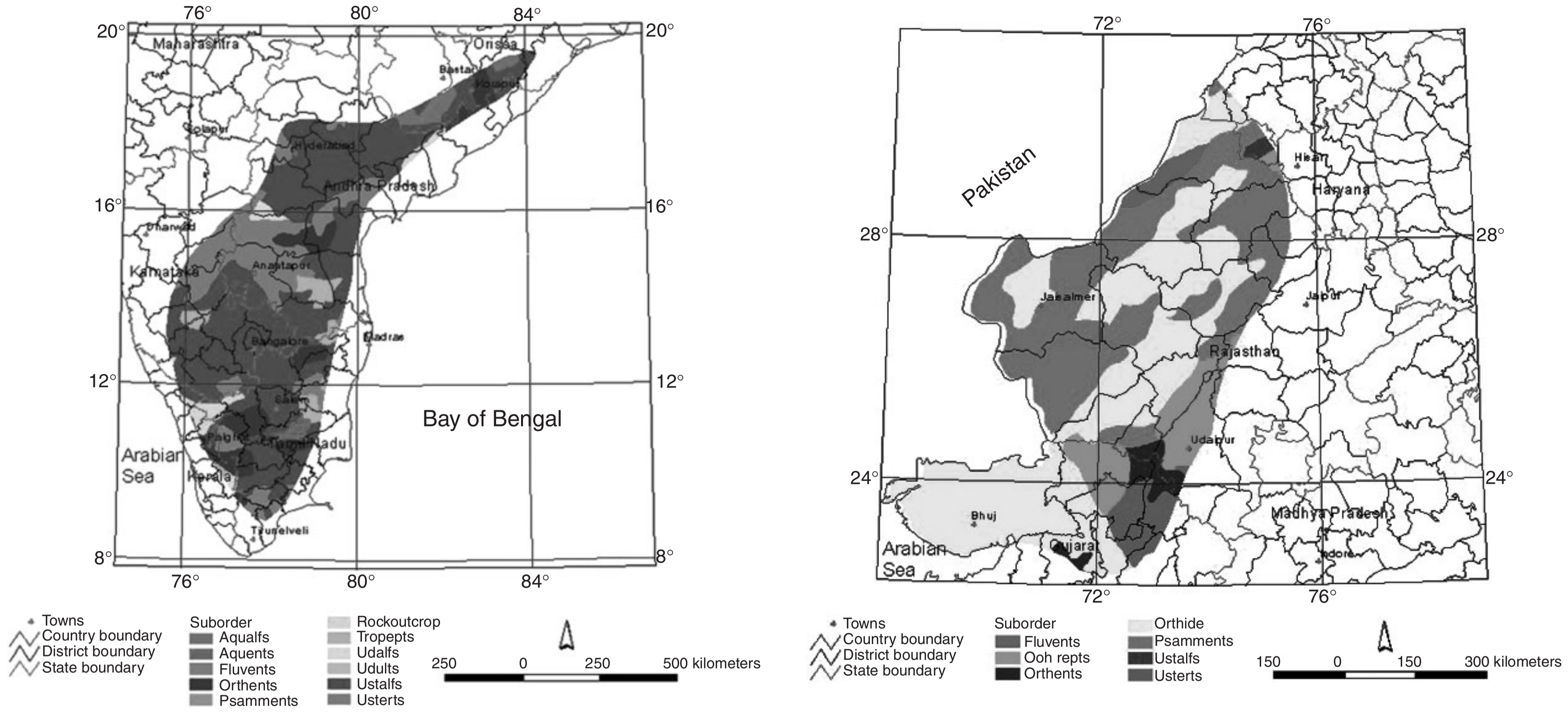
Preliminary definition of these PSs required that they assist in the prioritization essential for development of ICRISAT Medium Term Plans. It also allowed for better focusing of projects to particular PSs and of activities within projects. To identify the target regions and priority areas and allocate resources in PS research, the ability of GIS, which can analyze multiple layers of information and provide answers spatially, became evident.

Soil being the basis of life on earth and for agriculture, information on soil attributes was the most important input variable for any PS assessment. Production system-wise soil attributes were mapped and described to help researchers identify target locations for research and technology transfers. The NBSS&LUP map based on soil taxonomy was used in a GIS to provide soil information along with PS boundaries and district boundaries and area was estimated for each suborder in all the PSs.

Out of the 11 soil orders of soil taxonomy, seven occur in the 10 PSs in India. The Entisols are the most pervasive of all soils and occur in all the PSs. Alfisols (suborder Ustalfs) and Vertisols (suborder Usterts) are found in 8 of the 10 PSs, but Alfisols occupy a total area of 615016 km^2 and Vertisols 470148 km^2 in all the PSs with maximum area (Figure 6.2). This helped in understanding the soil types and their attributes in all the PSs of India to appropriately devise technologies and provide more options to farmers of the SAT.

6.6.2 Land use mapping for assessing fallows and cropping intensity

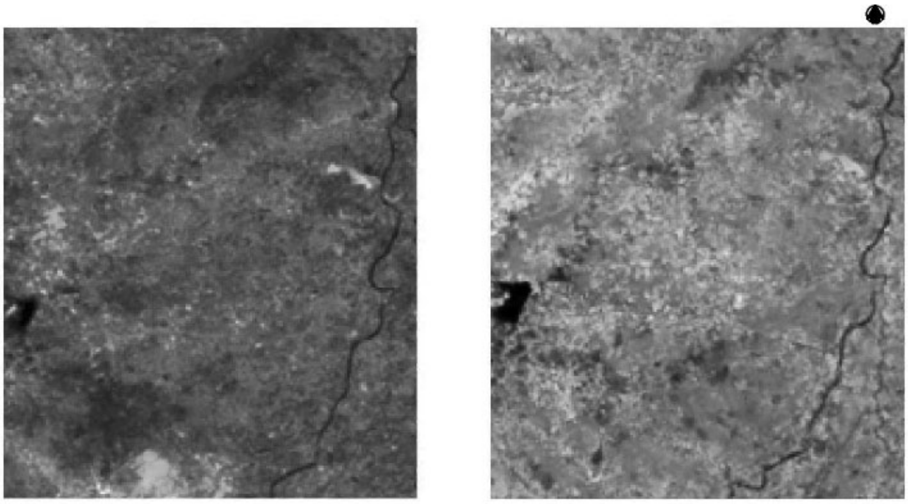
To delineate rainy season fallows in the state, data obtained from the Indian remote sensing satellite were analyzed. A deductive approach including delineation of agricultural land and forests from temporal satellite data was employed to identify (rainy season) fallow. Three sets of satellite data corresponding to three periods, namely mid-, late, and (postrainy) *season* were used. While mid-season satellite data provide information on agricultural lands, which were lying unutilized along with those agricultural lands that have been supporting crops, the satellite data of *season*, on the other hand, exhibited spatial distribution pattern of the land supporting crops. These lands include the areas, which were lying fallow during *season* in addition to the lands that were cultivated during *season*, and are now supporting crops. In contrast, satellite data acquired during late season showed agricultural lands that were laid fallow during *season* and the areas where crops were planted (Figure 6.3). Madhya Pradesh is covered by two WiFS (Wide Field Sensor) images. Owing to the presence of persistent cloud cover during *season*, the availability of cloud-free space borne multispectral data has been the major problem. However, very short repetivity and tandem operation of the IRS-1C and IRS-1D satellites, along with the IRS-P3 satellite, enabled acquiring



Source: NBSSA & LUP. 1985. digilized from a1:7 000 000 map
Projection: Lambert Conformal Conic

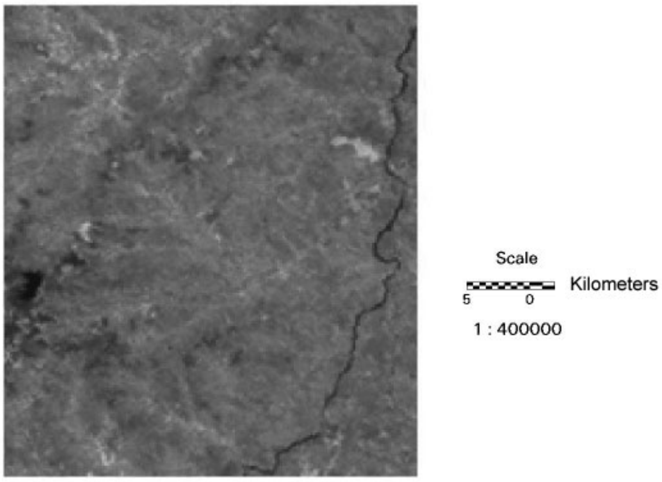
Source: NBSSA & LUP. 1985. digilized from a1:7 000 000 map
Projection: Lambert Conformal Conic

Figure 6.2 Distribution of different soil orders in the production systems in India (See color plate section)



Mid-rainy season image

Late-rainy season image



Postrainy season

Figure 6.3 A close view of WiFS images of part of Vidisha district, Madhya Pradesh during mid-rainy, late-rainy, and postrainy seasons (See color plate section)

virtually cloud-free WiFS data of September from IRS-1D and IRS-P3 satellites. The situation remains more or less same even during post-monsoon period also. Consequently, cloud-free WiFS data were not available and out of two images covering the former state of Madhya Pradesh, one image for October was used. Satellite data acquired during peak growing period of crops help identification of land where crops have been taken.

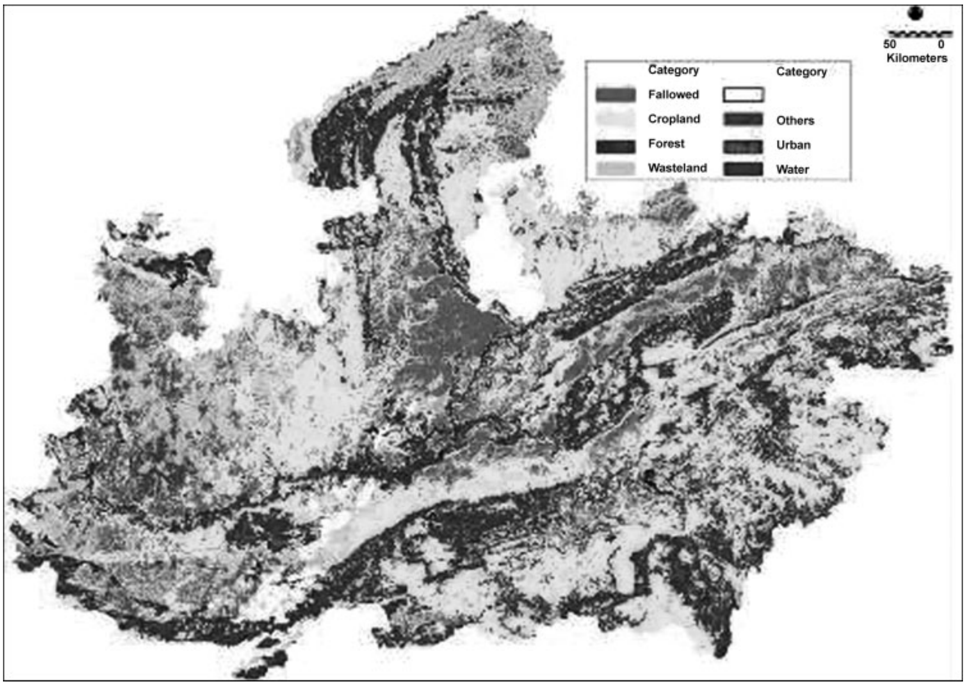


Figure 6.4 Spatial distribution of various land use and land cover categories in Madhya Pradesh (See color plate section)

Digital multispectral data from WiFS aboard IRS-1D/-P3 over the area acquired during the *season* of 1999–2000 and *season* of 2000–01 was utilized for deriving information on fallow lands. In addition, Survey of India topographic maps at 1:250,000 scales were also used (Figure 6.4). The approach essentially involved preparation of the mosaic of WiFS digital data covering entire state, preliminary digital analysis, ground truth collection, map finalization, and generation of area statistics.

Basically, a deductive approach was employed for delineation of fallow lands. Based on past experience, initially areas akin to fallow lands were identified after displaying the digital multispectral data onto color monitor of Silicon Graphics work station. Besides, topographic maps were used for exclusion of the areas with rock, outcrops, scrubs, hills, etc. Furthermore, other categories like forestland, crop land, wasteland, water, and settlements were also broadly delineated. Doubtful areas were located in the topographic maps of 1:250,000 scale for further verification in the field.

The second generation of Indian remote sensing satellites (IRS-1C and IRS-1D) have better resolution and wide applicability. The WiFS sensor provides reflectance data in red and near infrared bands at 188 m spatial resolution and at 5 days revisit, covering a swath of about 812 km, and is useful in deriving regional level crop information. Frequent availability of the WiFS data due to shorter revisit period also facilitates the monitoring of crops (Kasturirangan *et al.*, 1996). WiFS data was found to be suitable for deriving regional information on the spatial distribution of rice (*Oryza sativa*) crop grown in the Godavari delta of East and West Godavari districts and pulse crops cultivated in the rice-fallow fields of the Krishna delta of Krishna and Guntur districts of Andhra Pradesh, India (Navalgund *et al.*, 1996). In the present study, WiFS data of 1999 and 1999/2000 seasons were used to derive the regional level information on spatial distribution of rice and rice-fallow lands in the South Asian countries of Bangladesh, India, Nepal, and Pakistan.

Reflectance spectra of plant canopies are a combination of the reflectance spectra of plants and of the underlying soil (Guyot 1990). When a plant canopy grows, soil contribution progressively decreases. Thus, during the active vegetative growth phase, visible and middle infrared reflectance decreases and near infrared reflectance increases. During senescence, opposite phenomenon occurs. Maximum reflectance from vegetation is sensed when crop canopy fully covers the ground, which coincides mostly with the beginning of reproductive phase. Hence, satellite data corresponding to this stage were selected to discriminate rice crop during the season.

6.6.3 Spatial distribution of rainy season fallows in Madhya Pradesh

As pointed out earlier, a deductive approach including delineation of agricultural land and forests from temporal satellite data was employed to identify fallow in Madhya Pradesh. Three sets of satellite data corresponding to three periods, namely mid-season, late-*kharif* (rainy season), and *rabi* (postrainy season) were used. While mid-season satellite data provides the information on agricultural lands, which were lying unutilized along with those agricultural lands that have been supporting crops, the satellite data of *rabi*, on the other hand, exhibits the spatial distribution pattern of the land supporting crops. These lands include the areas, which were lying fallow during the season, and are now supporting crops. Contrastingly, the satellite data acquired during late season show the agricultural lands that were lying fallow during the season and the areas where crops were planted.

It was estimated that 2.02 million ha accounting for 6.57% of the total area of the state were under fallow (Figure 6.5). Madhya Pradesh is endowed with well distributed rains ranging from 700 to 1200 mm. Vertisols with good moisture holding capacity can be used to grow short-duration soybean by adopting sound land management practices (Dwivedi *et al.*, 2003). ICRISAT-led consortium through funding from Sir Dorabji Tata Trust (SDTT) and Sir Ratan Tata Trust (SRTT) in selected districts in Madhya Pradesh have initiated concerted farmer participatory research and development (PR&D) trials using broad-bed and furrow (BBF) system to alleviate waterlogging short-duration soybean and maize cultivars during rainy season and minimum tillage for *rabi* chickpea to minimize rainy season fallows.

6.6.4 Spatial distribution and quantification of rice-fallows in South Asia: Potential for legumes

Rice, the most extensively grown crop in South Asia, is cultivated on approximately 50 million ha. Despite growing demands for food production because of an increasing

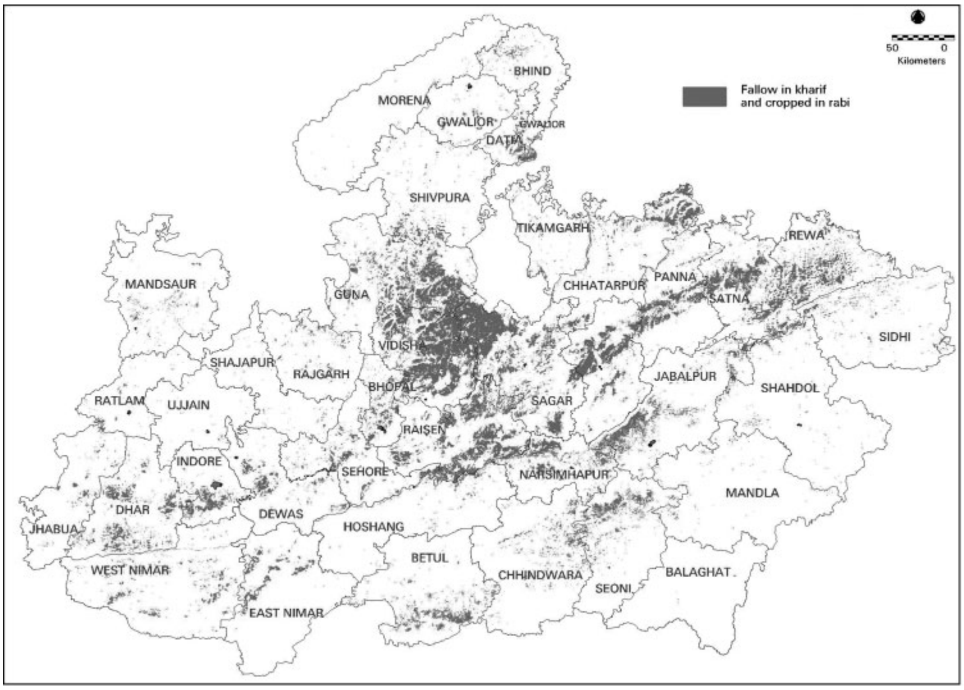


Figure 6.5 Spatial distribution of rainy season fallows in districts of Madhya Pradesh (See color plate section)

population in South Asia, there is little scope for expansion of cropping into new areas and therefore an increase in cropping intensity, along with improvement of yields, needs to take place on existing agricultural lands. Rice-fallows present considerable scope for crop intensification and diversification if the appropriate technology is applied. But there has been limited information on the area of rice-fallows available and on the potential technologies that could be implemented.

This study describes the use of satellite remote sensing and GIS technology to develop an accurate and updated quantification and spatial distribution of rice-fallow lands and a corresponding classification of their potential and constraints for post-rice legumes cultivation in South Asia (Bangladesh, India, Nepal, and Pakistan). These rice-fallows represent diverse soil types and climatic conditions and most of these areas appear suitable for growing either cool season or warm season legumes.

Introducing appropriate legumes in rice-fallows is likely to have significant impact on the national economies through increased food security, improved quality of nutrition to humans and animals, poverty alleviation, employment generation, and contribution to the sustainability of these cereal-based PSs in South Asia. This would also provide guidance to policy makers and funding agencies to identify critical research areas and to remove various bottlenecks associated with effective and sustainable utilization of rice-fallows in South Asia.

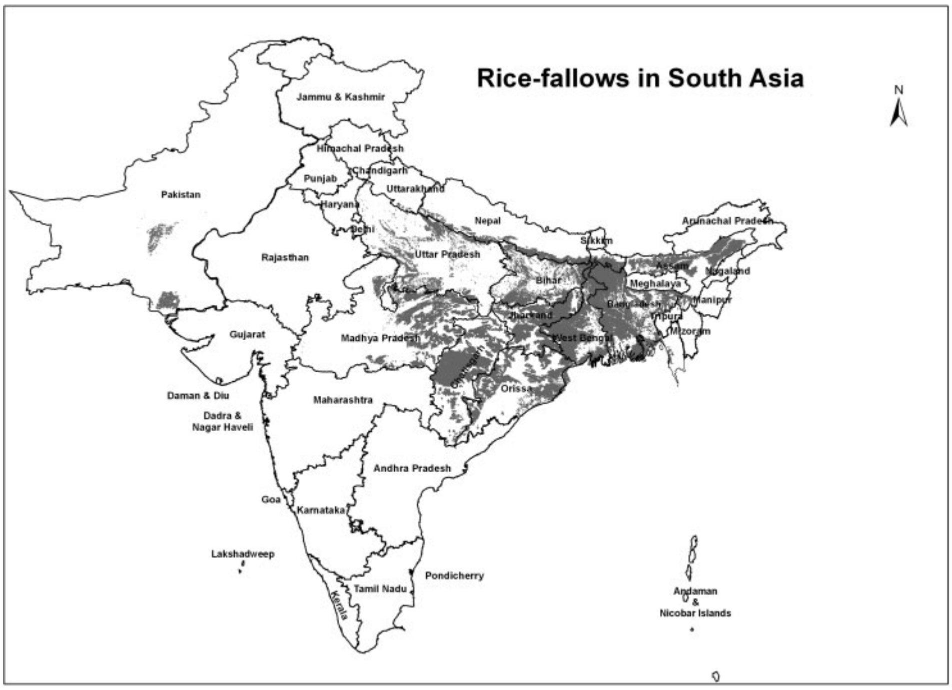


Figure 6.6 Spatial distribution of rice-fallows in the Indo-Gangetic Plains of South Asia (See color plate section)

Satellite image analysis estimated that rice area during 1999 season was about 50.4 million ha. Rice-fallows during 1999/2000 season were estimated at 14.29 million ha in Bangladesh, India, Nepal, and Pakistan. This amounts to nearly 30% of the rice-growing area (Figure 6.6). These rice-fallows offer a huge potential niche for legumes production in this region. Nearly 82% of the rice-fallows are located in the Indian states of Bihar, Madhya Pradesh, West Bengal, Orissa, and Assam. The GIS analysis of these fallow lands has indicated that they represent diverse soil types and climatic conditions; thus a variety of both warm season legumes [such as soybean (*Glycine max*), mung bean (*Vigna radiata;* green gram), black gram (*Vigna mungo*), pigeonpea (*Cajanus cajan*), and groundnut (*Arachis hypogaea*)] and cool season legumes [such as chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), *khesari* (*Lathyrus sativus*; grass pea), faba bean (*Vicia faba*), and pea (*Pisum sativum*)] can be grown in this region (Subbarao *et al.*, 2001).

An economic analysis has shown that growing legumes in rice-fallows is profitable for the farmers with a benefit-cost ratio exceeding 3.0 for many legumes. Also, utilizing rice-fallows for legume production could result in the generation of 584 million person-days employment for South Asia. Technological components of rainfed cropping, especially for chickpea crop, have been identified. These include the use of short-duration chickpea varieties, block planting so as to protect the crop from grazing animals, sowing using rapid minimum tillage as soon as possible after harvesting rice, seed priming for 4 to 6 hours with the addition of sodium molybdate to the priming water at 0.5 $g\,L^{-1}\,kg^{-1}$ seed and *Rhizobium* inoculum at 5 $g\,L^{-1}\,kg^{-1}$ seed, and application of manure and single superphosphate. Yield of chickpea following rice ranged from 0.4 $t\,ha^{-1}$ to 3.0 $t\,ha^{-1}$ across various rice-fallow areas in eastern India. More than six thousand farmers who have been exposed to this technology are now convinced that a second crop can be grown without irrigation in rice-fallows. Similar results have been obtained for the Barind region in Bangladesh. Seed priming has been shown to substantially improve the plant stand for chickpea in rice-fallows in the Barind regions of Bangladesh (Harris *et al.*, 1999). Rainfed cropping in rice-fallow areas increased incomes and improved food security and human nutrition (Subbarao *et al.*, 2001). In a number of villages in Chhattisgarh, Jharkhand, and Madhya Pradesh in India, the on-farm farmers' participatory action research trials sponsored by the Ministry of Water Resources, Government of India showed significantly enhanced rainwater use efficiency through cultivation of rice-fallows with a total production of ₹5600 to 8500 $kg\,ha^{-1}$ for the two crops (rice + chickpea) benefiting farmers with increased average net income of ₹51000 to 84000 ha^{-1} (US\$1130 to 1870 ha^{-1}) (Singh *et al.*, 2010).

6.6.5 GIS mapping of spatial variability of soil micronutrients at district level

Spatial variability of secondary nutrient sulfur and micronutrients boron and zinc in selected rainfed districts of Karnataka in South India was studied using GIS. Stratified random sampling methodology described by Sahrawat *et al.* (2008) was used for collecting soil samples from each watershed. About 30,000 soil samples were collected and analyzed for soil nutrients including boron, sulfur, and zinc content. Village-level geographical coordinates were obtained using a GPS. The IDW method in the ArcGIS 9.0 software for interpolation was standardized in this study. Nutrient availability maps for 15 districts were generated for all nutrients including boron, sulfur and zinc (Figure 6.7). All maps of predicted surfaces are classified into two classes viz., deficient and sufficient. Boundary limits of nutrient availability for the critically low, low, and normal classes were obtained from standard results (Sahrawat *et al.*, 2007).

Through the standardized GIS-based interpolation method, agricultural extension personnel and farmers in watersheds can be provided with reliable and cost-efficient soil analysis results of selected districts for developing balanced nutrient management strategies at *taluk* level. However, due to limitations in the IDW method, the generated maps are to be used only at district or *taluk* level and not for predicting the nutrient availability at single field level.

6.6.6 Assessment of seasonal rainfall forecasting and climate risk management options for peninsular India

Uncertainty of the climate and weather in the SAT has adverse effects on crop production and farmer income. Farmers are traditionally risk averse and conservative in adopting high input improved technologies because of the uncertainties in production associated with variable climate. Seasonal climate prediction before onset of the season could help them in taking appropriate decisions to minimize losses in low rainfall years and harness the potential in the normal or high rainfall years. With

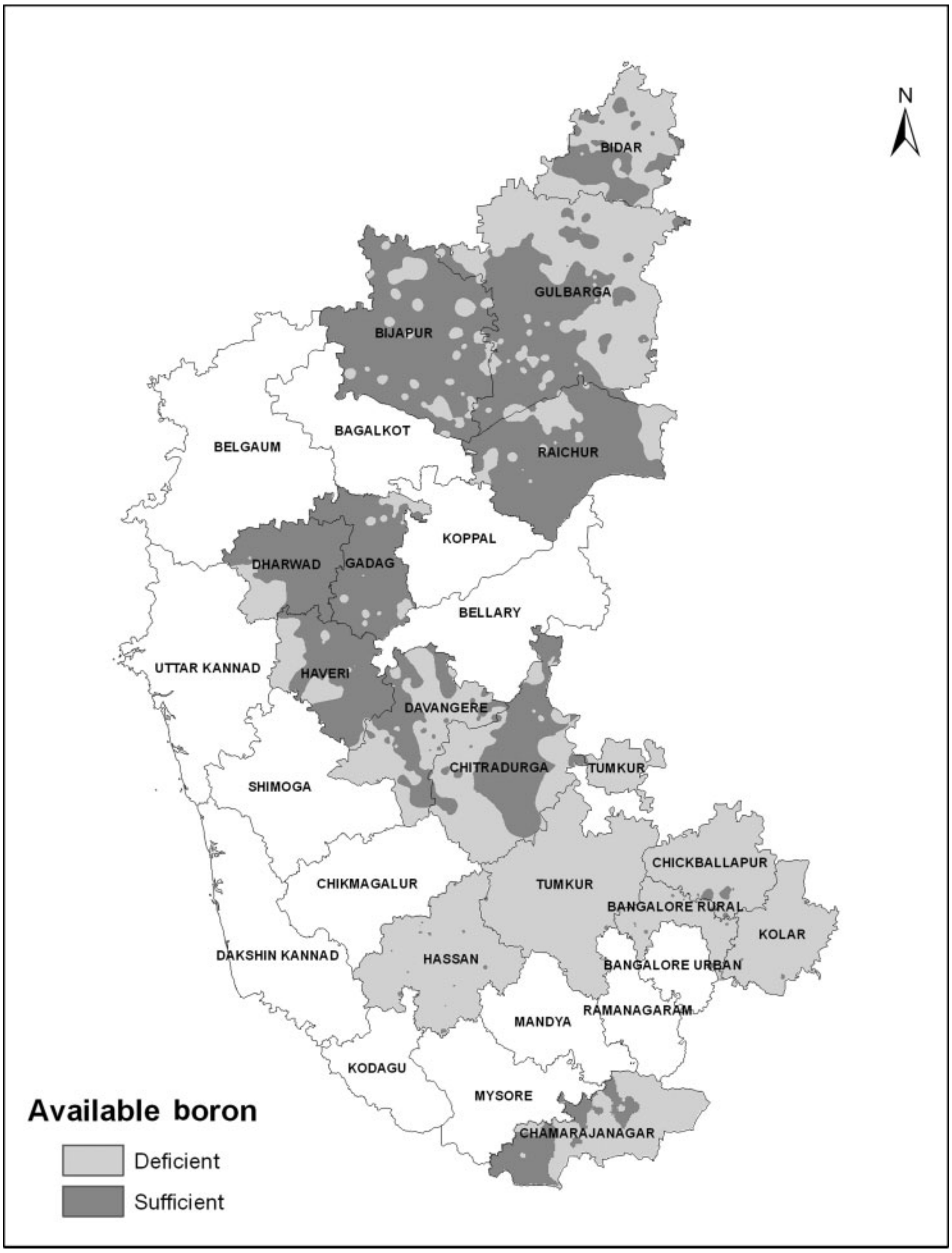


Figure 6.7 Availability of boron in selected districts of Karnataka (See color plate section)

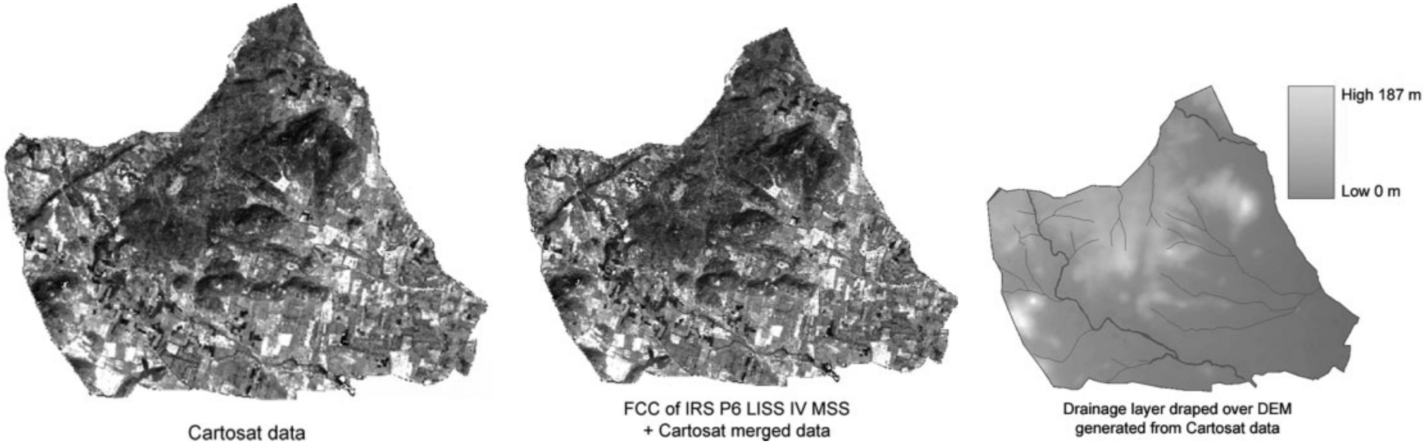
the technical input from the International Research Institute on Climate Prediction, a pilot project was carried out in Nandyal and Anantapur in Andhra Pradesh to assess the value and benefit of seasonal climate prediction at district scale to the farmers (Rao *et al.*, 2007). Using Global Circulation Model (GCM) predictor-based model output statistical (MOS) technique, the probabilistic seasonal rainfall prediction for 2003 was communicated to the farmers at a lead time of more than a month to take up appropriate cropping decisions for the two districts. Seasonal climate prediction for Nandyal proved accurate and the farmers derived significant benefit by adopting double cropping in the region as compared to the single crop. Farmers in Anantapur had mixed experience as the rains started late in the district. The farmers who adopted groundnut/short-duration pigeonpea intercrop were benefited and those who followed groundnut/medium-duration pigeonpea intercrop incurred losses as compared to the sole groundnut system.

6.6.7 Baseline studies to delineate watershed

Accurate delineation of a watershed plays an extremely important role in the management of the watershed. The delineated boundaries form the nucleus around which the management efforts such as land use, land cover change, soil types, geology, and river flows are analyzed and appropriate conclusions drawn. Digital elevation models provide good terrain representation from which watershed boundary can be delineated automatically using GIS technology. There are various data sources for generation of DEM. Usually, the height contours mentioned in topographical maps are digitized and are used for generation of DEM. Besides, photogrammetric techniques using stereo data from aerial or satellite platforms can also be used for DEM generation. In this context, data acquired across the path from satellites like IRS-1D and SPOT has shown temporal variation in terrain radiometry leading to poor DEM accuracies. To improve cross image correlation between stereo pair imagery, Cartosat-1 launched with two cameras beaming along the path with which DEM of 3–4 m height accuracy (Srivastava *et al.*, 2007) was achieved. Further, processing techniques like stereo strip triangulation has greatly improved throughput of DEM generation with limited ground control points and short time. Besides, the latest developments in interferometry and laser altimetry enable faster and precise generation of DEMs, especially the recent developments in laser altimetry and its data processing enable generation of DEM with centimeters accuracy under ideal condition.

The techniques for automated watershed delineation have been available since mid 1980s and have been implemented in various GIS systems and custom applications (Garbrecht and Martz 1999). Figure 6.8 portrays the Cartosat-1 data and the DEM derived therefrom along with LISS-IV multispectral data. In Figure 6.9, the perspective view generated from the DEM draped with LISS-IV multispectral data is presented. The field of view was 50, pitch was -5, and the azimuth was 328. This sort of analysis helps in understanding the watershed terrain in a perspective way. Besides, extraction of watershed boundaries from Cartosat-1 DEM in an automated way is also possible. For such extraction of watershed boundaries, identification of pour points (watershed outlet) is a prerequisite. Further, the DEM needs to be filled for sinks so that the runoff is accumulated as a concentric flow and passes through one of the outlets.

Watershed characterization involves inventorying and assessment of natural resources which are essential prerequisites of any watershed management activity. For example, watershed managers need timely and reliable information on soils, crops, groundwater potential, and land use. Similarly, an assessment of the properties of



Cartosat data

FCC of IRS P6 LISS IV MSS + Cartosat merged data

Drainage layer draped over DEM generated from Cartosat data

Figure 6.8 Satellite data and DEM of watershed in part of Nalgonda district, Andhra Pradesh (See color plate section)

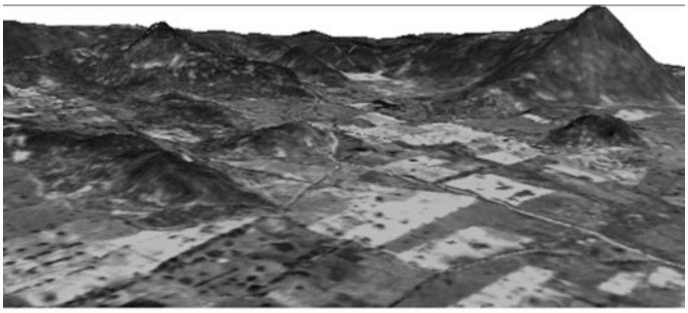


Figure 6.9 False Color Composite (FCC) draped over DEM for perspective view of watershed in part of Nalgonda district, Andhra Pradesh (See color plate section)

the soils and their response to management is required in agriculture and forestry, for decision-making in planning, and for many other engineering works. It has been proved beyond doubt that remotely sensed data can be effectively used to prepare maps on various themes such as land use/land cover, soil distribution, geomorphology, etc., which in turn form the basic tools for designing a proper management strategy. High resolution remotely sensed data when used in conjunction with conventional data can provide valuable inputs such as watershed area, size and shape, topography, drainage pattern, and landforms for watershed characterization and analysis (Obi Reddy *et al.*, 2001).

Prioritization of watersheds helps in focusing the implementation activities on a few watersheds that urgently need attention. Watershed prioritization is simply ranking of different sub-watersheds of a watershed according to the order in which they have to be taken up for treatment and soil and water conservation measures or to improve crop productivity. This also helps to avoid spreading too thin, the limited financial resources available for implementation over the entire area. Remote sensing derived inputs were considered for prioritizing the watershed when it is based on natural resources limitations or potentials in a watershed (Sharma 1997; Rao *et al.*, 1998; Saxena *et al.*, 2000; Khare *et al.*, 2001; Sekhar and Rao 2002; NRSA 2006).

The prioritization of watersheds in India is on the basis of natural resources status, and socioeconomic, biophysical, and other criteria. During initial stages, soil erosion control was the prime concern for watershed prioritization. Various methods were developed in this regard for watershed prioritization like sediment yield modeling (Sharma 1997) or erosion-proneness of land units (Sekhar and Rao 2002). Subsequently, land productivity was also considered through identification of critical areas (NRSA 2006). In latest guidelines for prioritization of watersheds the combination of natural resources, problem areas, and socioeconomic conditions (agricultural laborers, schedule caste and schedule tribe population, distribution of below poverty line families) were considered for prioritization.

Geospatial data and multi-criteria based prioritization of watersheds help in making unbiased choice of target areas for development. The multi-layer geospatial analysis results in the generation of composite mapping units which could further be processed through multi-criteria analysis to arrive at the end result. GIS and IT tools at watershed level have been successfully used to establish a strong baseline information system and prioritization (Khan *et al.*, 2001; Thakkar and Dhiman 2007; Diwakar and Jayaraman 2007). Success of conservation measures whether it is vegetative or structural, depends upon the selection of suitable sites. Various factors such as physiography, soil characteristics, and topographic features of the terrain have to be considered to arrive at a decision regarding sites for conservation measures. Computer-based database management systems for terrain and elevation modeling and GIS have enhanced the potential of remotely sensed data in identifying suitable locations for conservation measures.

6.6.8 Regional-scale water budgeting for SAT India

A soil water balance model (WATBAL) (Keig and McAlpine 1974) was used to estimate the available soil water spatially (2.5 arc minutes 4.5 km approximately) and temporally (monthly) using the above pedo-climatic datasets to run WATBAL. Input data for the WATBAL model are the precipitation and potential evapotranspiration (PET) as gridded interpolated surfaces from point data. The interpolated climatic surfaces are available at monthly temporal resolution. Maximum soil water-holding capacity is extracted from the Digital Soil Map of the World and its derived soil properties (FAO 1996).

For prioritization and selection of target regions for watershed development, first-order water budgeting using GIS-linked water balance model was used for the selected states in central and peninsular India. Such a simulation model used with monthly rainfall and soils data generated outputs that can be effectively used to prioritize the regions and strategies for improved management of rainwater (Figure 6.10). Once the target region is selected, then the selection of appropriate benchmark sites using second-order water budgeting with more detailed simulation models can be applied. The GIS map produced using this methodology shows the potential of various regions in central and peninsular India for the amount of water surplus available for water harvesting and groundwater recharging.

6.6.9 Spatial water balance modeling of watersheds

In partnership with Michigan State University, USA, we have attempted to integrate topographic features of watersheds with hydrological models. Automation of terrain analysis and use of DEMs have made it possible to quantify topographic attributes of the landscape for hydrological models. These topographic models, commonly called digital terrain models, partition the landscape into series of interconnected elements, based on topographic characteristics of landscape and are usually coupled to a mechanistic soil water balance model. Partitioning between vertical and lateral movement at a field-scale level helps to predict complete soil water balance and consequently available water for plants over space and time.

Data generated in the black soil watershed (BW 7) on-station experiment at ICRISAT, Patancheru, India was used for validating the model developed at Michigan

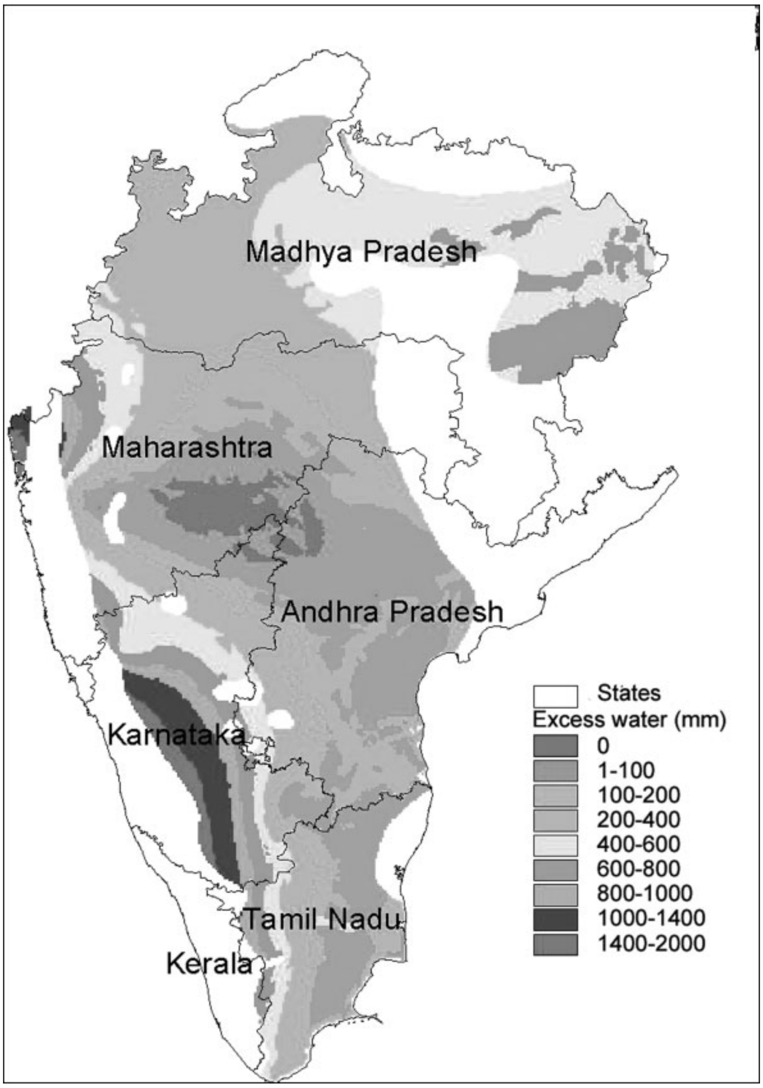
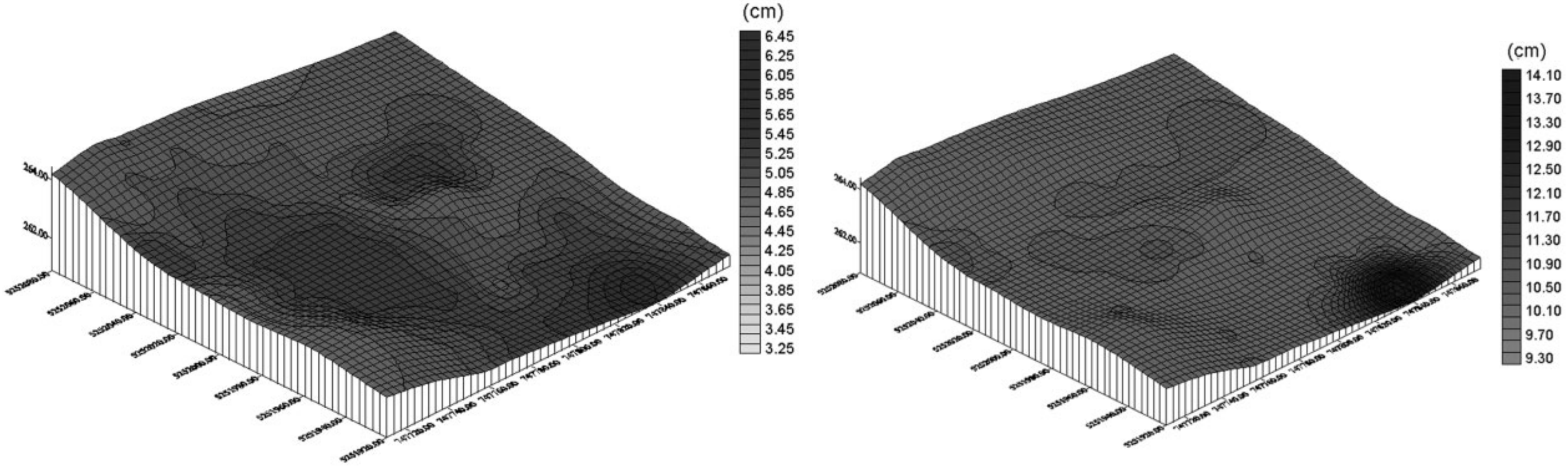


Figure 6.10 Excess water available for harvesting as runoff during June–October in the states of SAT India (See color plate section)

State University. This partnership research led to the development of SALUS-TERRAE, a digital terrain model for predicting the spatial and temporal variability of soil water balance. A regular grid DEM provided the elevation data for SALUS-TERRAE. We have successfully applied the SALUS-TERRAE, which was a functional spatial soil water balance model, at a field scale to simulate the spatial soil water balance and identified how the terrain effects the water routing across the landscape. The model provided excellent results as compared with the field-measured soil water content (Figure 6.11).



0-26 cm depth

26-77 cm depth

Figure 6.11 Soil water content on day-2 for scenario 1 (uniform soil type, high rainfall, no restricting soil layer)

6.7 INTEGRATED WATERSHED MANAGEMENT FOR LAND AND WATER CONSERVATION AND SUSTAINABLE AGRICULTURAL PRODUCTION IN ASIA

6.7.1 Assessment of agroclimatic potential

Maximizing agricultural production from rainfed areas in a sustainable manner is the need of the day to feed the ever-increasing population. Knowledge on agroclimatology is a valuable tool in assessing the suitability of a watershed for rainwater harvesting and crop planning. Role of climate assumes greater importance in the semi-arid rainfed regions where moisture regime during the cropping season is strongly dependent on the quantum and distribution of rainfall vis-à-vis the soil water-holding capacity and water release characteristics. In spite of cultivation of high-yielding varieties, improved cultural practices and plant protection measures and favorable weather are essential for good harvests (Rao *et al.*, 1999). A thorough understanding of the climatic conditions helps in devising suitable management practices for taking advantage of the favorable weather conditions and avoiding or minimizing risks due to adverse weather conditions. Agroclimatic analysis and characterization of watersheds need to be carried out using databases having long-period weather data and agroclimatic datasets need to be developed at individual watershed level. Agroclimatic analysis of the watersheds is based on the concepts of rainfall probability, dry and wet spells, water balance, length of growing period (LGP), droughts, crop-weather modeling and climate variability and change. Enhancing climate awareness among the rural stakeholders using new IT tools is the need of the hour.

6.7.2 Climatic water balance

Availability of water in right quantity and at the right time and its management with suitable agronomic practices are essential for good crop growth and yield. To assess water availability to crops, soil moisture should be taken into account and the net water available through soil moisture can be estimated using water balance technique. Simple single-layer water balance model of Thornthwaite and Mather (1955) outputs various water balance elements like actual evapotranspiration (AET), water surplus, and water deficit based on rainfall, PET, and soil water-holding and release properties. PET (i.e., amount of water that is lost into the atmosphere through evaporation and transpiration from a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile) can be estimated using the modified FAO-Penman-Monteith method (Allen *et al.*, 1998). Water balance though simple, is a powerful tool to quantify water deficit, water surplus, and runoff potential, to delineate the rainfed LGP, dry and wet spells during the crop growth period, and to monitor moisture stress leading to drought in watersheds.

6.7.3 Climatic water balance of watersheds in China, Thailand, Vietnam, and India

Weekly water balances of selected watersheds in China, Thailand, and Vietnam were completed based on long-term agrometeorological data and soil type. The water balance components included PET, AET, water surplus, and water deficit. PET varied

Table 6.2 Annual water balance characters (all values in mm)[a]

Country	*Location*	*Rainfall*	*PET*	*AET*	*WS*	*WD*
China	Xiaoxingcun	641	1464	641	Nil	815
	Lucheba	1284	891	831	384	60
	Wang Chai	1171	1315	1031	138	284
Thailand	Tad Fa	1220	1511	1081	147	430
Vietnam	Vinh Phuc	1585	1138	1076	508	62
India	Bundi	755	1641	570	186	1071
	Guna	1091	1643	681	396	962
	Junagadh	868	1764	524	354	1240
	Nemmikal	816	1740	735	89	1001
	Tirunelveli	568	1890	542	Nil	1347

[a] PET = Potential evapotranspiration; AET = Actual evapotranspiration; WS = Water surplus; WD = Water deficit.

from about 890 mm at Lucheba in China to 1890 mm at Tirunelveli in South India (Table 6.2). AET values are relatively lower in the watersheds in China and India compared to those in Thailand and Vietnam. Varying levels of water surplus and water deficit occur in the watersheds. Among all the locations, Tirunelveli in India has the largest water deficit (1347 mm) level and no water surplus. Chine in Vietnam has the largest water surplus level of 907 mm. These analyses defined the dependability for moisture availability for crop production and opportunities for water harvesting and groundwater recharge.

6.7.4 Rainfed length of growing period

Knowledge on the date of onset of rains will help plan better the agricultural operations, particularly, land preparation and sowing. Length of rainy season is the duration between onset and end of agriculturally significant rains. Rainfed LGP is defined as length of the rainy season plus the period for which the soil moisture storage at the end of rainy season and the postrainy season and winter rainfall can meet the crop water needs. Therefore, LGP depends on not only the rainfall distribution but also the soil type, soil depth, and water retention and release characteristics of the soil. This assumes greater importance from a watershed perspective where soil depth in a toposequence can also alter the LGP across the watershed being highest in the low-lying regions and lowest in the upper reaches of the watersheds.

Agroclimatic characterization of selected watersheds in Nalgonda, Mahabubnagar, and Kurnool districts of Andhra Pradesh based on water balance and rainfed LGP (Kesava Rao *et al.*, 2007) indicated that the beginning and end of the crop-growing season varied across the years in the watersheds. In all the watersheds, the end was more variable compared to the beginning; however, there was no definite relationship between the beginning and length of growing season. Nemmikal (medium-deep Vertisol) and Nandavaram (deep Vertisol) watersheds provide greater opportunity for double cropping. Appayapally, Thirumalapuram, and parts of Nemmikal watersheds having medium-deep Alfisols, provide opportunity for double cropping with relatively short-duration crops, but are more suitable for intercropping with medium-duration crops like pigeonpea and castor (*Ricinus communis*). Kacharam, Mentapally,

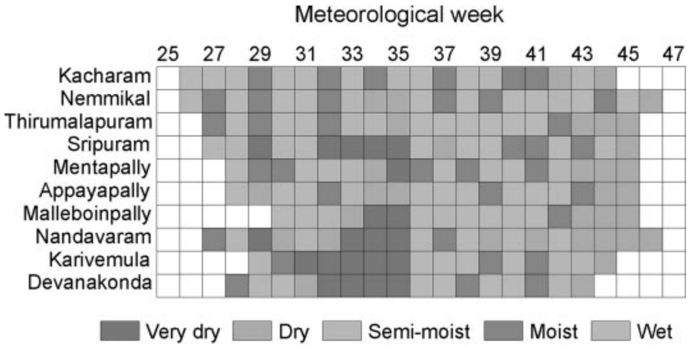


Figure 6.12 Drought monitoring at benchmark watersheds in Andhra Pradesh during 2004 (See color plate section)

Sripuram, Malleboinpally, and Karivemula have medium-deep Alfisols and provide greater potential for sole cropping during rainy season with crops of 120 to 130 days duration and intercropping with short- to medium-duration crops to make better use of soil water availability. Early season drought occurs at Karivemula and Thirumalapuram and early and mid-season droughts occur at Nandavaram. These sites would require crop/varieties tolerant to early or mid-season droughts depending upon the location. Mentapally, Malleboinpally, Nemmikal, and Appayapally have greater potential for water harvesting.

6.7.5 Drought monitoring at watersheds

Based on the weather data generated by the AWS and using the simple water balance model, weekly moisture stress conditions were monitored at selected benchmark watersheds during 2004 in Andhra Pradesh (Figure 6.12). The analysis indicated that among the 10 watersheds, the longest crop growing period of about 21 weeks was observed at Nemmikal while Karivemula and Devanakonda had only 16 weeks. Kacharam, Nemmikal, Thirumalapuram and Appayapally experienced good moisture conditions. Sripuram, Nandavaram, and Devanakonda experienced severe drought conditions before flowering period. Karivemula experienced a disastrous drought of 5-week duration. At most locations, growing period ended by 1st week of November, two-weeks early compared to the normal. Near-real time monitoring of moisture conditions at watershed level offers great scope in drought management for stabilizing crop yields.

6.7.6 Weather forecasting for agriculture

Day-to-day agricultural operations are weather sensitive; hence farmers show keen interest to know the weather in advance. Weather forecasts provide guidelines for seasonal planning and selection of crops and day-to-day management practices. Weather forecasts for agricultural operations are required in terms of rainfall and its intensity, air temperature, wind speed and direction, humidity, and sunshine/radiation. All three types of weather forecasts, viz., short, medium, and long range, are being issued by the India Meteorological Department (IMD).

One of the major functions of weather forecasts is to provide need-based information to enable the farmers to decide on taking a positive action, evasive action, or no action at all. Weather-based advisories can help farmers in minimizing the loss of inputs mainly seed, diesel, fertilizer, pesticide, labor, and time. Recommendations of land preparation for nursery and sowing will be of great help to farmers. IMD in collaboration with several organizations is implementing Agromet Advisory Services on an experimental basis at about 125 locations in India. Improvement in the accuracy of forecasts and providing appropriate advisory will result in increased economic returns. A state-of-the-art Integrated Forecasting and Communication System was implemented during September 2010 at IMD, New Delhi that is expected to provide more accurate weather data. Weather alerts by E-mail are being planned.

An understanding of the distribution and magnitude of biophysical resources of watersheds is required to develop technology intervention plans for the management of natural resources and to increase agricultural productivity in an area. Characterization of agroclimatic and other biophysical resources such as soils and vegetation resources of the watersheds helps in planning and in quantifying the impacts made during the project period as well as at the termination of the project.

6.7.7 Watershed monitoring

Repetitive nature of satellite data enables monitoring change and assists in understanding the effect of management activity undertaken. Projects like Integrated Mission for Sustainable Development (IMSD), National Agricultural Technology Project (NATP), and Sujala watershed project demonstrated the operationalization of remote sensing in the sphere of watershed management, ranging from resource appraisal to implementation and monitoring (NRSA 1995, 2002; Kaushalya Ramachandran *et al.*, 2010; Rao *et al.*, 2010). Cyclic revisit of space-borne sensors enables to repetitively cover the same watershed at regular time intervals to detect, monitor, and evaluate the changes occurring in the treated watersheds. Satellite images of watersheds acquired during pre- and post-treatment periods offer a rich source of information about the process of implementation of the program and its impact. Changes like increase in crop land, cropping intensity, clearing of natural vegetation, change in surface water spread/levels, afforestation, etc. could be monitored using multi-date satellite images.

6.7.8 Satellite images for impact assessment

Remotely sensed data has the advantages of providing synoptic view and large area coverage, which helps in obtaining a bird's-eye view of the ground features. Satellites, which orbit around the earth, provide a vantage point to find, measure, map, and monitor the earth's natural resources. Remotely sensed data potentially offer a rich source of information about conditions on the earth surface that change over time. Measuring and evaluating changes in a landscape over time is an important application of remote sensing. With the launch of Indian Remote Sensing (IRS) satellites, data availability both in the multispectral and panchromatic domains with varieties of spatial resolution is assured for the user community. The repetitive coverage of the same area over a period of time provides a good opportunity to monitor the land resources and evaluate land cover changes through a comparison of multi-temporal images acquired for the same area at different points of time. Changes like increased area under cultivation, conversion of annual crop land to horticulture, change in surface water body, afforestation, soil reclamation, etc. could be monitored through satellite remote sensing. Due to large area coverage at different points of time, the technology facilitates evaluating the ground realities at any given point of time.

The satellite images from different space platforms have various sensors in the visible and infrared region and are good for assessing the dynamics of watershed development, type of vegetation, crop vigor, crop growth, green biomass, and soil and water characteristics of a watershed. However, these sensors have a constraint of not being able to sense the earth's surface during cloud cover conditions. This is particularly a constraint while imaging in the optical region of the electromagnetic spectrum during the *kharif* season.

6.7.9 Monitoring and evaluation of NWDPRA watersheds using remote sensing

During the first phase of the project, 60 watersheds were identified for impact evaluation in Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, and Uttar Pradesh. Similarly, evaluation of 62 NWDPRA (National Watershed Development Project for Rainfed Areas) watersheds treated during the 9th Five Year Plan period was taken up during the second phase in Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttaranchal (Uttarakhand), Uttar Pradesh, and West Bengal. Evaluation of identified watersheds was carried out using remote sensing technique by considering the parameters such as *cropped area*: change in area extent of agricultural crops, cropping pattern, extent of wetland and irrigated crops; *plantations*: increase in agricultural and forest plantations; *wastelands*: change in aerial extent; *alternate land use*: switching over from marginal crop land to agro-horticulture and agroforestry; *water body*: change in number and aerial spread; and *biomass*: overall changes in biomass or canopy cover or productivity.

Satellite remote sensing data of identified watersheds pertaining to pre- and post-treatment periods were analyzed. The analysis involved geometric corrections, digitization, and extraction of the study area from the satellite imagery, preparation of land use/land cover maps of two periods data, preparation of normalized difference vegetation index (NDVI) images for both data sets, and quantification of improvements in the arable and non-arable lands using time-series analysis of both data sets. Digital analysis of satellite data was carried out at the Regional Remote Sensing Service Centre (RRSSC), ISRO. The analysis involved geometric correction of image data with respect to reference map to start with, digitization of watershed boundary, land use/land cover mapping, and NDVI generation and image comparisons (Figure 6.13). Geometric correction of IRS-LISS-III sensor data covering the study area was done through acquisition of ground control points (GCPs) from 1:50,000 reference map with respect to corresponding satellite images followed by computation of polynomial transformation model with two-way relationship, followed by output image generation through resampling techniques to obtain rectified final image. Image-to-image

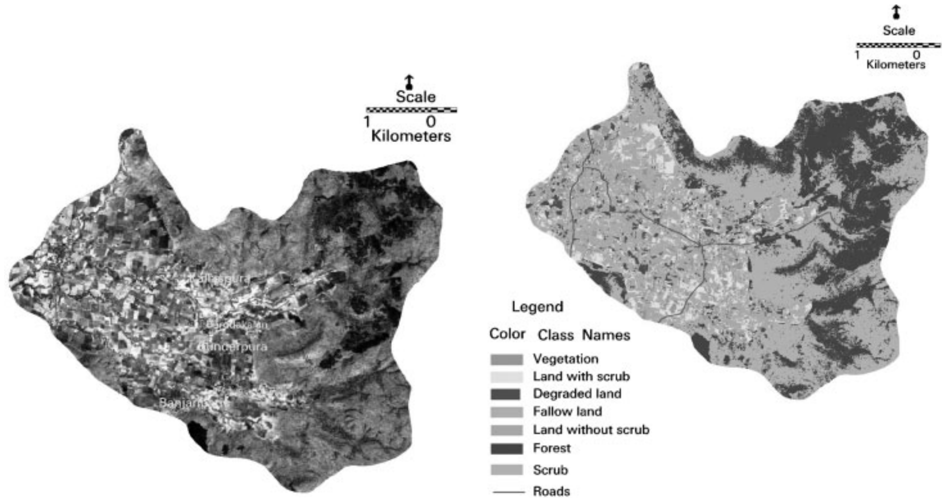


Figure 6.13 NDVI Image of Guna watershed in Madhya Pradesh (See color plate section)

registration of two-date satellite data was done by identifying accurate common GCPs on both images for computing yet another transformation model followed by re-sampling, resulting in co-registered images for comparative analysis.

Change detection is a process of determining and evaluating difference in a variety of surface phenomena over time while using geospatial data sets of multiple dates. Changes can be determined by comparing spectral responses at the same spatial location amongst a set of two or more multispectral data acquired at different points of time. There are many change detection algorithms using digital techniques such as image differencing, image rationing, principal component analysis, and comparison of classified images.

6.7.10 Monitoring and impact assessment of Adarsha watershed

Adarsha watershed in Kothapally is bound by geo-coordinates 17°21′ to 17°24′ N and 78°5′ to 78°8′ E and forms part of Shankarpally mandal (an administrative unit) of Ranga Reddy district, Andhra Pradesh, India. Vertisols and associated Vertic soils occupy 90% of the watershed area. However, Alfisols do occur to an extent of 10% of the watershed area. The main (rainy season) crops grown are sorghum (*Sorghum bicolor*), maize (*Zea mays*), cotton (*Gossypium* sp.), sunflower (*Helianthus annuus*), mung bean (green gram), and pigeonpea. During (postrainy season) wheat (*Triticum aestivum*), rice, sorghum, sunflower, vegetables, and chickpea are grown (Figure 6.14). The mean annual rainfall is about 800 mm, which is received mainly during June to October.

A number of watershed case studies using satellite data are available in addition to the centrally sponsored initiatives (Wani *et al.*, 2003; Sreedevi *et al.*, 2009; Kaushalya Ramachandran *et al.*, 2009, 2010; Roy *et al.*, 2010). For Adarsha watershed,

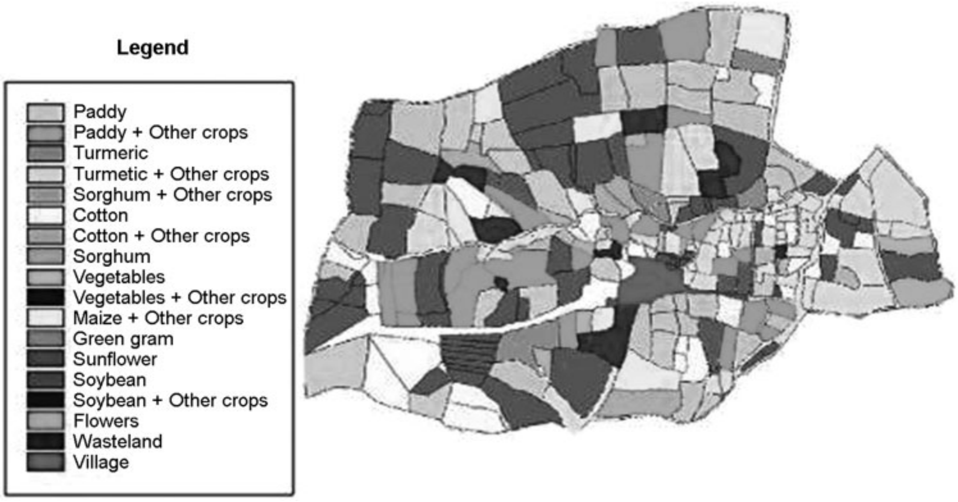


Figure 6.14 Land use and cropping pattern of Adarsha watershed, Kothapally, Andhra Pradesh (See color plate section)

Kothapally in Andhra Pradesh, thematic maps were prepared by enhancing the low resolution multispectral data with high resolution panchromatic data by a process of merging to obtain information on hydrogeomorphological conditions, soil resources, and present land use/land cover. The maps have been generated through a systematic visual interpretation of IRS-1B/-1C/-1D LISS-II and -III data in conjunction with the collateral information in the form of published maps, reports, wisdom of the local people, etc. supported by ground truth. The information derived on the lithology of the area and geomorphic and structural features in conjunction with recharge condition and precipitation was used to infer groundwater potential of each lithological unit.

In addition, derivative maps, namely, land capability and land irrigability maps were generated based on information on soils and terrain conditions according to criteria from the All India Soil and Land Use Survey Organization (All India Soil and Land Use Survey 1970). Land use/land cover maps have been prepared using monsoon and winter crop growing seasons and summer period satellite data for delineating single-cropped and double-cropped areas apart from other land use and land cover categories. Furthermore, micro-watersheds and water bodies have been delineated and the drainage networks have also been mapped (Figure 6.15). Slope maps showing various slope categories have been prepared based on contour information available at 1:50,000 scale topographical sheets. Rainfall data were analyzed to study the rainfall distribution pattern in time and space. Demographic and socioeconomic data were analyzed to generate information on population density, literacy status, economic backwardness, and the availability of basic amenities.

Since the watershed very often experiences drought, apart from alternate land use based on potential and limitations of natural resources, various drought proofing measures such as vegetative barriers, contour bunding, stone check-dams, irrigation water management, horticulture, groundwater development with conservation

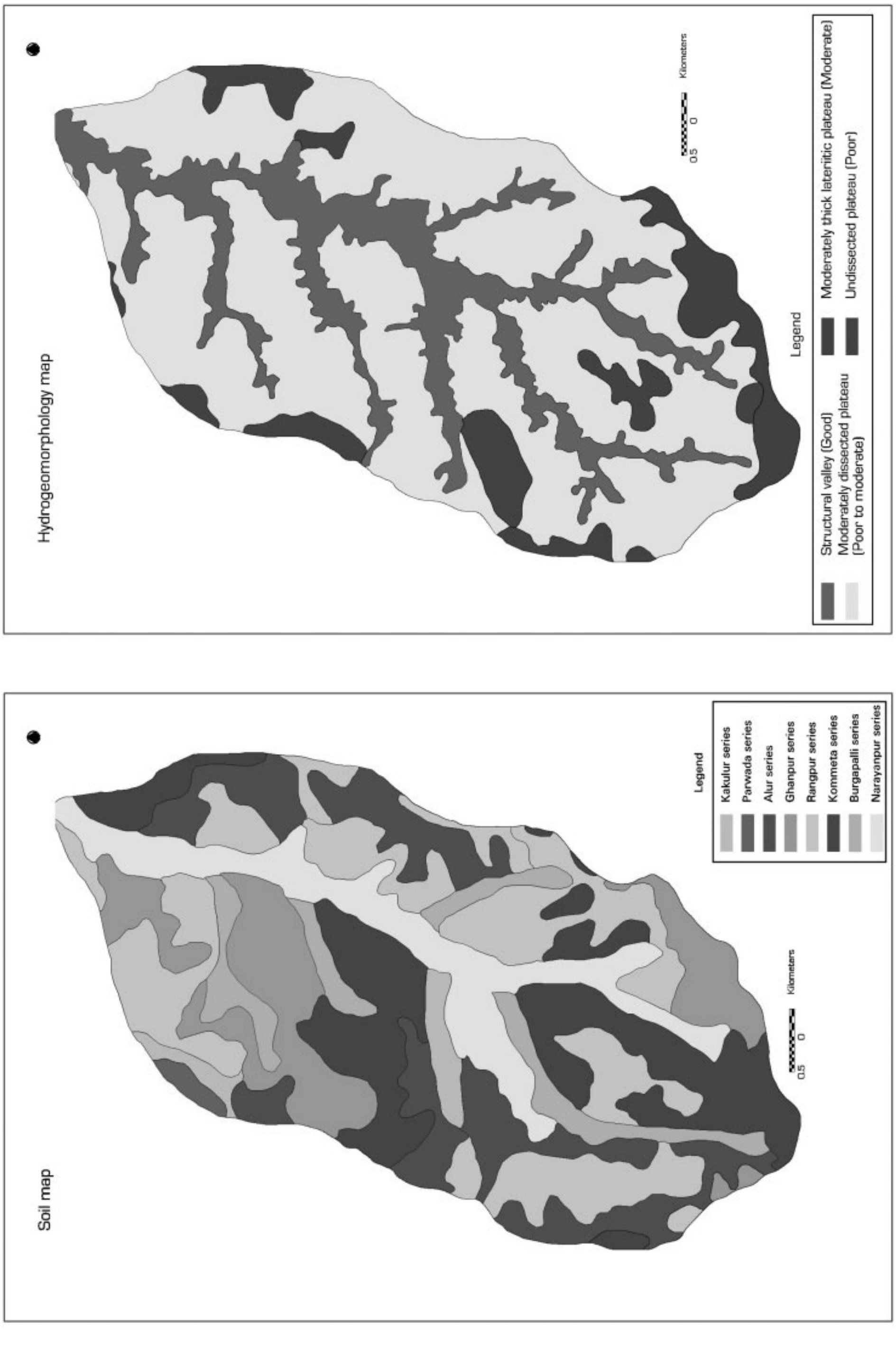


Figure 6.15 Thematic maps depicting soils, land use pattern, and proposed drought proofing measures in Adarsha watershed, Kothapally, Andhra Pradesh

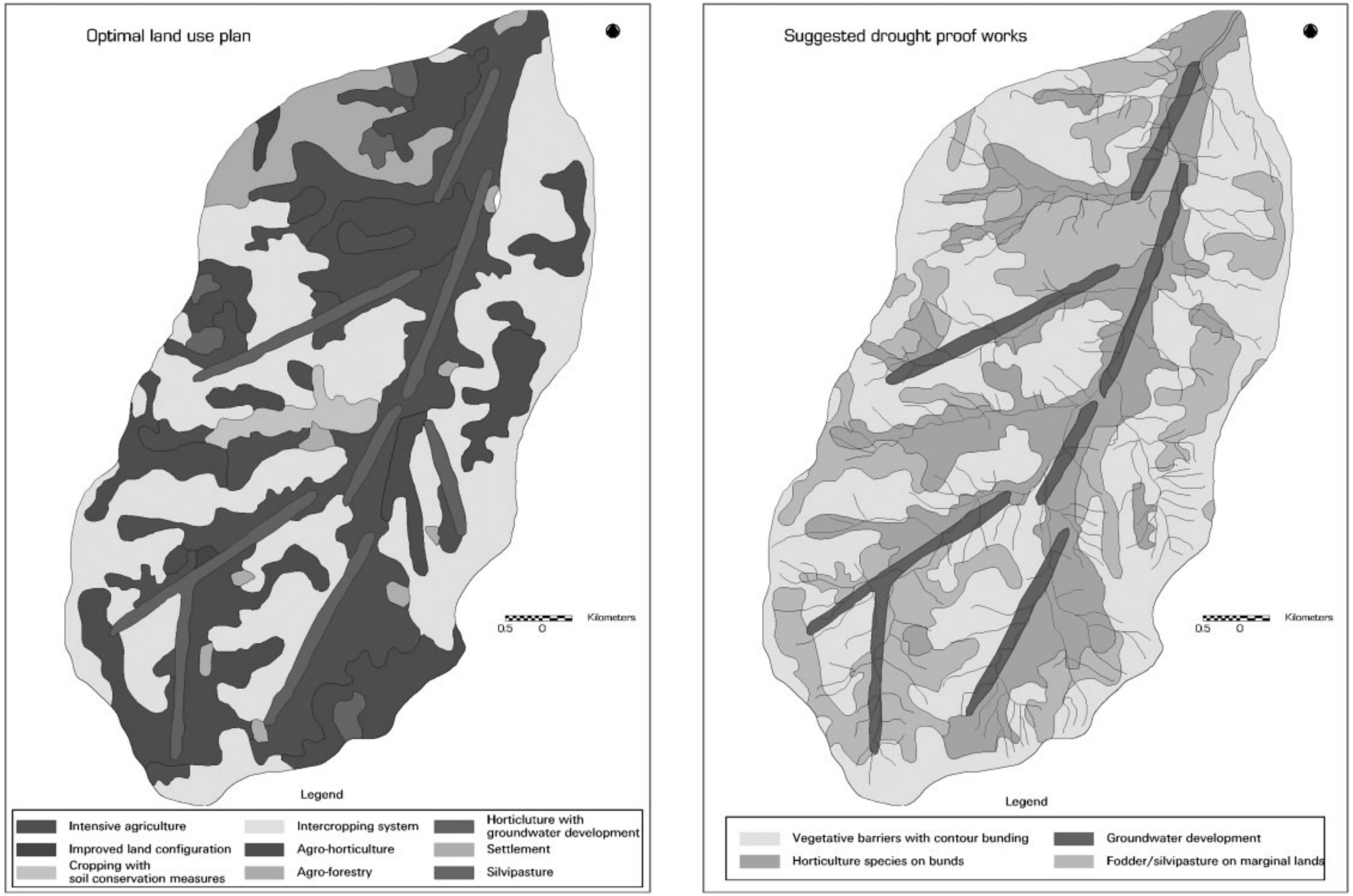


Figure 6.15 Continued

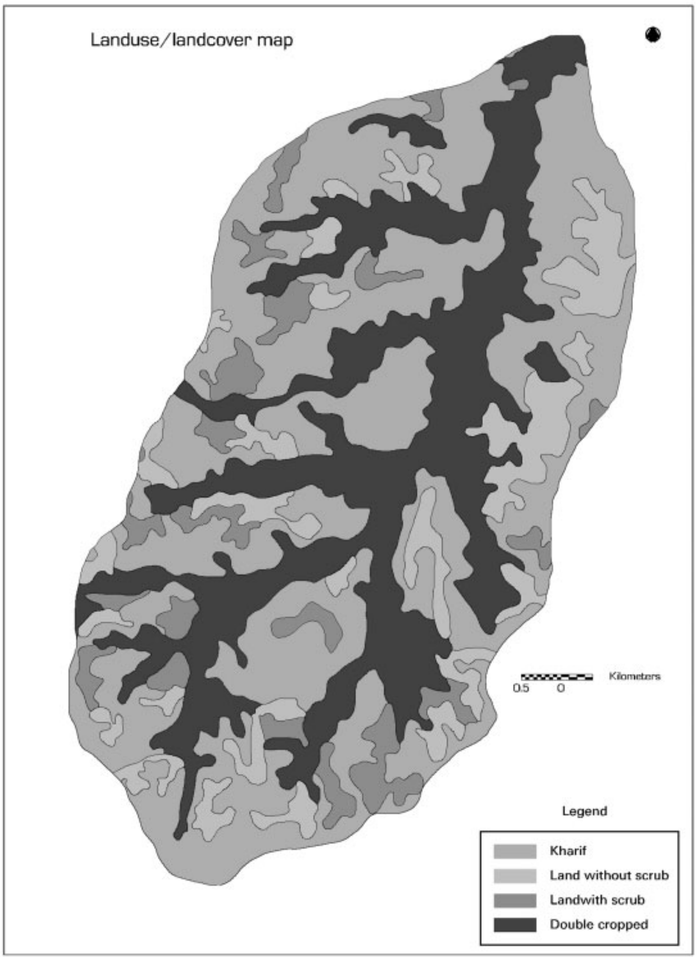


Figure 6.15 Continued

measures, and silvipasture in marginal lands have been undertaken. The suggested optimal land use practices are intensive agriculture, intercropping system, improved land configuration, agro-horticulture, horticulture with groundwater development, and silvipasture. Soon after implementation of the suggested action plan, the watershed underwent transformation, which was monitored regularly. Such an exercise not only helps in studying the impact of the program, but also enables resorting to mid-course corrections, if required. Parameters included under monitoring activities are land use/land cover, extent of irrigated area, vegetation density and condition, fluctuation of groundwater level, well density and yield, cropping pattern and crop yield, occurrence of hazards, and socioeconomic conditions. Land use/land cover parameters

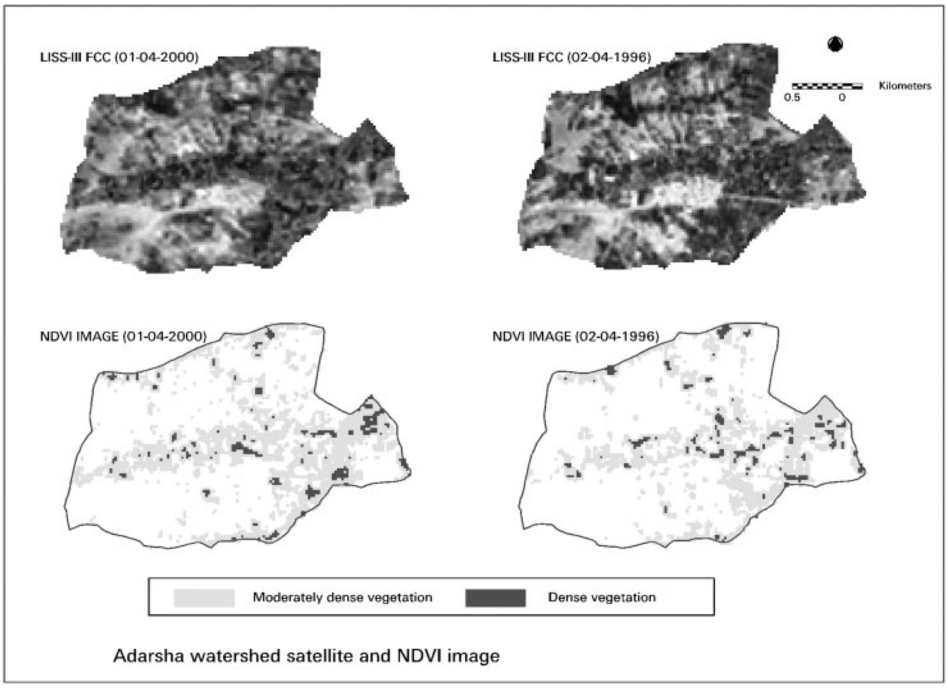


Figure 6.16 FCC and NDVI image of Adarsha watershed, Kothapally, Andhra Pradesh (See color plate section)

include changes in the number and aerial extent of surface water bodies, spatial extent of forest and other plantations, wastelands, and cropped area.

NDVI has been used to monitor the impact of implementation of action plan. NDVI images of 1996 and 2000 reveal an increase in the vegetation cover, which is reflected in improvement in the vegetation cover. The spatial extent of moderately dense vegetation cover, which was 129 ha in 1996, has risen to 152 ha in 2000. Though the satellite data used in the study depicts the terrain conditions during 1996, implementation activities started only in 1998. It is, therefore, obvious that it will take considerable time for detectable changes in terrain and vegetation conditions (Dwivedi *et al.*, 2003) (Figure 6.16).

In another study from CRIDA, use of GIS and remote sensing capabilities to evaluate watershed projects in Rangareddy and Nalgonda districts of Andhra Pradesh has been showcased. A suite of thirty-nine sustainability indicators was constructed to assess the sustainability of watershed development program in four villages at three spatial levels: household, field, and watershed. The multidisciplinary and transdisciplinary approach has helped to identify critical indicators for evaluation of watershed projects (Kaushalya Ramachandran *et al.*, 2010) (Figure 6.17).

Using GIS and survey data, the watersheds in India, Thailand, and Vietnam were characterized for the distribution of natural resources like soils, climate, water resources, and land use systems at the initiation of the watershed projects. In India,

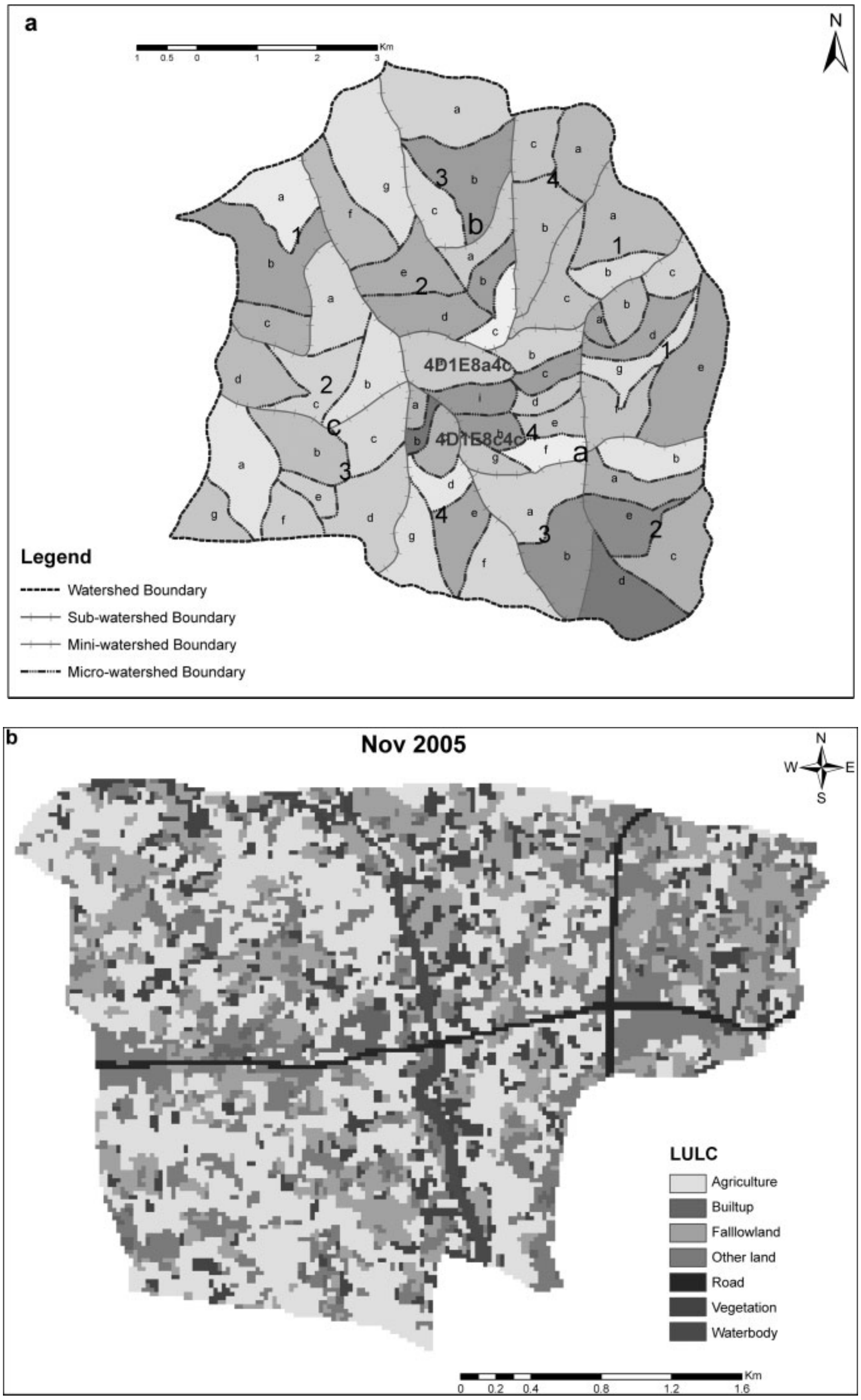


Figure 6.17 Use of GIS to delineate micro-watershed and map two sustainability indicators – land use/land cover (LULC) and NDVI and Cob-web diagram showing impact of watershed development program on agricultural productivity in Pamana micro-watershed, Rangareddy district, Andhra Pradesh (See color plate section)

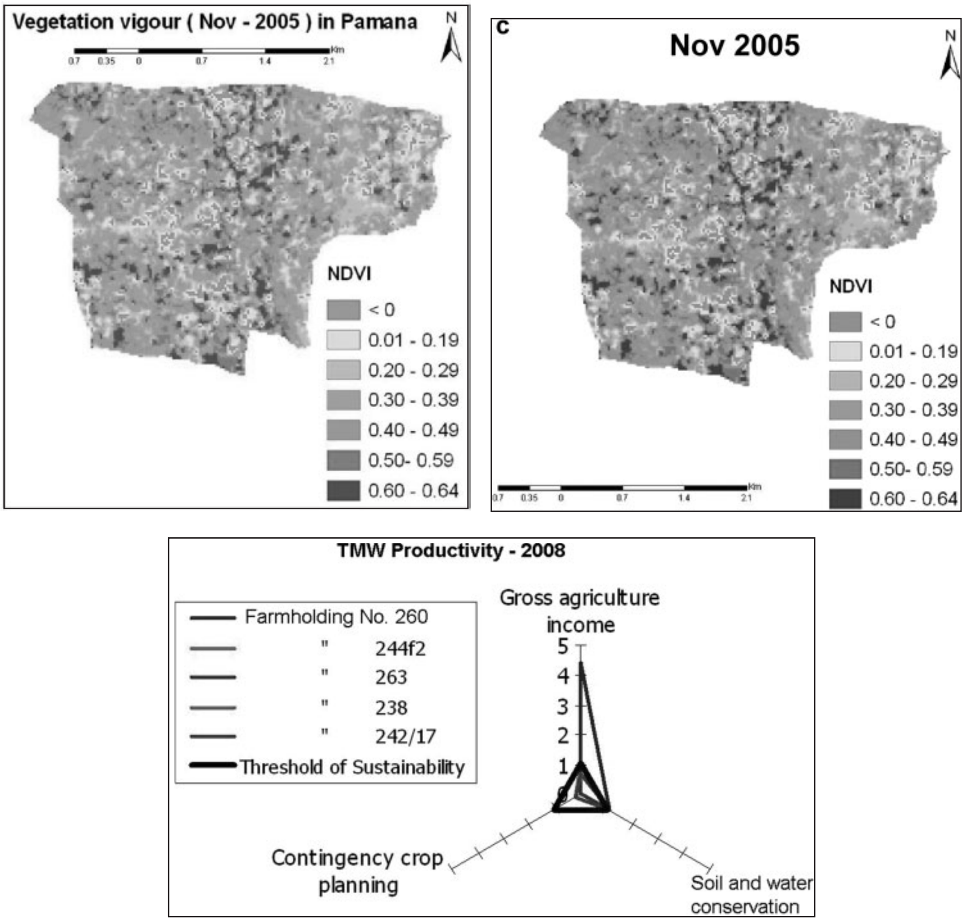


Figure 6.17 Continued

the watersheds in Andhra Pradesh (Kothapally, Malleboinpally, Appayapally, Thirumalapuram, Nemmikal, and Kacharam) and Madhya Pradesh (Lateri and Rignodia) were characterized; also Tad Fa watershed in Thailand and Thanh Ha watershed in Vietnam were characterized. Using remote sensing and GIS technology it was observed that significant improvements in the vegetation cover in Kothapally watershed in Andhra Pradesh and Lateri watershed in Madhya Pradesh with the introduction and adoption of improved resource management and crop production technologies over the period of five years occurred.

6.8 TECHNOLOGY INTEGRATION

A vast amount of technology encompassing different domains exists. As long as they are individual tools for collection of data or processing of data, their use is limited.

Hence they need to be integrated into a total solution system that can take care of most of the operational requirements as well as decisions to a great extent. In the following sub-sections, a few concepts about integration of various technologies have been discussed. Finally, the concept for achieving total solution has been presented.

6.8.1 Field data transmission

Even though the field data collection methods make use of IT products as and when they become mainstream (for example, laptop and handheld computers, GPS receivers, etc.), an integrated and comprehensive process formulation driven by a 'total solution' approach is emerging. As a result of such revolutions in ICT, access to the Internet via mobile-device based web browsers and other IP protocol based applications became possible. This provides a huge opportunity to develop customized applications on integrated PDA devices for specific end uses like those for field data collection and communicate to base server in real time. In this direction a system was developed at NRSC keeping in view 'total solution' approach to realize the mobile device based field data collection application (Figure 6.18).

It consists of configuration of mobile device prior to field visit, mobile device application, wireless network services, automated data receiving server program, central data storage (repository), and LAN based application to utilize the stored field data. The solution highlights the importance of prior planning and preparation of reference data to be carried on the mobile device, which includes the discipline, parameters to be collected, project information, team members information, etc. This also ensures that the mobile application is flexible and configurable enough to support field data collection activity for a variety of disciplines/end uses. It also uses a central data repository

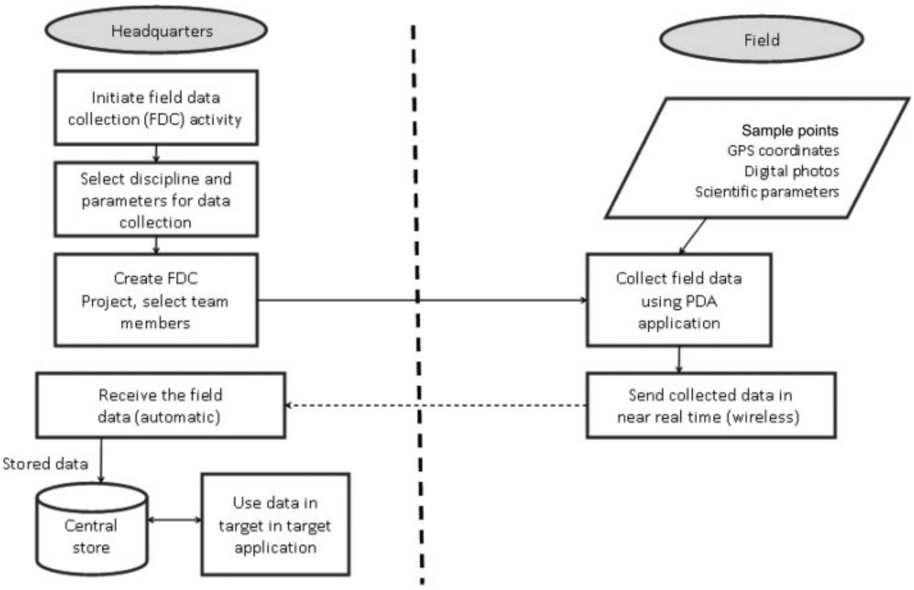


Figure 6.18 Total solution to field data collection system

to store all the reference and sample data that continuously accumulates with each field data collection activity.

The central data repository is a critical component for ensuring systematic data organization and management for the process. The deployment of this solution enables the near-real time transmission of collected data directly from the field to the base headquarters for initiating immediate further action. The scope of this solution can be enhanced with the implementation of additional functionalities like visualization, historical studies, data mining, data extraction, and GIS export.

6.8.2 Sensor Web

It is a physical platform for a sensor which is aerial or terrestrial, fixed or mobile, and data collected by the sensor could be accessible in real time via wireless networks and Internet. At times the term "Sensor Web" is used to refer to sensors connected to the Internet for a real time application. The purpose of a Sensor Web system is to extract knowledge from the data it collects and use this information to intelligently react and adapt to its surroundings. With the vast development in computer and telecommunication markets, the price of state-of-the-art electronic chips became very affordable and ushered the development of vertical applications. Even the multi-directional sensors-to-sensor communication is possible with the recent developments. The various sensors can be integrated together using a protocol similar to TCP/IP (used for networking various computers) and make them to share information among themselves and act as a single system. In essence, the Sensor Web is a macro-instrument comprising a number of sensor platforms.

The major advantage of the Sensor Web is that the sensors can be placed in very remote and harsh environments, where it is very difficult to collect data under direct human supervision. Further, the data can be collected continuously and delivered to the needy in near-real time basis. This has immense potential in applications related to agriculture, medical, life safety, emergency management, and so on. The Sensor Web is now focusing much on applications of this technology. This Sensor Web approach allows for various complex behaviors and operations such as on-the-fly identification of outlying sensor, mapping of vector fields from measured scalar values and interpreting them locally, and detection of critical events. As the Sensor Web infrastructure becomes more common in various user communities, there will be a demand for associated sensors to populate these systems. As a result, the combined exponential growth of both computer and telecommunication technologies will contribute to a similar explosive growth of sensor technology.

6.8.3 Spatial simulation modeling

The action plan for watershed essentially aims at reducing soil loss, improving ground or surface water harvesting, and improving crop productivity. Spatial modeling and integration of point models in spatial domain have greater significance in watershed studies to achieve the above-mentioned goals. They can enhance the impacts of agricultural research in watershed development. Simulation modeling using the surface and groundwater balance models and crop growth model enables to optimize the use of water resources in the watershed and to minimize the gap between the achievable yield and potential yield. Assessing long-term impacts of various management options on carbon sequestration, environmental balance, land degradation, etc. could be assessed using simulation modeling approaches, which would otherwise, not be possible using conventional approaches on a routine basis (Sreedevi *et al.*, 2009).

Temporal acquisition of satellite data during crop growing season enables to monitor the crop growth with the help of biophysical parameters such as leaf area index, soil/crop moisture, NDVI, etc. and when coupled with spatio-dynamic modeling facilities in GIS, scenario generation is quite possible for crop intensification analysis besides the sustainability assessment of the systems. There is a need to incorporate these dynamic parameters in refining prioritized watersheds for effective utilization of resources.

Baseline data generated using above tools forms the basic input to characterize the watershed spatially and also provides necessary inputs for spatial models after proper translation. While preparing any action plan aiming at overall development of watershed it is essential to visualize the impact of interference done with the existing environment. Better Assessment Science Integrating point and Nonpoint Sources (BASINS) and Soil and Water Assessment Tool (SWAT) are some of the comprehensive models available in GIS environment that help in modeling the watershed environment and visualizing the future scenarios. To run the above continuous simulation models, updation of information on climate (rainfall, PET, radiation, temperature, wind velocity, LGP), soils (organic carbon, nutrients, bulk density, pH, etc.), crops (cropping intensity, crops and their growth attributes, phenology, yield and yield attributes, pattern, cultivars, inputs applied), major plant nutrient uptake data, socioeconomic data (income sources, labor sources, input, output/income, infrastructure, etc), runoff and soil loss measurements and groundwater level (Wani 2002) is essential. For this, the Sensor Web, GPS, and communication networks are useful.

6.8.4 Use of ICT in watershed management

It is increasingly realized that facilitation of knowledge flow is a key in fostering new rural livelihood opportunities using modern ICTs. The concept adapted is one of intelligent intermediation for facilitation of flows of information and knowledge. The community center managed by the PIAs (project implementation agencies) functions as a Rural Information Hub connecting participating villages (or groups of villages, as the case may be) and also with other Internet connected websites (Figure 6.19). It is operated or managed by a rural group [women or youth self-help groups (SHGs)] identified by the village watershed council through a consultative process. The activities in this module are planned to adopt a hub-and-spokes model for information dissemination among the participants and stakeholders. The electronic network across select nuclear watersheds enables sharing of experience and best practices.

6.8.5 Intelligent watershed information system

The previous sub-sections discuss about the application of technologies in watershed related activities. There is a need to integrate these components into an intelligent information system for efficient management of watersheds. The spatial data of

Figure 6.19 Information and communication technology services enabled at Addakal, Mahabubnagar district, Andhra Pradesh

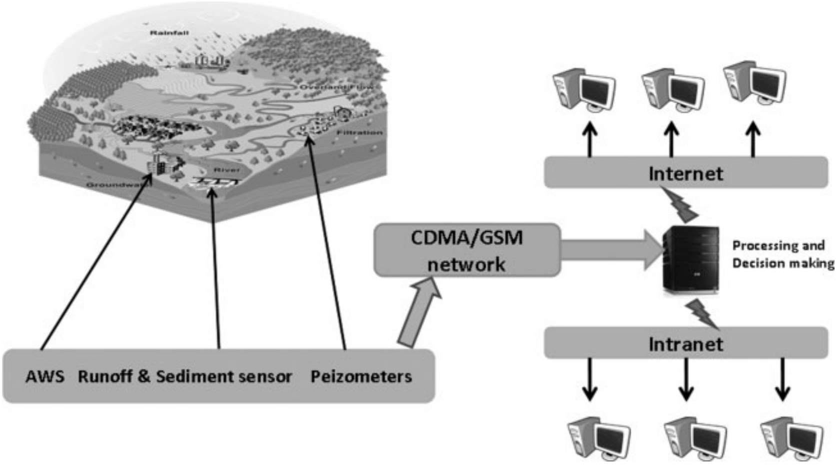


Figure 6.20 Technology integration for watershed management

watersheds (slope, soils, crops, land cover, wastelands, etc.) along with field data collected with field Sensors Web (runoff, sediment loss, nutrient loss, etc.) and AWSs can be directly communicated to the central server using mobile communication (CDMA/GSM) or WAP enables networks. These inputs could be translated into the input format required to run point or spatial models. Further, by suitably processing the above input data with simulation models, various scenarios can be generated and validated with field data.

To achieve this, initially a semantic network could be generated keeping the goal and objectives of the watershed program, which could be translated to automated decision-making system using adoptive algorithms like Artificial Neural Networks (ANN) and Decision Trees (DT) that could help in dynamically prioritizing watersheds. A schema towards achieving an Intelligent Watershed Information System (IWIS) for effective watershed management is depicted in Figure 6.20. The decisions generated from the above system have to be communicated to the stakeholder (farmers/extension staff) in a reasonable time frame.

6.9 SUMMARY AND CONCLUSIONS

Application of new science tools in rainfed agriculture opens up new vistas for development through IWMPs. These tools can help in improving the rural livelihoods and contributing substantially to meet the millennium development goals of halving the number of hungry people by 2015 and achieving food security through enhanced use efficiency of scarce natural resources such as land and water in the tropical countries. Till now rainfed areas of the SAT did not get much benefit of new science tools but the recent research using these tools such as simulation modeling, remote sensing, GIS as well as satellite-based monitoring of the natural resources in the SAT has shown that not only the effectiveness of the research is enhanced substantially but also the cost efficiency and impact are enhanced. The remarkable developments in space technology currently offer satellites which provide better spatial and spectral resolutions, more frequent revisits, stereo viewing, and on-board recording capabilities. Thus, the high spatial and temporal resolution satellite data could be effectively used for watershed management and monitoring activities at land ownership level. By using crop simulation modeling approach, yield gap analyses for the major crops in Asia, Africa, and WANA regions revealed that the yields could be doubled with the existing technologies if the improved crop land, nutrient, and water management options are scaled-out.

Similarly, technology application domains could be easily identified for better success and greater adoption of the particular technologies considering the biophysical as well as socioeconomic situations. GIS helped in speedy analysis of voluminous data and more rationale decision in less time to target the investments as well as to monitor the large number of interventions in the SAT. The satellite-based techniques along with GIS helped in identifying the vast fallow areas (2 million ha) in Madhya Pradesh during the rainy season. Similarly, 14 million ha rice-fallows in the Indo-Gangetic Plain offer excellent potential to grow second crop on residual soil moisture by using short-duration chickpea cultivars and simple seed priming technology. These techniques are also successfully used for preparing detailed thematic maps, watershed development plans, and continuous monitoring of the natural resources in the country in rainfed areas. Further, such data could be of immense help in tracking the implementation, applying midcourse corrections, and for assessing long-term effectiveness of the program implemented. The synergy of GIS and Web Technology allows access to dynamic geospatial watershed information without burdening the users with complicated and expensive software. Further, these web-based technologies help the field data collection and analysis in a collaborative way. However the availability of suitable software for watershed studies and their management in open GIS platform is very limited. Hence, there is a requirement to strengthen this area through collaborative efforts between various line organizations.

Use of ICT in IWMP can bridge the existing gap to reach millions of small farm holders who have no access to new technologies for enhancing agricultural productivity on their farms. Use of smart sensor network along with GIS, remote sensing, simulation modeling and ICT opens up new opportunities for developing intelligent watershed management information systems. However, it calls for a new partnership involving corporates, development agencies, researchers from various disciplines and most importantly to reach millions of small farm holders in rainfed areas of the world. Application of new science tools in IWMP have helped to substantially enhance productivity as well as income from rainfed agriculture and improved livelihoods of the rural people.

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