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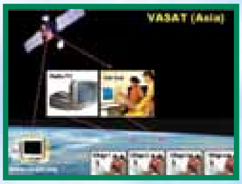


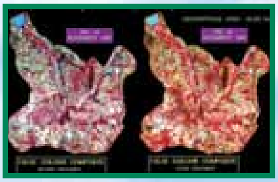

Use of High Science Tools in Integrated Watershed Management

Proceedings of the National Symposium

ICRISAT
Science with a human face

International Crops Research Institute for the Semi-Arid Tropics

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Editors

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Objectives of the Symposium

- To bring together the learnings, potential and live examples from the practitioners using high-science tools benefiting rain-fed agriculture.
- To sensitize senior policymakers about the potential of high-science tools for enhancing impact of Integrated Watershed Management Program in India.
- To develop recommendations for harnessing the benefits of high-science tools for effective and efficient implementation of the IWMP.

Contents

Harnessing New Science Tools through IWMP to Unlock Potential of Rain-fed Agriculture

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Abstract

Semi-Arid Tropics (SAT) are characterized by highly variable rainfall, poor soils, low yields and poor developmental infrastructure. Watershed management is now an accepted strategy for development of rain-fed agriculture in these areas. New science tools like remote sensing, geographical information systems (GIS), water balance, simulation modeling, information and communication technology (ICT) are currently being used very widely in irrigated and well-endowed areas. Importance of these tools in the SAT areas is now well understood and recognized. Application of new science tools in rain-fed agriculture opens up new vistas for development through integrated watershed management programs (IWMP). ICRISAT in partnership with national agricultural research systems and advanced research institutes in Asia has applied new science tools for enhancing the productivity of rain-fed systems in the SAT through science-led development.

The remarkable developments in space technology currently offers satellites, which provide better spatial and spectral resolutions, more frequent revisits, stereo viewing and on board recording capabilities. High spatial and temporal resolution satellite data could be effectively used for watershed management and monitoring activities at land ownership level. Techniques are also successfully used for preparing detailed thematic maps, watershed development plans and continuous monitoring of the natural resources in rain-fed areas. Synergy of GIS and Web Technology allows access to dynamic geospatial watershed information without burdening the users with complicated and expensive software.

Use of smart sensor network along with GIS, RS, simulation modeling and ICT opens up new opportunities for developing intelligent watershed management information systems. These tools can help in improving the rural livelihoods and contribute 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.

Introduction

Semi-Arid Tropics (SAT) are characterized by highly variable rainfall, poor soils, low yields and poor developmental infrastructure. The fragile eco-systems of these rain-fed areas also suffer from severe land degradation. Watershed management is now an accepted strategy for development of rain-fed agriculture. Watershed approach has many components to cope with biotic and aboitic stresses through resource conservation and management measures like rainwater harvesting and recycling, *in situ* moisture conservation, agroclimate-based selection of suitable crops and varieties, crop rotations, intercropping, integrated nutrient and pest management, agroforestry and income-generating activities for sustainable improvement of rural livelihoods. There is a need to undertake a comprehensive study of watersheds with respect to their selection, planning, implementation, monitoring and impact assessment through diverse techniques and modalities for the success of watershed development programs. New science tools like remote sensing, geographical information systems (GIS), water balance, simulation modeling, information and communication technology (ICT) are currently being used very widely in irrigated and well-endowed areas. Importance of these tools in the SAT areas is now well understood and recognized.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is one of the 15 Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR). ICRISAT in partnership with national agricultural research systems and advanced research institutes in Asia has applied new science tools for enhancing the productivity of rain-fed systems in the SAT through science-led development. Major partners of ICRISAT are Central Research Institute for Dryland Agriculture (CRIDA), National Remote Sensing Centre (NRSC) and State Agricultural Universities (SAUs) in India, Department of Agriculture (DoA) and Department of Land Development (DLD), Khon Kaen University (KKU) in Thailand, Yunnan Academy of Agricultural Sciences (YAAS), The Guizhou Academy of Agricultural Sciences in China and Vietnam Academy of Agricultural Sciences (VAAS) in Vietnam.

Basic requirement for successful implementation of watershed programs without sacrificing the interests of stakeholders is to assess the problems and prospects of the watershed after considering factors such as natural resources, physiography and socio-economic status. Watershed development needs a balanced participatory approach and all the stakeholders have to be involved from the planning level itself for smooth and efficient execution of the watershed related works in a timely manner. Spatial technologies play a very crucial role in watershed planning. Advances in space research have enhanced the availability of spatial and temporal data. Electronic sensors, dataloggers, portable electronic devices, Internet and communication technology are vital in the program planning, execution, monitoring and evaluation of watersheds. In tropical rain-fed areas, 80-85 per cent farmers are small farm holders cultivating < 2 ha each. To reach the millions of small farm holders spread across 3.65 million km^2 SAT area in Asia in sharing knowledge and information about new technologies and products to improve productivity on their farms, is indeed a gigantic task. Processing of billions of data points to translate into information and knowledge to benefit policy makers, development investors, extension and development workers and farmers has become feasible with the availability of advanced scientific tools, communication technologies and combination of one or more of such tools (Diwakar and Jayaraman 2007, Wani et al. 2008, Kaushalya et al. 2009 and Sreedevi et al. 2009).

New Science Tools for Integrated Watershed Management

Geographic Information System (GIS)

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. Present GIS technology enables ‘map any where and serve any where’. 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 is watershed planning, wherein these techniques are effectively used for land resources as well as water resources planning, watershed prioritization and monitoring.

Watershed-level planning requires a host of inter-related information to be generated and studied in relation to one another. GIS is used in the development of digital database, 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.

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 has become a 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. 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 like climate, soils, water, etc 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 the generation and spatial analysis of data, important facet of GIS technology is speedy in public outreach. Now with the availability of Blade servers with RAID capability, which can serve data at faster rates, gigabit data transfer capabilities and Mbps Internet speeds, outreach to the world community has improved tremendously. Spatial data with on-the-fly spatial analytical capabilities is being served over Internet these days.

Remote Sensing

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 socio-economic facets. Although remote sensing started during Second World War period, developments in satellite remote sensing started in early seventies and have undergone significant improvements in sensors as well as spatial, spectral, temporal and radiometric resolutions. Satellite image resolutions increased from 80 m (coarse resolution- Landsat-MSS) in seventies to 20 - 36 m (medium resolution – SPOT-MLA/Landsat-TM/IRS-LISS II) in mid eighties to 0.68 – 5.8 m during late nineties (high resolution-QuickBird–PAN, MLA/IKONOS/IRS-PAN, LISS-IV, Cartosat-1,2). In tune with these developments, application of satellite data has extended from watershed level to sub-watershed and micro-watershed level (Table 1).

Sources of the Results

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 HRS imagery have absolute planimetric accuracy of 15 to 30 m and absolute elevation accuracy of 10 to 20 m (Annon. 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.

Table 1. Suitability of various RS sensors in watershed studies.

Sl. No	Level of study	Suitable spatial resolutions	Sensors	Application potential
1	Basin level (1:250000 scale)	50 to 150m	IRS-WiFS, AWiFS, LISS-I	Deriving overall base information on natural resources and land cover; large scale monitoring of changes
2	Watershed level (1:50000 scale)	20 to 50m	IRS-LISS-III, SPOT-MLA, TM, ETM,	Deriving natural resources information for watershed prioritization, planning, monitoring
3	Sub/micro-watershed level (1:10000 or larger)	0.5 to 20m	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

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 watersheds boundaries at 1:25,000 and 1:50,000 scales, generation of contours at 10m interval and generating thematic maps at a scale of 1:10,000 (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 centimetre accuracy under ideal condition. Such data are 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) are useful for sub-watershed/ micro-watershed level applications like mapping infrastructure (roads/ drainage network), natural resources inventory (crops/soils groundwater potential), water resources (water bodies/natural springs/ ponds), land use (single cropped areas/double cropped areas/waste lands/fallow lands/forest cover at level 4), etc. They can be employed for disaster management at block/ village level like drought or flood damage, etc., and also for monitoring and impact assessment of the 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-IA/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 otherwise not possible using broadband multispectral sensors. Some of application areas in agriculture are crop stress (moisture/pest/nutrient) detection, yield prediction, soil quality and agro-environmental health assessment.

Crop-Growth Simulation Modelling

Crop simulation models are mathematical, computer-based representations of crop growth and interaction with weather, soil and nutrients. They play 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 cost effectively 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 modelling software like Agricultural Production Systems Simulator (APSIM) and InfoCrop are 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 estimation. Results showed that the actual yields of food and other crops obtained by farmers are much below the potential yields that can be obtained with improved management. Crop yields can at least be doubled from their current levels by the promotion and adoption of existing ‘on-the-shelve’ technologies available with the national and international research institutes. The governments need to provide enabling policy environments and institutional support to promote greater adoption of new and improved technologies to benefit the poor farmers of rain-fed areas and to meet the challenge of greater food needs of future.

Singh et al. (2009) analyzed yield gaps for several crops in various countries including India, Thailand, Northern Vietnam and WANA region. Estimations of potential rain-fed yields and yield gaps in Northern Vietnam were based on simulated yields, experimental station yields and province yields – all obtained under rain-fed 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). Rain-fed potential yields of crops were simulated using weather data of 28 years for the five locations (Vinh

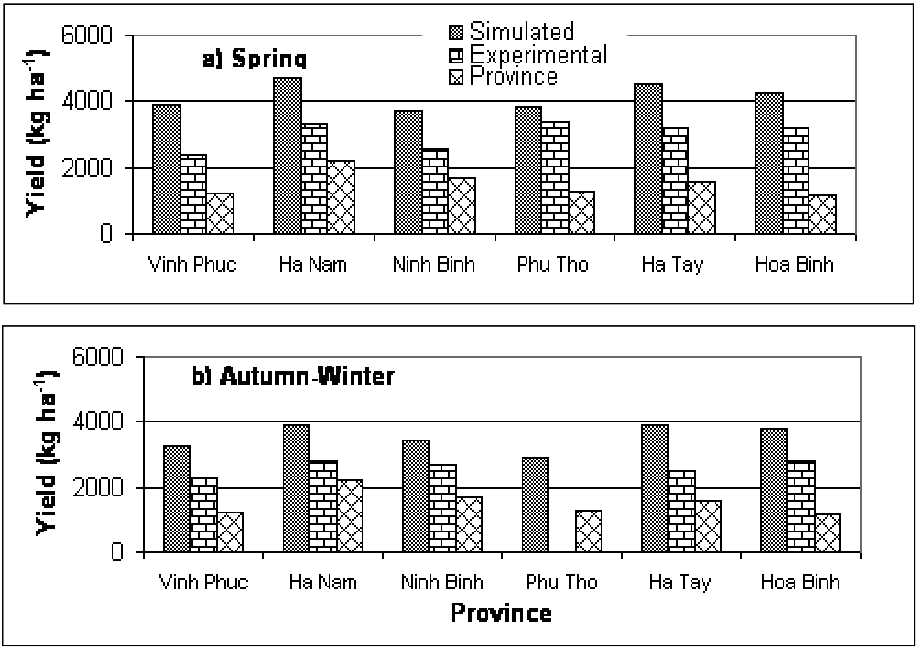

Figure 1. Simulated potential, experimental and province mean pod yields and yield gap of rain-fed groundnut in (a) spring and (b) autumn-winter seasons at selected sites in northern Vietnam.

Phuc, Ha Nam, Ninh Binh, Ha Tay and Phu Tho) and 10 years for the Hoa Binh (Fig 1). 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.

Crop simulation models are also used to understand the impacts of climate change on crop growth and productivity. Cooper et al (2009) used a *factorial combination* of climate change of five different temperature increases (1, 2, 3, 4 and 5°C) and 3 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 predicted that temperature increases have greater negative impacts on crop production than relatively small changes in rainfall. They showed that the *ex ante* analyses clearly illustrate both the challenges that climate risk poses as well as the opportunities it offer.

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/ 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. Important technology areas impacting the field data collection process are:

Global Positioning System (GPS) is one 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. Now, GPS is a known electronic device to most of the tech-savvy people and became 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 15m using ordinary code receivers. In differential mode, sub-metre accuracies are possible. 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 obtain detailed weather information at the watershed areas. AWS records data on parameters like 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. AWS data find 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 computation 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 socio-economic aspects related to agricultural drought is required for the generation of spatial decision support system and AWS data are of value for drought management.

Mobile devices that are of interest to field data collection process are – Personal Digital Assistants (PDAs) and cell phones. PDAs are basically palm-size devices that 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. Desktop applications (word processing, spreadsheets, email clients, web browser, etc) are made available on PDAs also. Thus, this forms a handy device to record and store field level information in an organized way.

Cellular phones have 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 person 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 improved processors and larger memory. They also have larger color touch screens and full QWERTY keypads for better inputting of data. With these powerful configurations, it is now possible to deploy rich GUI applications, which were considered to be difficult just a few years ago.

Data Storage and Dissemination

Latest development in server technology enabled the availability of blade servers with RAID capabilities at a very cost effective price. These servers act as storage houses 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.

Application of Spatial Technologies in Rain-fed Agriculture and Watershed Management

Characterization of Production Systems in India

A production system (PS) is defined by the environmental resources, geography, and important issues, or constraints to, and opportunities for improving productivity and sustainable agriculture (ICRISAT, 1994). Production systems based approach to agricultural research was found to be more relevant at ICRISAT during the 1990s and the SAT was divided into 29 production systems. A GIS database of PS maps consisting of soils, climate, crops and other socioeconomic variables was used. It was proposed to refine these PSs using GIS to be able to compare with the national agro-ecological zones (AEZs) so that these PSs are useful for up-scaling and downscaling 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. 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 the 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 eight 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 (Fig. 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.

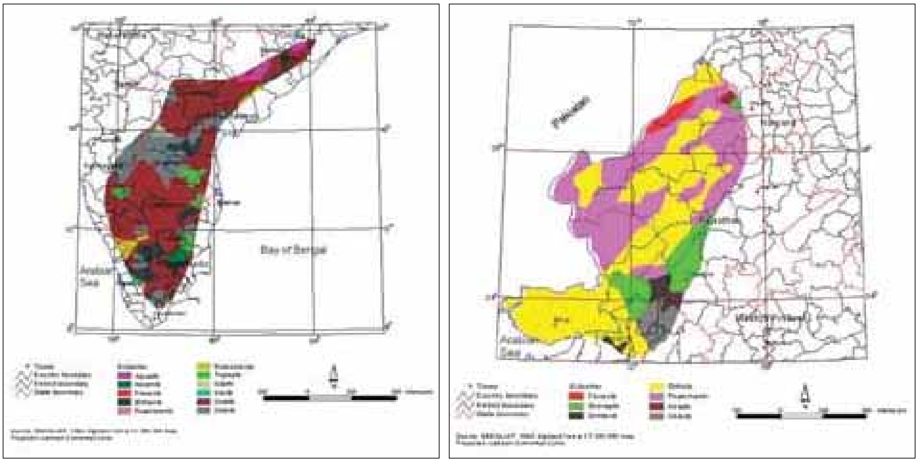

Figure 2. Distribution of different soil orders in the production systems in India.

Land use Mapping for Assessing Fallows and Cropping Intensity

To delineate rainy season fallows in a 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 area under (rainy season) fallow. Three sets of satellite data corresponding to three periods, namely mid-, late-, and post-rainy seasons 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 (Fig. 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,

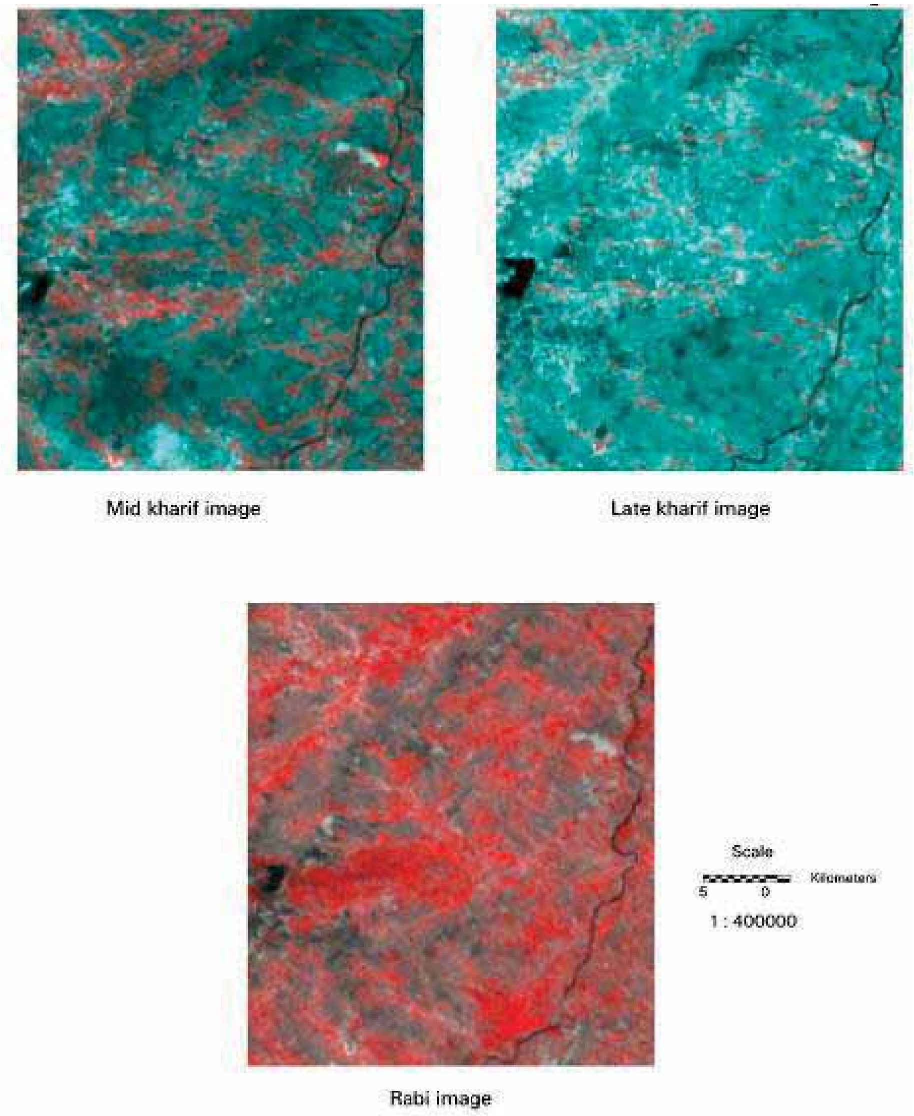

Figure 3. A close view of WiFS images of part of Vidisha district, Madhya Pradesh, during mid-rainy, late-rainy and post-rainy seasons

enabled acquiring virtually cloud-free WiFS data of September from IRS-1D and IRS-P3 satellites. Situation remains more or less same even during post-monsoon period. 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.

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 (Fig. 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.

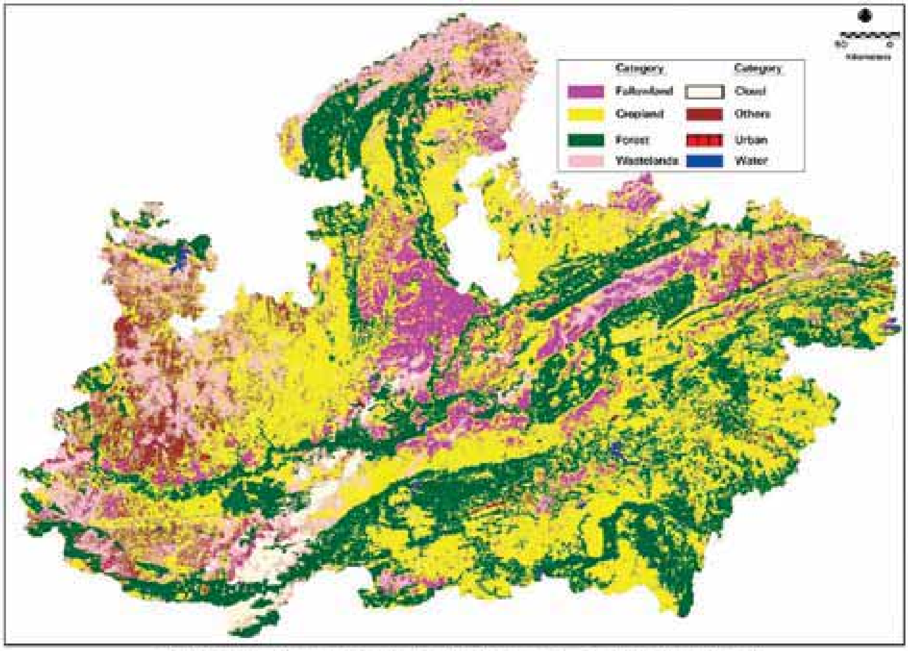

Figure 4. Spatial distribution of various land use and land cover categories in Madhya Pradesh.

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, cropland, 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 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 five 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 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-fallows 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.

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* (post-rainy 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 (Fig. 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, India have initiated concerted farmers participatory

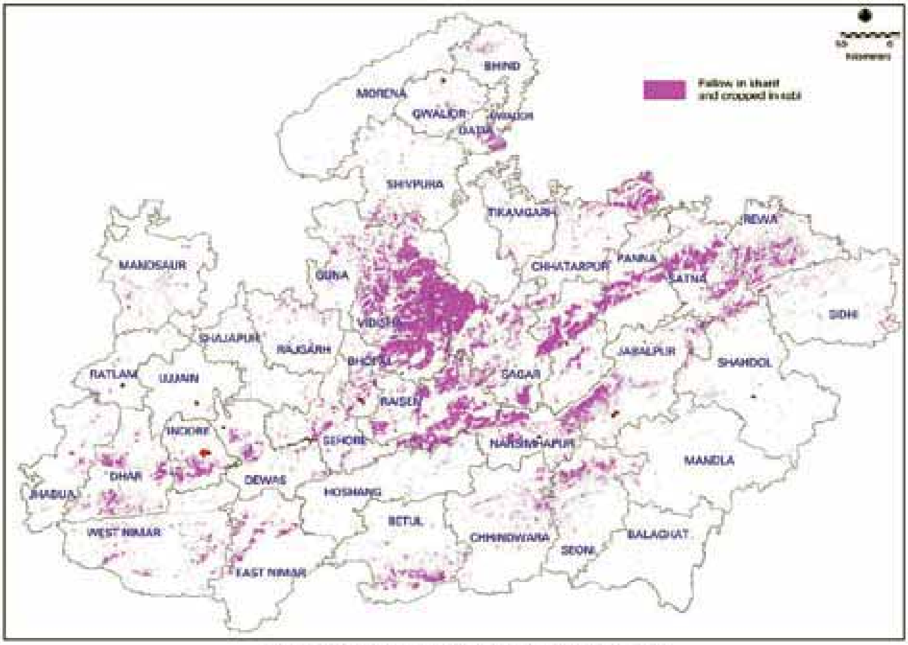

Figure 5. Spatial distribution of rainy season fallows in districts of Madhya Pradesh.

research and development (PR&D) trials using broad-bed and furrows (BBF) to alleviate waterlogging short duration soybean and maize cultivars during rainy season, minimum tillage for *rabi*, chickpea to minimize rainy season fallows (Wani et al. 2010).

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 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 with the use of appropriate technology. 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 into 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.

Satellite image analysis estimated that rice area during 1999 season was about 50.4 million ha. Rice-fallows during 1999/2000 season were

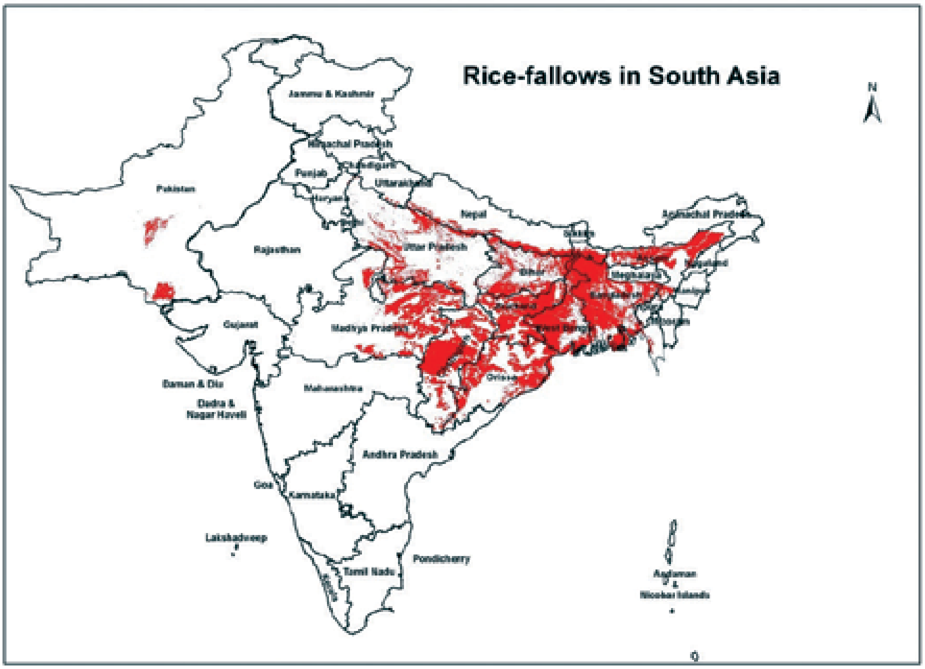

Figure 6. Spatial distribution of rice-fallows in Indo Gangetic Plains of South Asia.

estimated at 14.29 million ha in Bangladesh, India, Nepal and Pakistan. This amounts to nearly 30% of the rice-growing area (Fig. 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, mung bean (*Vigna radiata;* green gram), black gram (*Vigna mungo*), pigeonpea and groundnut)] and cool season legumes [such as chickpea, 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 rain-fed 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 4–6 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). Rain-fed 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.

GIS Mapping of Spatial Variability of Soil Micronutrients at District Level

Spatial variability of secondary nutrient sulphur and micronutrients boron and zinc in selected rain-fed 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, sulphur 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, sulphur and zinc (Fig. 7). All maps of predicted surfaces

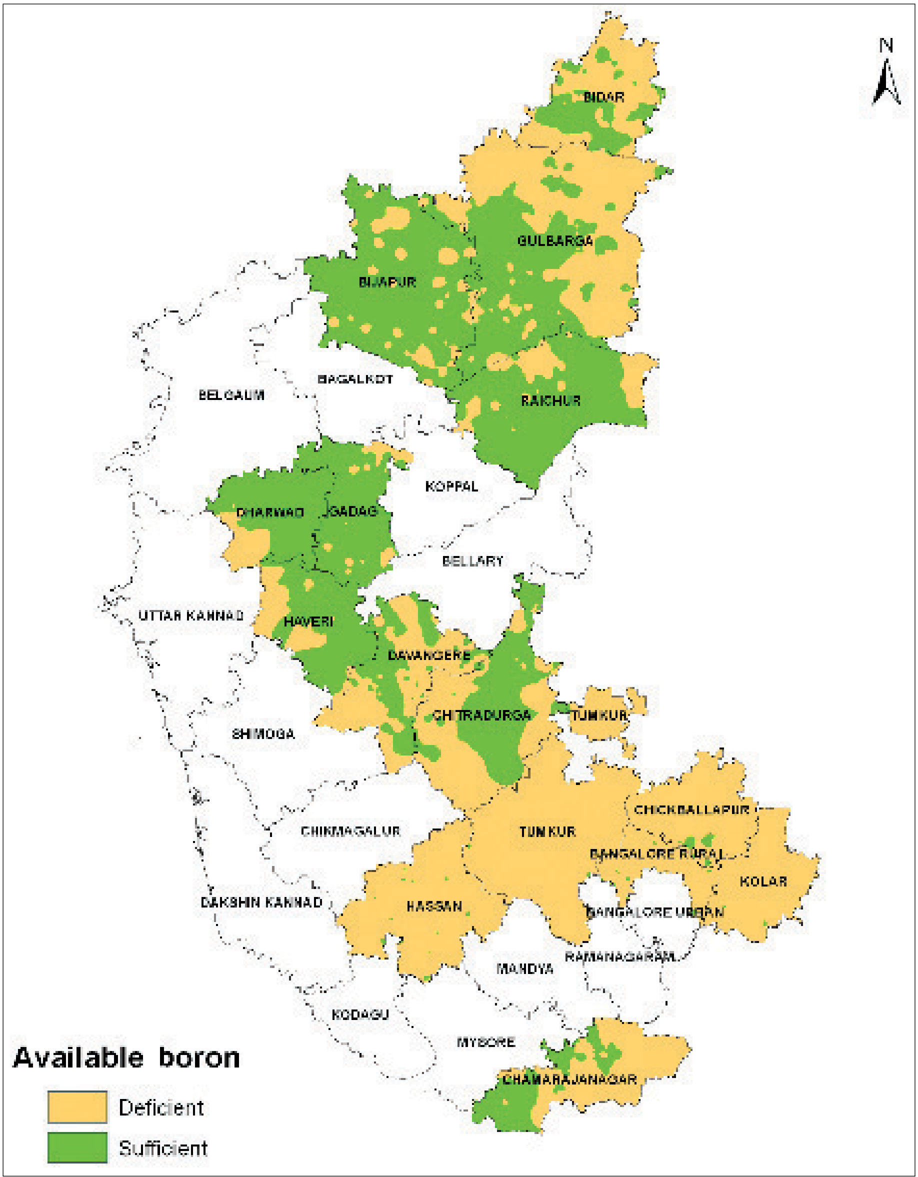

Figure 7. Availability of phosphorus in selected districts of Karnataka.

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* levels. 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.

Assessment of Seasonal Rainfall Forecasting and Climate Risk Management Options for Peninsular India

Uncertainty of the climate and weather has adverse effects on crop production and income of the farmers in the SAT. They 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 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 GCM predictor-based model output statistical (MOS) technique, the probabilistic seasonal rainfall prediction for the year 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.

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 (DEM) 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 2 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. Recent developments in laser altimetry and its data processing enable generation of DEM with centimetres accuracy under ideal condition.

The techniques for automated watershed delineation have been available since mid-eighties and have been implemented in various GIS systems and custom applications (Garbrecht and Martz 1999). Figure 8 portrays the Cartosat-1 data and the DEM derived there from along with LISS-IV multispectral data.

Figure 8. Satellite Data and DEM of watershed in part of Nalgonda district, Andhra Pradesh.

Watershed characterization involves inventorying and assessment of natural resources, which is essential pre-requisites 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 the soils and their response to management is required in agricultural and forestry, for decision making in planning and for many other engineering works. It has been demonstrated 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).

Prioritisation 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 prioritising the watershed when it is based on natural resources limitations or potentials in a watershed (Sharma 1997, Khare et al. 2001, Sekhar and Rao 2002, NRSA 2006, Rao et al. 1998 and Saxena et al. 2000).

The prioritization of watersheds in India is on the basis of natural resources status, socio-economic, 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 modelling (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 socio-economic conditions (agricultural labourers/SC, ST population/distribution of BPL families) were considered for prioritization.

Geospatial data and multi criteria based prioritization of watersheds helps 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 has been successfully used to establish a strong baseline information system and prioritization (Khan et al. 2001, Thakkar and Dhiman 2007, and 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 Geographic Information Systems have really enhanced potential of remotely sensed data in identifying suitable locations for conservation measures.

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 (SWHC) 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. 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. GIS map produced by 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.

Spatial Water Balance Modeling of Watersheds

ICRISAT consortium with national partners started watershed development activities from year 2000 onwards in one of the micro-watershed, Kothapally, located at Musi catchment in Southern India. Since the on-set of the program, water flows and crop parameters have been monitored, creating a good database of hydrological data and crop yield information. GIS based hydrological model, Soil and Water Assessment Tool (SWAT) is applied to study the water balance for different water management options. Impact of watershed management practices on water availability, and sediment loss was assessed. Four scenarios were developed with combination of (a) with or without in-situ land management practices and (b) with or without building storage structures in stream channel (called as ex-situ management). Thus scenarios are: 1) in-situ + ex-situ; 2) in-situ + no ex-situ; 3) no in-situ + ex-situ; 4) no in-situ + no ex-situ.

Water Balance of Different Water Intervention Scenarios

Results shows different water interventions significantly change the water balance components in watershed (Fig. 9). Before the introduction of the watershed development program (scenario four), approximately 60% of the rainfall became evaportranspiration (ET), while some 10% recharged the groundwater aquifer and 20% was lost from the watershed boundary as outflows, during the first cropping season. When the watershed development program was in place, the amount of water leaving the watershed as ET had increased to around 70%, groundwater recharge was also higher than previously, while outflows from the watershed was now less than 10% of the total water balance (scenario 1). Constructing check-dams substantially increased groundwater recharge (scenario 3), while in-situ practices resulted in a higher ET, since more water was available as soil moisture in the fields, and higher groundwater recharge (scenario 2).

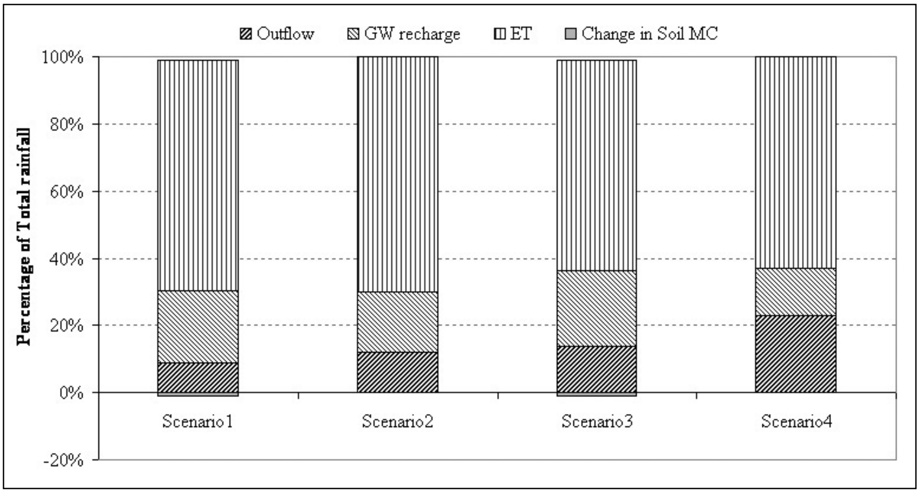

Figure 9. Water balance for the four different water management scenarios for the first cropping season (from June to Dec); scenario 1: in-situ + check-dams; scenario 2: in-situ + no check-dams; scenario-3: no in-situ + check-dams; scenario-4: no in-situ + no check-dams. (GWrecharge = groundwater recharge. ET = evapotranspiration).

Sediment Transport and Soil loss

Soil loss is strongly affected by rainfall intensity (Fig. 10). Rainfall intensities below 20-30 mm day^{-1} did not generate much soil loss in any of the four management scenarios. However, a clear difference in soil loss can be seen between the situation before and after the implementation of the watershed development program at rainfall intensities above 50 mm/day, where more soil is lost from the system without water interventions.

Without watershed development, it is seen that soil loss from the fields as rainfall intensities above 100 mm day^{-1} significantly impacts downstream systems. High rainfall intensities are expected to become more common with a changing climate, and soil loss from the fields can therefore be expected to increase in the future.

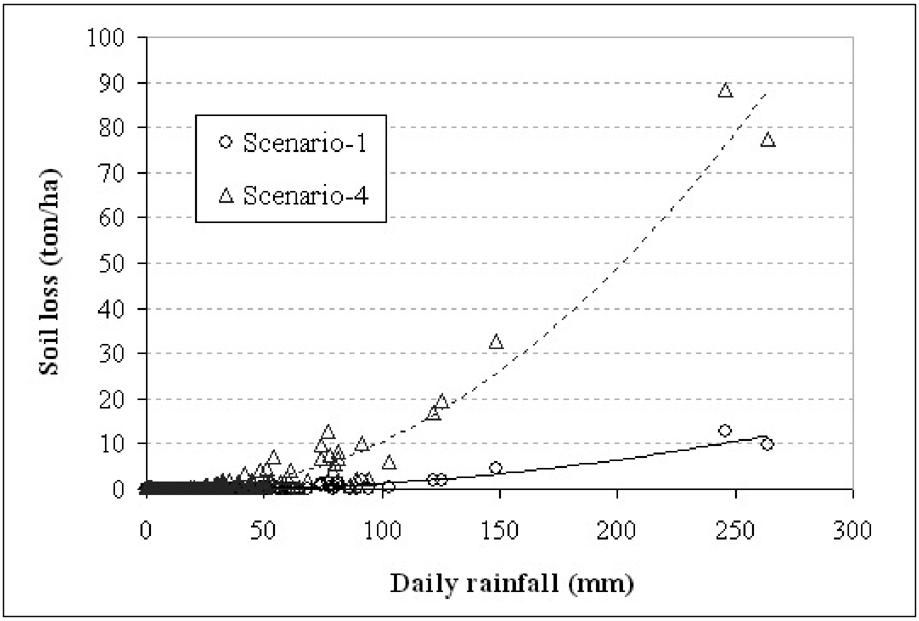

Figure 10. Rainfall vs. soil loss; scenario 1: in-situ + check-dams (post watershed development); scenario 4: no in-situ + no check-dams (no watershed development).

Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia

Assessment of Agroclimatic Potential

Maximizing agricultural production from rain-fed 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 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, favourable weather is a must 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 favourable 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 analyses 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 modelling, climate variability and change. Enhancing climate awareness among the rural stakeholders using new IT tools is the need of the hour.

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 is to 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 (WS) and water deficit (WD) based on rainfall, potential evapotranspiration (PET) and soil water holding and release properties. PET (amount of water that is lost in to 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 rain-fed LGP, dry and wet spells during the crop growth period, and for monitoring of moisture stress leading to drought at watersheds.

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, WS and WD. PET varied from about 890 mm at

Country	Location	Rainfall	PET	AET	WS	WD
China	Xiaoxingcun	641	1464	641	Nil	815
	Lucheba	1284	891	831	384	60
Thailand	Wang Chai	1171	1315	1031	138	284
	Tad Fa	1220	1511	1081	147	430
Vietnam	Chine	2028	1246	1124	907	122
	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

Table 2. Annual water balance characters (all values in mm)

Lucheba in China to 1890 mm at Tirunelveli in South India (Table 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.

Rain-fed LGP

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. Rain-fed 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 post-rainy season and winter rainfall can meet the crop water needs. Therefore, the LGP depends not only on the rainfall distribution but also on the type of soil, soil depth, 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. It is the highest in the low-lying regions and the 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 rain-fed LGP (Kesava Rao et al. 2007) indicated that the beginning and ending of the crop-growing season varied across the years at the watersheds. In all the watersheds, the end has 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. Kacharam, Mentapally, 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.

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 the year 2004 in AP (Fig. 11). The analysis indicated that among the 10 watersheds, 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.

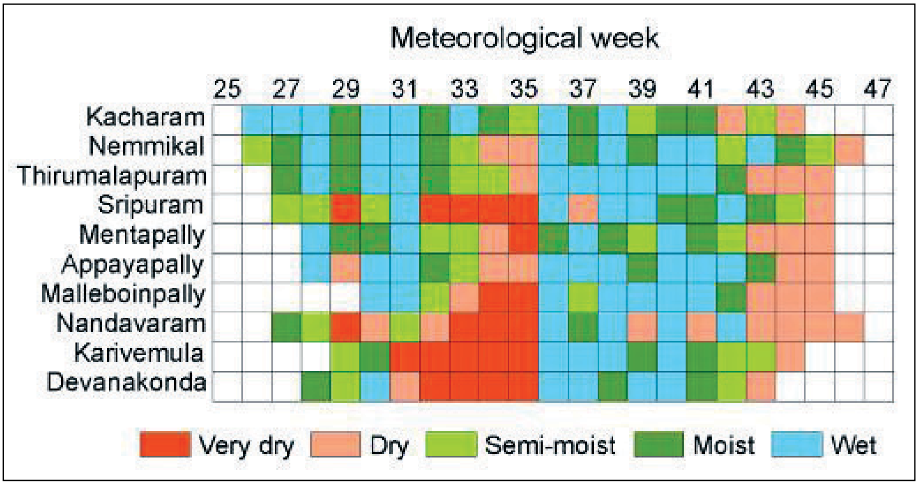

Figure 11. Drought monitoring at benchmark watersheds in Andhra Pradesh during 2004.

Karivemula experienced a disastrous drought of five-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.

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 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. Improvements 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 is implemented during September 2010 at the IMD, New Delhi that is expected to provide more accurate weather data. Weather alerts by E-mail are being planned.

Watershed Monitoring

Repetitive nature of satellite data enables change monitoring 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; NRSA, 2002, Rao et al., 2010, Kaushalya et al., 2010). Cyclic re-visit 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 the 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.

Satellite Images for Impact Assessment

The remotely sensed data has the advantages of providing synoptic view and large area coverage which helps in obtaining the proverbial "birds 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 Satellites (IRS), data availability both in the multispectral and panchromatic domains with varieties of spatial resolution are assured for 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 point of time, the technology facilitates for evaluating the ground realities at any given point of time.

The satellite images from different space platforms have varieties of sensors in the visible and infrared region and are good for assessing the dynamics of watershed development, type of vegetation, crop vigor, growth monitoring, green biomass, 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.

Monitoring and Evaluation of Watersheds using Remote Sensing

During first phase of the project, 60 watersheds were identified for impact evaluation from Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu and Uttar Pradesh and similarly 62 NWDPRA watersheds were treated during IXth Five Year Plan period in the second phase from Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttaranchal, Uttar Pradesh and West Bengal. Evaluation of identified watersheds was carried out using remote sensing technique by considering the parameters like 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 areal extent; alternate land use: switching over from marginal cropland to agro-horticulture and agro-forestry; water body: change in number and areal 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, 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 (RRSSCs), Indian Satellite Research Organization. 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, NDVI generation and image comparisons (Fig. 12). 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 registration of two-date satellite data was done

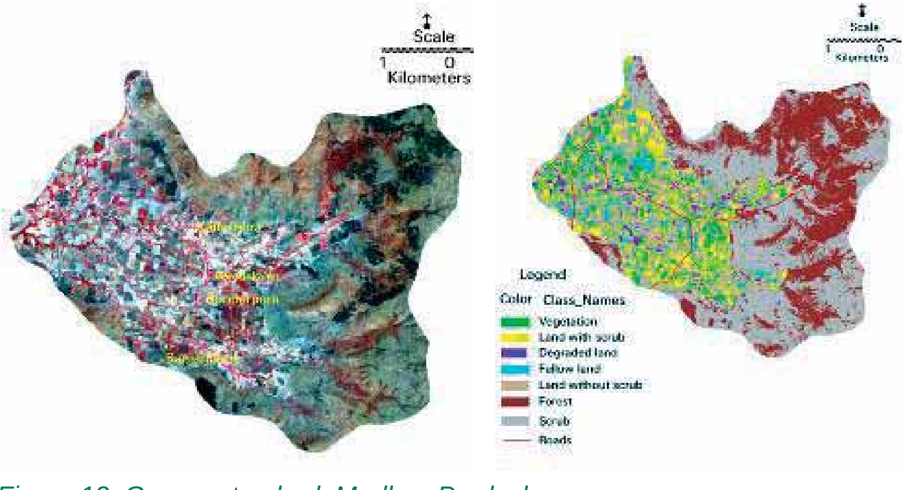

Figure 12. Guna watershed, Madhya Pradesh.

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 multi-spectral data acquired at different points of time. There are many change detection algorithms using digital techniques like image differencing, image rationing, principal component analysis and comparison of classified images.

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 (AP), 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, maize, cotton (*Gossypium* sp), sunflower, mung bean (green gram) and pigeonpea. During (postrainy season) wheat, rice, sorghum, sunflower, vegetables and chickpea are grown (Fig. 13). The mean annual rainfall is about 800 mm, which is received mainly during June to October.

There are 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 et al. 2009, 2010, Roy et al. 2010). For Adarsha watershed, 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 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

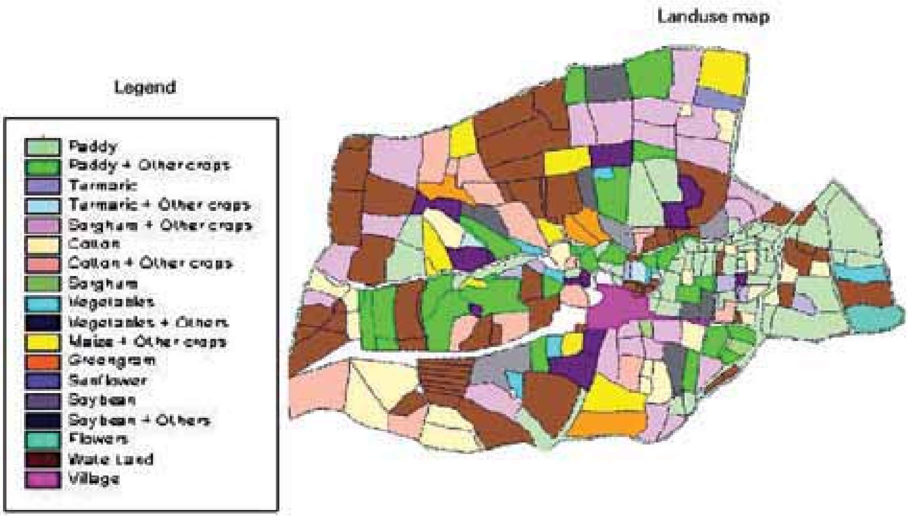

Figure 13. Landuse and cropping pattern of Adarsha watershed, Kothapally, Andhra Pradesh.

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 (Fig. 14). 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.

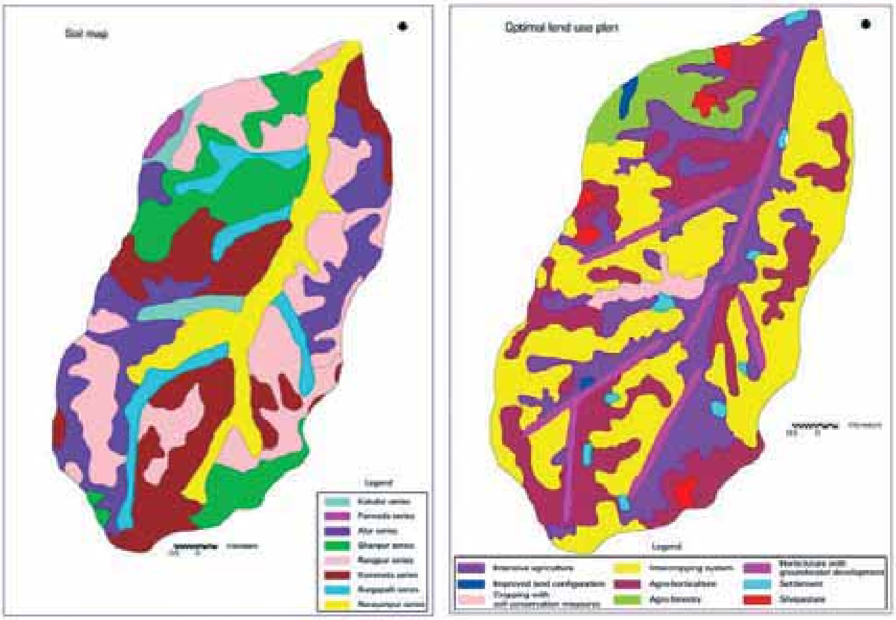

Figure 14. Thematic maps depicting soils and land use plan in Adarsha watershed, Kothapally, Andhra Pradesh.

Since the Adarsha watershed 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 measures, and silvipasture in marginal lands have been undertaken (Fig. 11). 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 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).

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, the watersheds in Andhra Pradesh (Kothapally, Malleboinpally, Appayapalli, 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 there were 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.

Spatial Simulation Modelling

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 above mentioned goals. They can enhance the impacts of agricultural research in watershed development. Simulation modeling using the surface and ground water 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 like LAI (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), Soil and Water Assessment Tool (SWAT) are some of the comprehensive models available in GIS environment that helps in modeling the watershed environment and visualizing the future scenarios.

To run the above continuous simulation models, it is essential to have 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). In this aspect, the Sensor Web, GPS and communication networks have greater role to play.

Use of ICT in Watershed Management

It is increasingly realized that facilitation of knowledge flows is a key in fostering new rural livelihood opportunities using modern information and communication technologies (ICTs). The concept adapted is one of intelligent intermediation for facilitation of flows of information and knowledge. The community centre managed by the PIAs 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 (Fig. 15). It is operated or managed by a rural group (women or youth SHGs) identified by the village watershed council through a consultative process. The activities on 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.

Figure 15. Information and communication technology services enabled at Addakal, Mahabubnagar district, Andhra Pradesh, India.

Summary

Application of new science tools in rain-fed agriculture opens up new vistas for development through integrated watershed management programs. 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 rain-fed 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 offers 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. The GIS systems 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. 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 rain-fed areas. The synergy of GIS and web technology allows access to dynamic geospatial watershed information without burdening the users with complicated and expensive software. Use of ICT in IWMP can bridge the existing gap to reach millions of small farm holders; new science tools when applied in IWMP can substantially enhance planning, implementation, monitoring and evaluation of IWMP in the country. Use of smart sensor network along with GIS, RS, simulation modeling and ICT opens up new opportunities for developing intelligent watershed management information systems.

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Application of Geomatics in Watershed Prioritization, Monitoring and Evaluation – CRIDA's Experience

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Abstract

Watershed-based development has been the prime strategy for rain-fed regions of India since 1980s to conserve natural resources, enhance agricultural production and improve rural livelihoods. Although soil and water conservation was initially the primary objective of watershed program that saw large public investments since inception, its focus later shifted to people's participation, equity and livelihood security, particularly from the mid nineties. One of the major goals of the watershed program is also regeneration of degraded lands. Many of these interventions need modern tools like GIS and remote sensing so that planning, prioritization and monitoring becomes more science based and the methodology and approaches can become universally applicable.

Application of GIS, remote sensing and use of GPS for monitoring and evaluating watershed projects is a recent development. Two exercises in this direction were initiated in CRIDA wherein relevant sustainability indicators were developed that could be quantified and monitored using these tools and the outcome of these studies have been presented in this paper. The bio-physical parameters were temporally evaluated from two standpoints – the pre- and the post-project implementation phases. The indicators were geo-referenced in the field using GPS and changes in NDVI and land cover were analyzed to assess if agricultural development within treated watersheds were sustainable.

Utility of Geomatics for developing criteria for watershed selection, as indicated in various guidelines including the recent Common Guidelines of 2008, cannot be overemphasized. Major bio-physical parameters that include potential runoff and soil erosion besides percentage of irrigated area, etc., could be quantified and used as indicators for monitoring and evaluation in the post-project phase. Lack of information on these parameters at watershed - level, as evidenced earlier have been made-up to a large extent through application of

better resolution data and generation of surrogate indicators. With the availability of DEM datasets in public domain and with the availability of GIS software, it is now possible to estimate certain parameters that have a direct bearing on potential runoff and soil loss, thus providing a scope for characterization of watersheds as mentioned earlier. The paper also presents an example of use of DEM dataset in GIS environment for prioritization of watersheds based on runoff -potential and soil loss parameter at the district- level.

Introduction

Application of Geomatics in CRIDA Watershed Program

Use of tools of Geomatics like GIS, RS, GPS, spectro-radiometer in tandem with the conventional tools like civil survey with total station, soil analysis, socio-economic survey and PRA have been in vogue in CRIDA since 1996-1997 when the ICAR – Institute Village Linkage program (IVLP) was launched at Nallavelli (Katyal et al. 1996; 1997). In 2000 these tools were used to develop suitable Land Use Plan for watersheds across sixteen centers in fifteen agro-ecological sub-regions (AESR) across the country under the NATP-MM-LUP program for rain-fed ecosystems. These tools were used to develop, monitor (Kaushalya 2001, Kaushalya et al. 2001, Vittal 2004) and evaluate watershed projects funded by NABARD, under IWMI study in Krishna Basin and under the National Fellow Scheme by Kaushalya et al. 2007, 2009).

Scope of application of GIS and RS for watershed development include:

- land use – resource inventory and planning for optimum use;
- delineation and prioritization of watersheds – automated watershed delineation, drainage basin morphological analysis, stream order, drainage density, basin slope and shape, circularity, cumulative area distribution, hypsometric curves;
- identification of vulnerable areas;
- rainfall-runoff modeling;
- implementation of development program in rain-fed areas for resource conservation – land use planning;

- soil fertility and its quality assessment.

In different initiatives by the institute, the above applications were implemented in watershed activities.

Resource Inventory and Planning for Technology Upscaling

In 1996, ICAR launched the Institute Village Linkage Program (IVLP) with a view to demonstrate technologies necessary for all cropping systems within the village. A prerequisite for implementation of the program was the identification of cropping systems. A conventional approach would give information on the type of cropping systems available in the village without any perspective on resource inventory. Through GIS, existing cropping systems were superimposed on prevailing soil and water resources and suitable technologies which could make impact were identified for demonstration purpose. The work was carried out at Nallavelli in Yacharam mandal of Rangareddy during 1996-97. Similarly, under the NATP mission-mode project for optimum utilization of agricultural resources for land use planning, CRIDA as lead center along with sixteen centers across the rain-fed ecosystems in the country, worked for development and implementation of land use plans in selected watersheds during year 2000-03. The use of GIS with information from satellite data to draw land use plans was successfully demonstrated as indicated in Fig. 1.

Watershed Delineation and Prioritization

Delineation of watershed is often done manually, which require good capabilities on the staff and a lot of time is spent to cover a larger area. With the availability of GIS software along with facilities for spatial analysis and watershed delineation modules, the same task can be performed in a shorter period. Traditional toposheets for elevation/ contours information is also getting replaced with digital elevation datasets, which are available at either 90m or 30m resolution in a public domain. Further, parameters such as runoff potential index, which has a more relevance for watershed program in semi arid areas, can be assessed through set of surrogate parameters using GIS techniques by using the DEM information. A case study of Mahabubnagar district

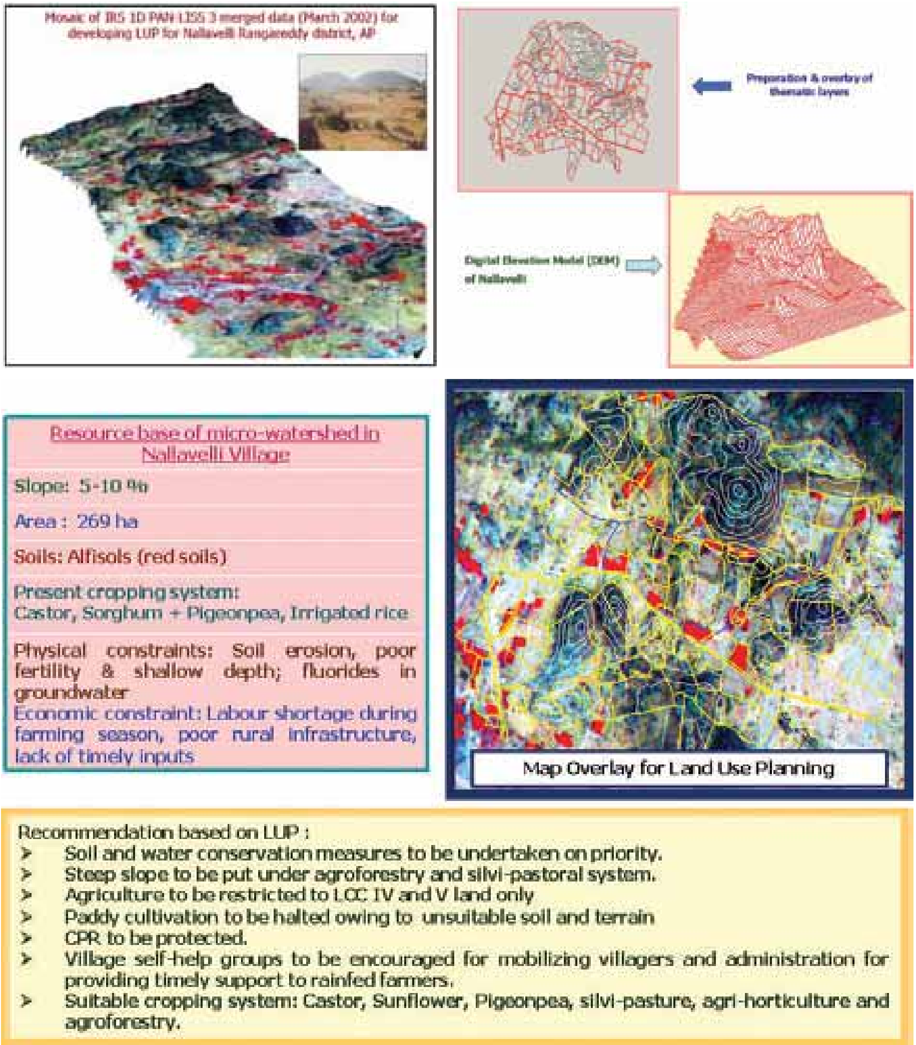

Figure 1. Characterization of NRM status using Geomatics.

is described below (Fig. 2).

Case Study

Mahabubnagar district is in the Telangana region of Andhra Pradesh State, falling in the Southern Plateau and Hill Agro-climatic region of India. It lies between 16°46' North Latitude and 77°56' East longitude. The

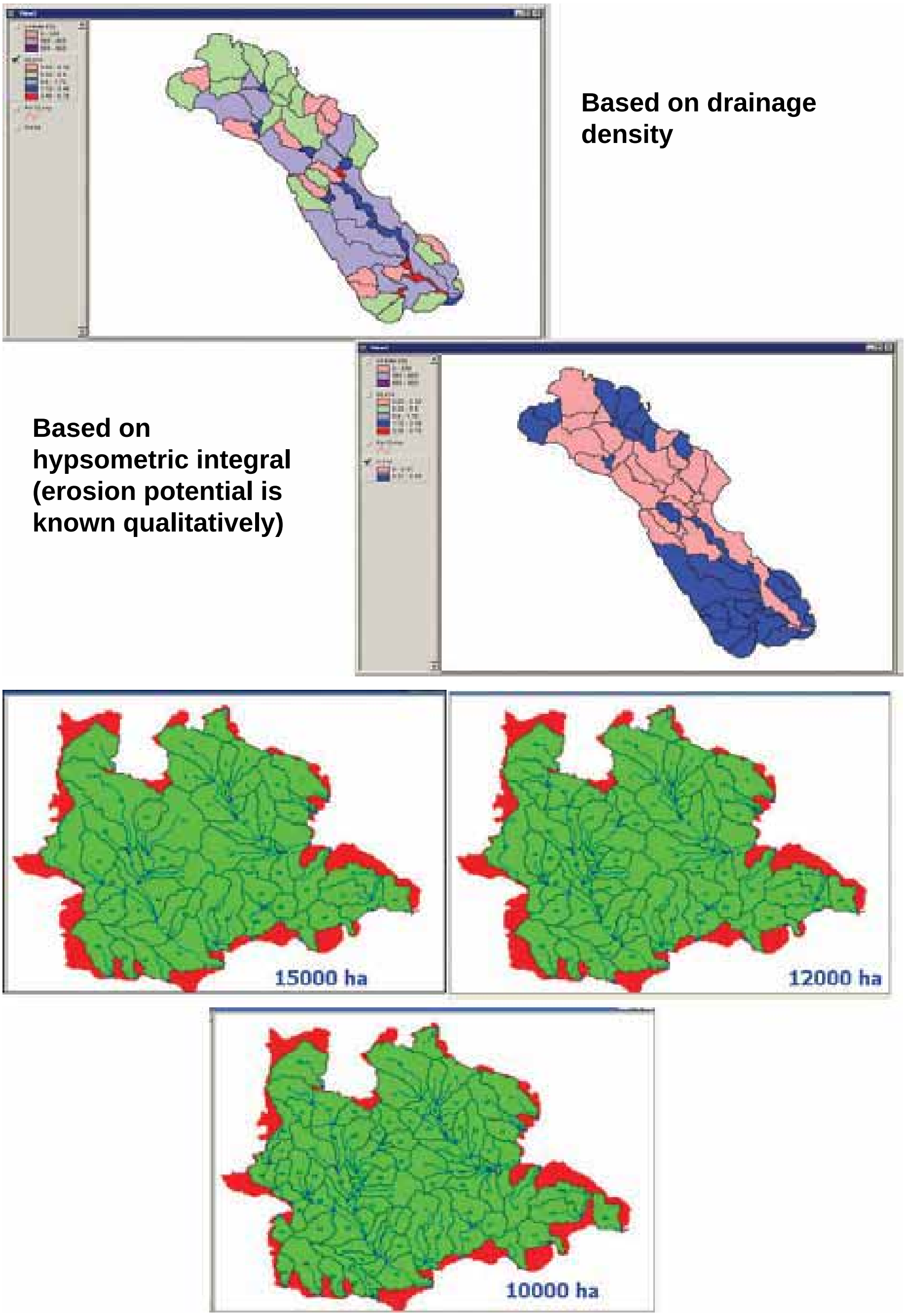

Figure 2. Geomorphological characterization of watersheds for prioritization – a case study of Mahabubnagar district.

total geographical area of the district is 18,432 sq. km. The major rainfall is through southwest monsoon. Average rainfall is 754 mm. Annual evaporation of the region is in the range of 25-300 cm. There is a wide range of variation in the rainfall, number of rainy days and temperature in this region, and hence the climatic variation is remarkable. The total agricultural area and forestlands occupy about 37% and 14.5% (1997-98), respectively. The percentage of wastelands from the satellite data interpretation is about 13.5 to the total geographical area.

The following geomorphological parameters were estimated for the study area:

a) average slope of the watershed (S_a), b) relief ratio (R_r), c) relative relief (R_R), d) elongation ratio (Re), e) shape factor (Sb), f) form factor (Ff), g) circularity ratio (Rc), h) stream length ratio (Rl), i) bifurcation ratio (Rb), j) drainage density (m^{-1} or km^{-1}) (Dd), k) stream frequency (km^{-2}) (Sf), l) drainage factor (Df), m) ruggedness number (RN), n) hypsometric integral (His)

The extracted Mahabubnagar DEM from the SRTM data was processed for watershed delineation. The threshold areas of 50000, 25000, 15000, 12000 and 10000 ha were analyzed for the study. Evaluation reports for the watershed and for each sub basin were obtained. The evaluation report contains the minimum, maximum and mean elevation data and also the standard deviation. Percentage area below elevation was obtained. The hypsometric interval is calculated for the watershed and sub basin watersheds using the hypsometric interval formula:

$$H_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$$

$Elev_{mean}$, $Elev_{min}$ and $Elev_{max}$ are the mean, minimum and maximum elevation, respectively.

The hypsometric integral and the geomorphological parameters were calculated for all the threshold areas. The graphs were plotted for the drainage density verses geomorphological parameters and the Hypsometric Integral Vs geomorphological parameters.

Drainage density is the ratio of the total length of all the streams to the watershed area (A), both measured in consistent units.

$$D_d = \frac{\sum_{i=1}^{n} L_i}{A}$$

L_i is the length of each drainage channel. If drainage density is high, it implies a well developed natural surface drainage pattern. A high drainage density may occur due to several watershed features as well as the rainfall pattern. A high drainage density also reflects quick transformation of overland sheet flow into rill, channel, rivulet and stream flows, which in turn, implies low infiltration characteristics of the watershed surface soils. Besides, drainage density will be usually low in well vegetated or well forested watersheds as the direct impact of rainfall is reduced due to abstraction through interception of the incoming rain water. Also, D_d does not necessarily assume the highest values in mountainous regions and the lowest values in gently sloping areas with moderate rainfall, but characterized by a relatively sparse vegetation cover and rather impermeable soils or rocks, may have a greater drainage density than hilly terrain with heavier rainfall.

The threshold area of 50000 ha area was divided into 12 sub basin watersheds. The entire area was divided into three classes based on the erosivity (Table 1 and Table 2). In this 421375.33 ha area was already eroded and 926704.26 ha area was under the erosivity process. For the threshold area of 25000 ha the area was sub divided into 33 sub basins. In this 538588.89 ha area was already eroded and 1007443.13 ha area is under erosion. For a threshold area of 15000 ha,

Table 1. Estimation of priority area for treatment based on erosion potential – prioritization and decisions on SWC interventions based on higher HI.

Hypsometric Integral	No. of sub basins	Area (ha)		
		HI < 0.3	HI 0.3 – 0.6	HI > 0.6
15000 ha	56	502732.42	1123791.19	27448.75
10000 ha	89	480847.61	1150003.51	27448.75

Table 2. Estimation of priority area for treatment based on runoff potential – higher drainage density – more water harvesting.

Threshold area (ha)	Drainage density	No. of watersheds
15000	0.00-0.38	52
	0.38-0.72	2
	>0.72	2
12000	0.01-0.41	65
	0.41-0.82	2
	>0.82	3
10000	0.00-0.61	87
	0.61-1.22	-
	>1.22	2

the area was sub divided into 56 sub basins. In this, 502732.42 ha area was already eroded and 1123791.19 ha area was under erosion. But 27448.75 ha area was prone for erosion. For a threshold area of 12000 ha, the area was sub divided into 70 sub basins. In this, 499641.35 ha area was already eroded and 1154331.01 ha area was under erosion. For a threshold area of 10000 ha, the area was sub divided into 89 sub basins. Out of that 480847.61 ha area was already eroded and 1150003.51 ha area was under erosion. But 27448.75 ha area was prone for erosion.

Soil Quality Assessment using GIS and RS:

Soil quality assessment has been recognized as an important step toward understanding the effects of land management practices within agricultural watershed. An investigation was carried out to assess the soil quality in a watershed scale considering the spatial variability of soil for optimizing land use. Soil samples from 0 to 20 cm depth were collected within 118 locations on a 100m × 100m grid over a 87 ha watershed at Sakaliseripalli village of Nalgonda district in Andhra Pradesh state of India, during 2006. Differential GPS was used to delineate the ridgeline as well as field boundary of each plot within the watershed. The DGPS file was imported in Arc-GIS and edited to get a combined map for each field boundary. Satellite imagery was also analyzed to get field level information. Yield information was collected from the farmers through survey for preparing yield map. As farmers were growing diverse crops, yield of each crop was converted to rice equivalent yield by multiplying a factor, considering the Indian market price of that crop to that of rice (Mandal 2009).

Satellite Imagery

False colour composite (FCC) of satellite imagery of the study area was presented in Fig. 3. QuickBird image is the clearest image and even each field can be identified in the image. LISS-III image is not suitable for field level information of an area of <100ha. The LISS-III and PAN image was spatially enhanced through resolution merge option using principal component analysis method. In all multispectral (MS) imagery, red colour related to vegetation was quite less. Out of five MS imagery, four imageries were from *rabi* season (January, February and March) and most of the area was under fallow (no crop) during *rabi* season, only few rice fields had irrigation facility. The reddish color was also less

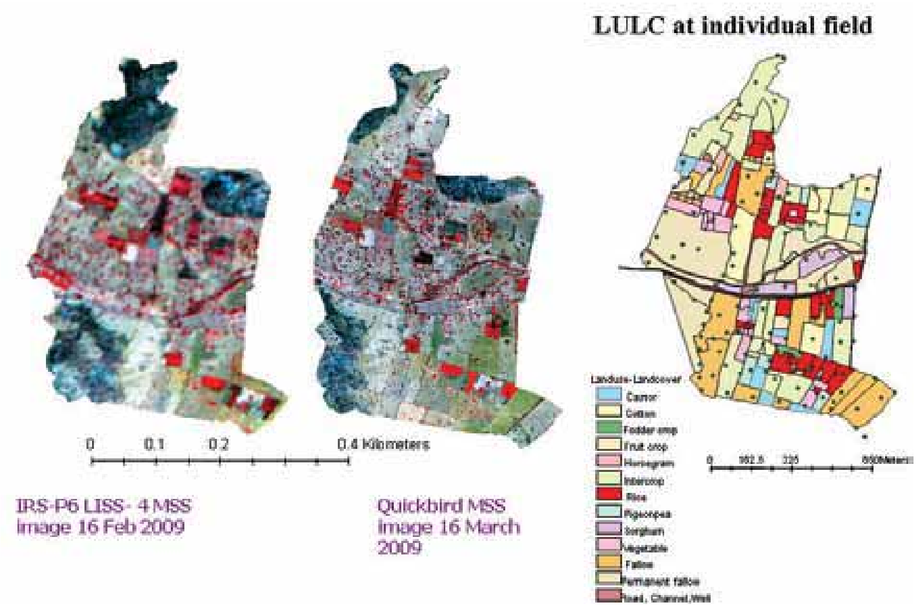

Figure 3. Satellite images with varying ground resolution – Sakaliseripalli watershed.

for August P6-LISS-IV image. It may be that *kharif* crop during August end was not in luxuriant growth stage.

Soil Health Report

A soil health card for all 118 soil sampling points has been prepared and distributed to farmers. The soil health card highlighted the suitability of crop, present land use land cover practice, all macro-micro nutrient status of the soil, pH, and salinity-sodicity condition of the soil. The entire material has been translated into local Telugu language.

Soil Quality Index

An assessment framework, including a minimum data set, linear scoring functions and additive indices were used to evaluate the soil quality index (SQI). Principal component analysis identified cation exchange capacity, exchangeable sodium percentage, DTPA extractable Zn, available P, available water and dehydrogenase activity as the most important indicators to evaluate soil quality.

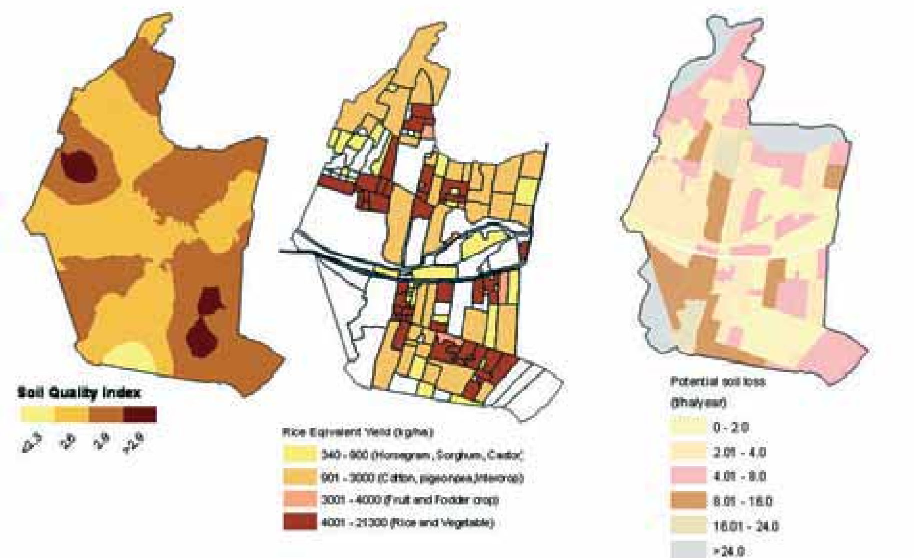

Figure 4. Thematic maps of soil quality, agricultural productivity and soil loss potential of Sakaliseripalli watershed.

A kriged map of SQI (Fig. 4) was prepared for the watershed and the highest SQI was recorded in vegetables fields (3.06) followed by rice (2.97), cotton (2.682), fallow (2.61), redgram (2.60), fruit crop (2.57), intercropping system (2.54), wasteland (2.53), sorghum (2.52), castor (2.47), and the lowest in horsegram (2.35) field. The SQI value under irrigated system (3.01) was better than the SQI value under rain-fed condition (2.53). In this study, potential soil loss calculated using universal soil loss equation (Fig. 4) along with crop yield were defined as the quantifiable management goals.The results indicated good soil having higher soil quality index were also productive and less erosion prone too.

On Farm Experiment

Considering soil related constraints, four on farm experiments were conducted by selecting four farmers for four different cropping systems, maize, sorghum, sorghum + pigeonpea, castor + pigeonpea during *kharif* season of 2007. Gypsum was applied at 1 t acre^{-1} considering the level of sodicity in soils. Also gypsum was applied for castor crop considering as source of sulphur. Fertilizer were applied at 60, 40 kg N and P_2O_5 ha^{-1}. As maize plot was low in Zn, it was applied as $ZnSO_4$ at 20 kg ha^{-1} at the time of sowing. FYM was applied at 2 t ha^{-1} for all the crops. Yield record showed a maize yield of 3.6t ha^{-1} and 2.4 t ha^{-1} of sorghum and 1.08 t ha^{-1} of sorghum and 0.186 t ha^{-1} pigeonpea under sorghum+pigeonpea intercropping system. The overall increase of 20% above the average yield in the watershed was recorded during the experiment.

Evaluation of Watershed Development Program under ICAR National Fellow Scheme at CRIDA

Under this program, four watershed project villages were selected for study where watersheds developed by various agencies in the semi-arid and dry sub-humid tropics of northern Telangana were identified as AESR 7.2 (Velayutham et al. 1999). For assessing the impact of WDP, four untreated watersheds located in the vicinity were taken as control although not in a strict sense in view of the implementation of other

Table 3. List of sustainability indicators constructed for the study.

S. No.	Level/spatial extent of analysis	No.of suitable indicators used	Pllars of Sustainability				
			Agricul-tural producti-vity	Liveli-hood security	Environ-mental protec-tion	Economic viability	Social accept-ability
1	Household level	20	0	11	0	7	5
2	Field level	29	11	22	15	20	11
3	Watershed level	35	14	27	17	22	15
4	Village level	43	-	-	-	-	-
5	AESR level	8	-	-	-	-	-
	Total no. of unique indicators	51	14	29	17	25	17

developmental activities in the village. Impact of sustainability of WDP was evaluated in each watershed at three levels - household, field and watershed during 2005 to 2009 and the outcome were compared annually with the situation prevalent during the preceding year in the respective watersheds. For evaluation, valuation of economic returns from a unit land area (ha) was estimated across the watersheds annually. The hallmark of this study was the use of Geomatics tools for construction of sustainability indicators and measurement of various parameters for evaluation of impact of WDP in the study area (Kaushalya et al. 2010).

Satellite data was used to create authentic baseline data where it was unavailable so that accurate evaluation of impact of WDP could be undertaken. The study demonstrates the use of Geomatics for evaluation of WDP in the country by overcoming the bottleneck of lack of quantifiable baseline data, a general problem faced by all earlier projects in the country. Using these tools, it was possible to construct sustainability indicators and develop a methodology for quantitative evaluation that was applied to evaluate eight micro-watersheds in the study area in Andhra Pradesh, as described in this paper.

Statistical techniques such as Bivariate Correlation technique and Principal Component Analysis were used to choose critical indicators as Minimum Data Sets for evaluation of WDP. Outcome of this study was compared across the selected watershed villages, both spatially and temporally and the results of this post-facto assessment and evaluation were discussed in brief here. Table 3 lists the number of sustainability indicators for evaluation of WDP at three spatial levels for five aspects of sustainability.

In order to evaluate impact of WDP at three spatial levels – household, field and watershed level, thirty-nine sustainability indicators were constructed and used for evaluation. While some of the indicators were quantified directly from primary field survey for e.g., land holding size, agricultural production or land use, etc., other indicators like field-wise slope information was derived from GIS thematic maps of the selected watersheds. For quantifying other indicator like crop vigour, NDVI derived from IRS – 1D and IRS- P6 satellite data were used. To quantify impact of human-intervention on land, temporal analysis of land use - land cover change (LCCS) was carried out and the information was used as proxy. Fig 5 indicates the temporal variations in LULC in Pamana village. In a similar manner, NDVI and Soil fertility variations in treated and untreated watersheds were analyzed and impact of WDP was evaluated (Figs. 5 & 6.).

Based on this multi-disciplinary exercise, impact of WDP was assessed for five aspects of sustainability at three spatial levels mentioned earlier in the paper. Fig.7. indicates the performance of critical indicators identified for ensuring sustainable agricultural productivity through WDP at field-level in a treated and untreated watershed in Pamana in 2008. The cob-web diagram clearly indicates that except for some progress in the area of agricultural production and gross returns, the impact of WDP has been low.

Conclusions

- Application of GIS and Remote Sensing is critical for planning, implementation & objective evaluation of watershed projects as indicated by CRIDA.
- Higher resolution satellite data enhances utility of Geomatics tools.

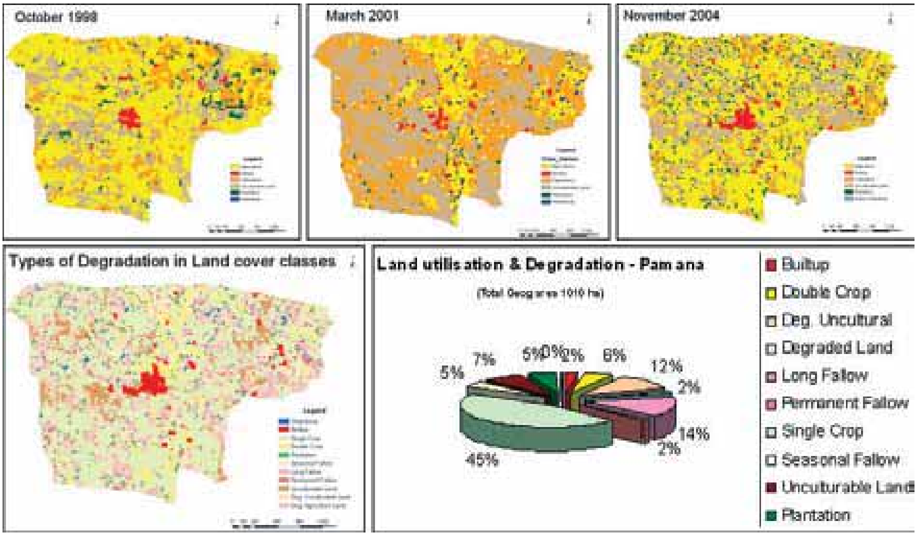

Figure 5. Assessing temporal variations in LULC & degradation.

- Use of DGPS enhances utility of GIS and satellite data by permitting geo-referencing of spot location, mapping of individual field boundary and facilitating interpolation of site specific management decision.
- CRIDA is using tools of Geomatics for delineation & development of watersheds, implementation of suitable land use plan, monitoring of watershed program and assessment and evaluation of watersheds.

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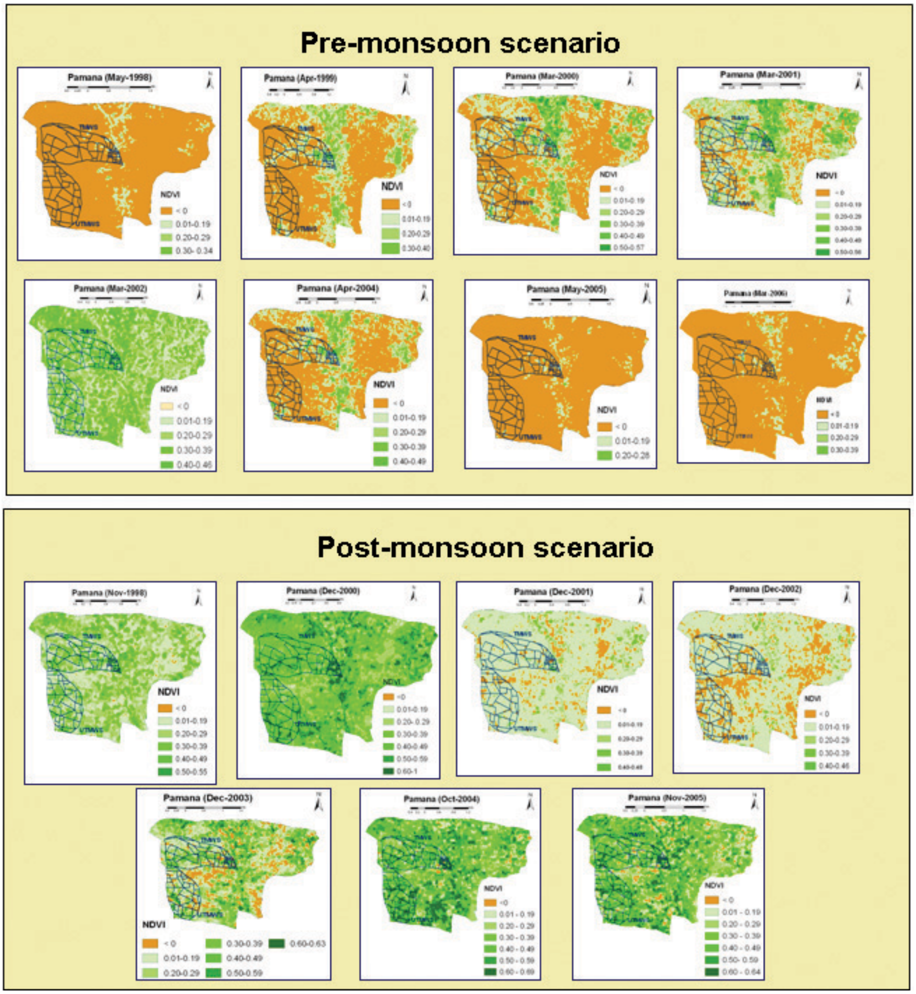

Figure 6. Estimating seasonal variations in crop vigour using NDVI as a indicator.

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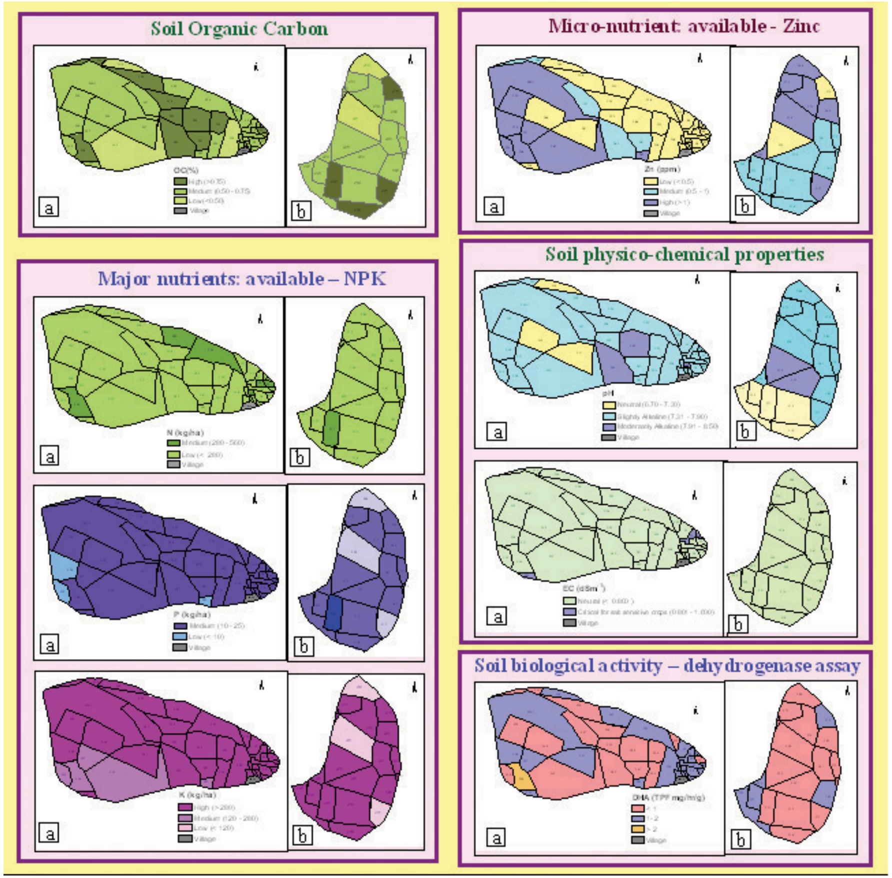

TMW – Treated micro-watershed

UTMW – Untreated micro-watershed

Fig. 7. Mapping soil fertility status – quantification of indicator.

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Use of Hi-Science Tools in IWMP

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Abstract

Gujarat has been at the forefront of watershed development program in the country, both in terms of quantity and quality. By the end of the year 2008, more than 8000 micro-watershed projects involving more than Rs.25000 million have been either completed or on going in the state. However, a lot remains desired in overall project planning, implementation and post project management so as to make the program sustainable. Considering the different concerns regarding project management, the New Common Guidelines for Watershed Program has prescribed for use of high science tools like application of Remote Sensing & Geographic information System (GIS), Management Information System (MIS) and other Information & Communication Technologies.

Accordingly, the Government of Gujarat has undertaken the Integrated Watershed Management Program (IWMP) incorporating the available high science tools; GIS is a major part of the whole process. The Gujarat State Watershed Management Agency (GSWMA), the nodal agency at the state level for IWMP in collaboration with Bhaskaracharya Institute of Space Applications and Geo-informatics (BISAG) has taken initiative in this regard by integrating GIS based data at both micro and macro level planning.

Introduction

Sustainable development of India (as different from the India's growth story fuelled by the IT revolution) depends largely upon three factors: i) how we increase our agricultural growth rate, ii) how we improve rural livelihood options, and iii) how we conserve our natural resources. Today, along with the National Rural Employment Guarantee Scheme (NREGS), the Integrated Watershed[1] Management Program (IWMP) has the biggest potential to propel the sustainable development. Watershed development in India is at a crossroads at the moment, looking forward to a whole new approach and a focus. The directions have been provided by the New Common Guidelines, 2008. But the ideas envisioned therein need to be translated into reality in the field. For this to happen, appropriate technology, latest practices in natural resource management, appropriate livelihood strategies and indigenous knowledge base have to go hand in hand.

A major portion of the agriculture in India is rain-fed. The increasing pressure of population on land has resulted in over exploitation of land, water and other natural resources, resulting in water scarcity, land degradation and rapid depletion of ground water-tables. As a consequence, the agricultural growth rate is stagnating, and inflation in food prices is spiralling. Agriculture being the main source of livelihood, the rural masses are increasingly migrating to the urban centres, which in turn puts pressure on urban centres and resources. A solution demands integration of traditional local knowledge with modern agricultural research, high end science, quality human resources and strategic investment.

Background

The Government of India adopted watershed development as a strategy to address issues of natural resource degradation and stagnating agricultural growth way back in 1994-95 with the Hanumantha Rao committee report advocating for such an approach. The Watershed Guidelines, 1995, mandated the watershed approach for area development programmes like Drought Prone Area Program (DPAP), Desert Development Program (DDP) and Integrated Wasteland Development Program (IWDP). Since then, thousands of projects involving billions of rupees have been invested in these programs all over the country. Several guidelines thereafter emerged from different ministries depending upon the developmental schemes under implementation. Finally the New Common Guidelines, 2008, based on the recommendations of the Parthasarathy Committee Report were issued, which integrate all the watershed based programs into a common program called Integrated Watershed Management Program from 2009-10.

During the pre-IWMP watershed development program, some of the main concerns were:

Prioritization of the watersheds: This task was with the respective district authorities which were granted projects by the Government of India, mainly based on socio-economic parameters. Without any scientific criteria or scientific tools, the district authorities chose the villages to be taken up under the projects either on the basis of their conscience or some political considerations. The prioritization was never scientific or objective.

Technical inconsistencies: Some of the technical inconsistencies in project implementation came from improper site selection for water harvesting structures and other engineering works as the technical persons did not have sufficient knowledge of the geo-hydrology of the area.

People vs. technical experts dilemma: The exercise of planning and implementation in the past generated conflict between the people living in the project area and the technical personnel regarding site selection and appropriate interventions in project areas.

Developing a scientific action plan: Without a proper GIS of the area, a scientific action plan was difficult to arrive at. At best, the concerned persons would come up with some activities which sometimes proved to be unsuitable for the area in the long run.

Preparation of detailed project report: There was no established mechanism for detail project report preparation. Without the village level GIS based maps, the action plan was never mapped. This made the relevance of DPR limited.

Monitoring and evaluation: Poor quality DPRs led to poor quality monitoring and evaluation mechanism to start with. Without an appropriate MIS, the task became tough and it was done arbitrarily and randomly.

Impact assessment: Any kind of impact assessment in the post project period was too heavily dependent on socio-economic researches. These studies have their limitations looking at the nature and enormity of the task.

Watershed Development in Gujarat

Over the next two decades, Gujarat proposes to cover all the micro-watersheds in the state and to adopt science and technology in a big way to enhance the transparency, efficiency and effectiveness of the program.

Gujarat State Watershed Management Agency (GSWMA) was constituted with the specific objective of managing and upgrading this massive program that includes construction of water harvesting structures, soil conservation activities, afforestation, agriculture development, dairy development, micro enterprise development and creation of other direct livelihood opportunities and to ensure the necessary technical rigour to the process.

Use of GIS in Watershed Management

Use of GIS and other high science tools at all stages such as prioritization, planning, implementation and consolidation has helped Gujarat to address most of the concerns regarding pre IWMP watershed programs.

The strategy regarding application of GIS and other high science tools involved the following steps:

- identification of fields in which these tools can be utilized;
- collaboration with institutions that can provide suitable back end support;
- placing competent human resource to handle these tools at different levels;
- capacity building of different stakeholders in application of these tools.

Among all the high science tools, the application of Geographic Information System (GIS) is perhaps the most significant.

The GSWMA, is the state-level nodal agency (SLNA) for IWMP, in collaboration with Bhaskaracharya Institute of Space Applications and Geo-informatics (BISAG) have taken the initiative of integrating GIS based data at both micro and macro level of planning.

BISAG formerly known as Remote Sensing Communications Centre (RESECO) is a state level nodal agency of Gujarat state which started its operations in April 1997. It was renamed to its present name in December 2003. The institute was formed to facilitate the use of spatial and geo-spatial technologies for planning and developmental activities pertaining to a agriculture land and water resource management, wasteland/watershed development, forestry, disaster management and rural and urban planning activities.

Geographic Information System may be defined as “A system which provides a computerized mechanism for integrating geo-referenced data sets and analyzing them in order to generate information relevant to management needs in a given context.”

A Geographic Information System (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. It allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps answer questions and solve problems by looking at data in a way that is quickly understood and easily shared. (ESRI)

The New Common Guidelines for Watershed Programs, 2008, Government of India, have prescribed use of high science tools like Remote Sensing and Geographic information System (GIS), Management Information System (MIS) and other Information and Communication Technology (ICT) tools.

The use of GIS in IWMP in Gujarat spans all three phases of watershed development:

1. during planning period;
2. during implementation phase;
3. during consolidation phase.

Planning

Planning of a watershed development project involves the use of GIS in various aspects of prioritization, development of action plan and later for monitoring and evaluation of these projects. The initial process involved creation of different spatial layers from the non-spatial dataset collected from various sources. Due to the focus provided by the State Government to the need for scientific planning and management, substantive data was already mapped and available with BISAG (Table 1).

Table 1. Various GIS datasets used and their sources.

	Features	Source
Land	Land use	Satellite data
	Landform (hill, Alluvial, coastal areas, etc)	Satellite data
	Soil type	Soil and Land Use Survey of India, National Bureau of Soil Survey & Land Use Planning, Agricultural Department
	Slope/elevation	Satellite data & Open Source
Water	Surface water bodies	Satellite data
	Ground water condition	GWRDC, CGWB
	Wells	Revenue department
	Check dam	Departmental data
Vegetation	Agriculture	Agriculture department, satellite data
	Forest	Forest department, satellite data
Household	Socio-economic facilities, SC & ST data, actual wages, drinking waters, % of SF &MF, % poverty index	Department of Rural Development, Bureau of Economic & Statistics
	Village map	Computerized maps from revenue department
Infrastructure	Roads, canals, water supply	Line departments
Ownership details	Forests, government, panchayat, private	Revenue department
Others	Sanctuaries, mining areas, CRZs, SEZs	Line departments

Box-1: Excerpts from Common Guidelines 2008

Scientific Planning: Special efforts need to be made to utilize the information technology and remote sensing inputs in planning, monitoring and evaluation of the programme.

(Preface –VII)

The endeavour would be to build in strong technology inputs into the new vision of watershed programmes. At the state and national levels, core GIS facilities, with spatial and non-spatial data, would be established and augmented with satellite imagery data received from NRSA, ISRO and Survey of India. All the GIS layers for various themes would be overlaid having a geo-referenced base layer up to the level of village boundaries in the first instance. This core GIS data may be given controlled access/distribution over network for local project planning. Application software for web-enabled integrated watershed development, spatial and non-spatial data standards and meta-data would also be worked out. Once such a knowledge base is in place, it would be possible to define watershed project boundaries with assignment of unique-identification (unique-id) to each project. It would also be possible to map treatment area with respect to their respective administrative formations in terms of villages, blocks and districts.

(Chapter 3. Technology Inputs -13)

Remote sensing data would be utilized for finalizing contour maps for assessment of run-off and for identifying structures best suited for location of projects. This would result in cost and time optimization in project implementation. Technology would also contribute immensely in assessing the actual impact of various programs in a given area. Due to availability of latest remote sensing techniques, it is now possible to assess periodic changes in geohydrological potential, soil and crop cover, run-off, etc, in the project area.

(Chapter 3. Technology Inputs -14)

Different parameters were categorized into the natural resource base (including the historical data) of the area and the socio-economic aspects.

The implementation of IWMP was initiated with the BISAG preparing district-wise watershed prioritization maps on a scale of 1:10000 using satellite data. The selection of the project sites was then made on the predetermined criteria (developed by DoLR) according to the ridge to valley approach and the New Common Guidelines for Watershed Program, 2008, Government of India.

The approach followed for planning involved three basic activities:

- creation, development and management of the geo-spatial data base depicting current conditions of land, water and vegetation with respect to watershed incorporating different ownerships and administrative boundaries at village level;
- incorporation of socio-economic aspects and their analysis;
- incorporation of historical perspective of watershed development in the area.

Fig.1 shows how the micro level planning is done by overlaying various spatial layers like the cadastral layer, watershed boundary, etc. The planning started with the state level satellite imagery where the natural boundaries were identified. The administrative boundaries were obtained from revenue records that were overlayed onto the satellite imagery. Imagery was panned upto the village level where land parcel level information was collected. Survey number wise plotting of land was prievously done based on the data collected from the village level. For example as shown in the image a survey number in Fajalpur village in Vadodara *taluk* of Vadodara district will contain details on slope, soil type, ownership, program under which the land was prievously treated, etc.

Prioritization

Of all the tasks, the most important and difficult step was the prioritization of watersheds. The difficulty lay in the fact that Gujarat state is delineated into a total of 13,587 watersheds (geographic area

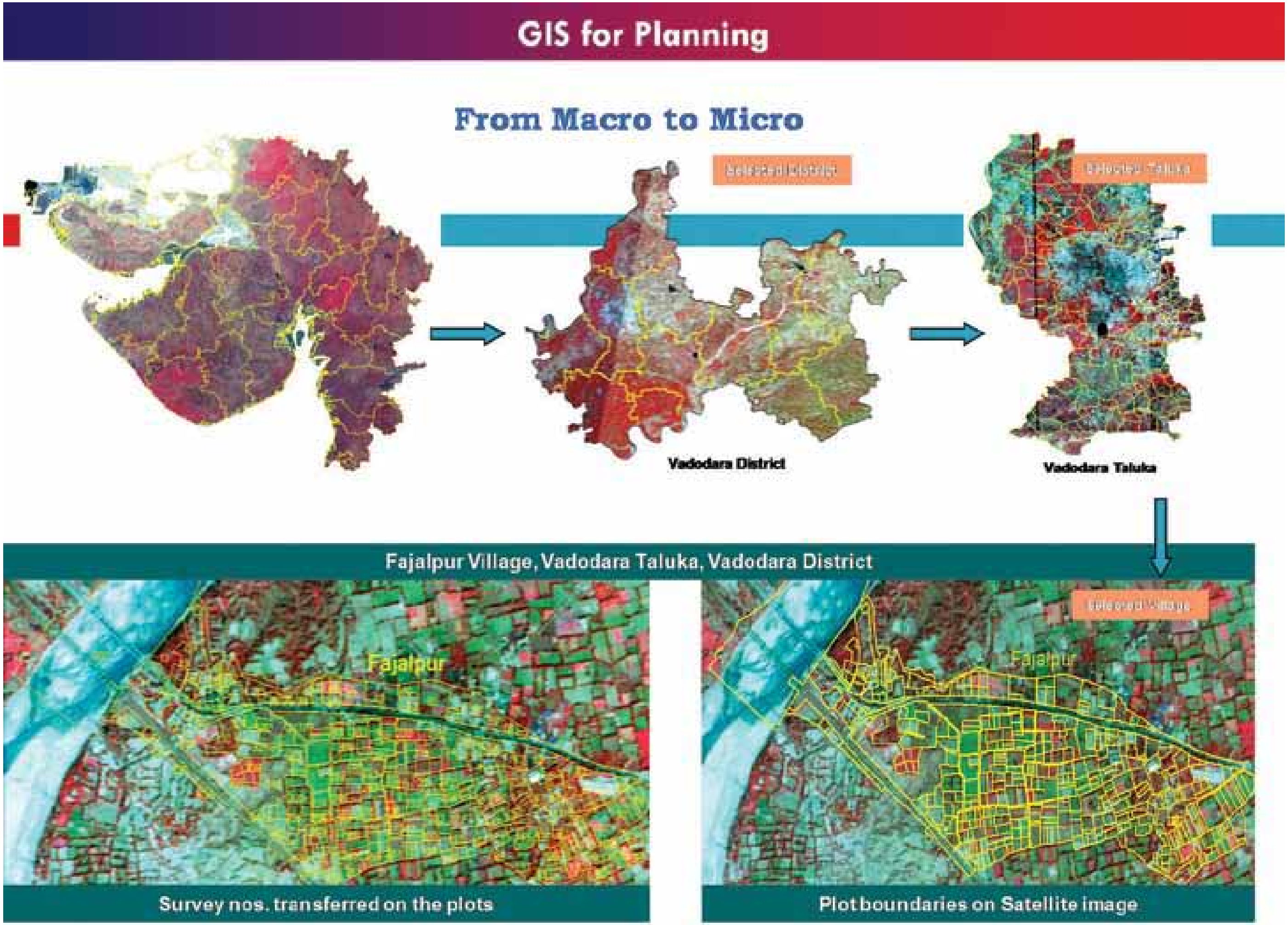


Figure 1. Planning from macro level to the micro level.

– 196.024 lakh ha). The Pre-Hariyali, Hariyali program and similar other schemes had already covered 4,540 watersheds in the state. The Irrigation Command area, the Rann of Kutch (desert) and similar other untreatable areas constituted another 1,005 watersheds, which left us with a total of 8,042 watersheds (131.076 lakh ha) to be prioritized. The first step was to overlay all watershed boundaries onto a cadastral map. The treatable watersheds were then ear-marked and a ranking was assigned to each, based on clear cut parameters identified by the Department of Land Resources (DoLR). The parameters included natural resource indicators, the socio-economic indicators, the contiguity factor and the cluster approach. Factors such as the poverty index, percentage of SC/ST and the small and marginal farmers provide focus to provision of better livelihood options to the local population in project areas. The natural resource parameters, which include factors such as moisture index and the productivity potential of the land ensured true representation of the watershed. Contiguity factor and the cluster approach ensured that the watersheds would be treated through holistic area development. The overall goal was to ensure prioritization based on the objective and equitable criteria.

Based on the ground level data obtained from each watershed area a database was created linking the village level data with their respective Census 2000 (C2K) code and mapping of this data was done accordingly. Satellite images of all the parameters mentioned in Table 2 were collected as different layers (Fig. 2) and then superimposed to get a composite picture of the prioritized areas. This process led to the formation of a 'Priority Map' for the whole of Gujarat state (Fig. 3). The priority map elicits the areas to be selected in the order of priority for the next 18 years. Thus, project areas were identified and awarded with a specific identity name.

The prioritization process has helped in the following ways:

1. the projects could be equitably distributed among all the districts;
2. the most needy watershed areas could be identified; the districts were able to take those watersheds on priority;
3. the planning for the convergence of IWMP with other developmental schemes of various government departments is prepared on the basis of thematic maps.

Table 2. Criteria & weightage for prioritization set by DoLR.

S. No	Criteria	Max score	Ranges & scores			
i	Poverty index (% of poor to population)	10	Above 80% (10)	80 to 50% (7.5)	50 to 20% (5)	Below 20% (2.5)
ii	% of SC/ ST population	10	More than 40% (10)	20 to 40% (5)	Less than 20% (3)	
iii	Actual wages	5	Actual wages are significantly lower than minimum wages (5)	Actual wages are equal to or higher than minimum wages (0)		
iv	% of small and marginal farmers	10	More than 80% (10)	50 to 80% (5)	Less than 50% (3)	
v	Ground water status	5	Over exploited (5)	Critical (3)	Sub critical (2)	Safe (0)
vi	Moisture index/ DPAP/ DDP Block	15	-66.7 & below (15) DDP Block	-33.3 to -66.6 (10) DPAP block	0 to -33.2 (0) Non DPAP/ DDP block	
vii	Area under rain-fed agriculture	15	More than 90% (15)	80 to 90% (10)	70 to 80% (5)	Above 70% (reject)
viii	Drinking water	10	No source (10)	Problematic village (7.5)	Partially covered (5)	Fully covered (0)
ix	Degraded land	15	High – above 20% (15)	Medium – 10 to 20% (10)	Low- less than 10% of TGA (5)	
x	Productivity potential of the land	15	Lands with low production and where productivity can be significantly enhanced with reasonable efforts (15)	Lands with moderate production and where productivity can be enhanced with reasonable efforts (10)	Lands with high production and where productivity can be marginally enhanced with reasonable efforts (5)	

Continued

Table 2. *Continued.*

S. No	Criteria	Max score	Ranges & scores			
xi	Contiguity to another watershed that has already been developed/ treated	10	Contiguous to previously treated watershed and contiguity within the microwatersheds in the project (10)	Contiguity within the microwatersheds in the project but non contiguous to previously treated watershed (5)	Neither contiguous to previously treated watershed nor contiguity within the microwatersheds in the project (0)	
xii	Cluster approach in the plains (more than one contiguous micro-watersheds in the project)	15	Above 6 micro-watersheds in cluster (15)	4 to 6 microwatersheds in cluster (10)	2 to 4 microwatersheds in cluster (5)	
xiii	Cluster approach in the hills (more than one contiguous micro-watersheds in the project)	15	Above 5 micro-watersheds in cluster (15)	3 to 5 microwatersheds in cluster (10)	2 to 3 microwatersheds in cluster (5)	
	Total	150	150	90	41	2.5

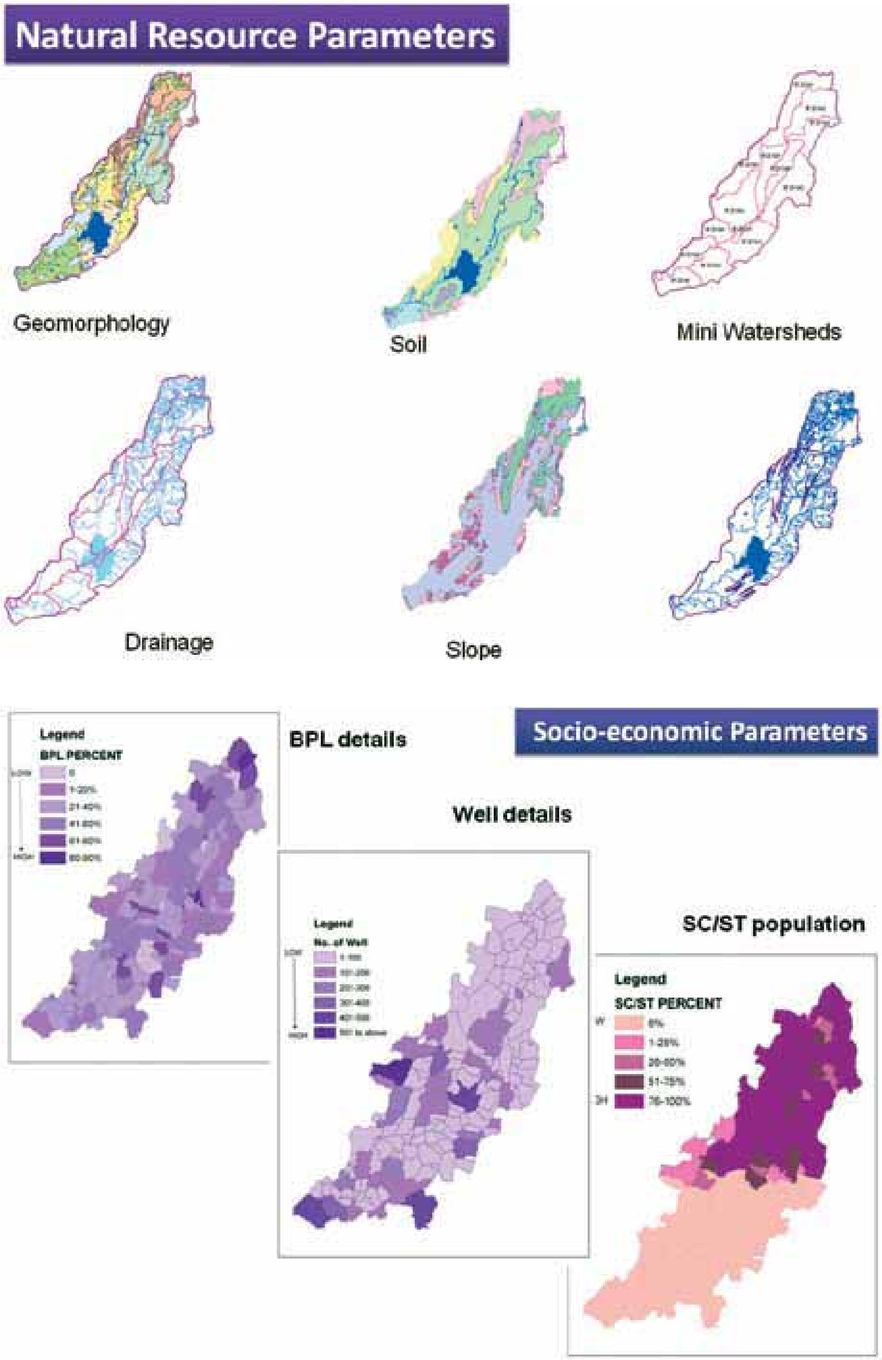


Figure 2. Various spatial layers.

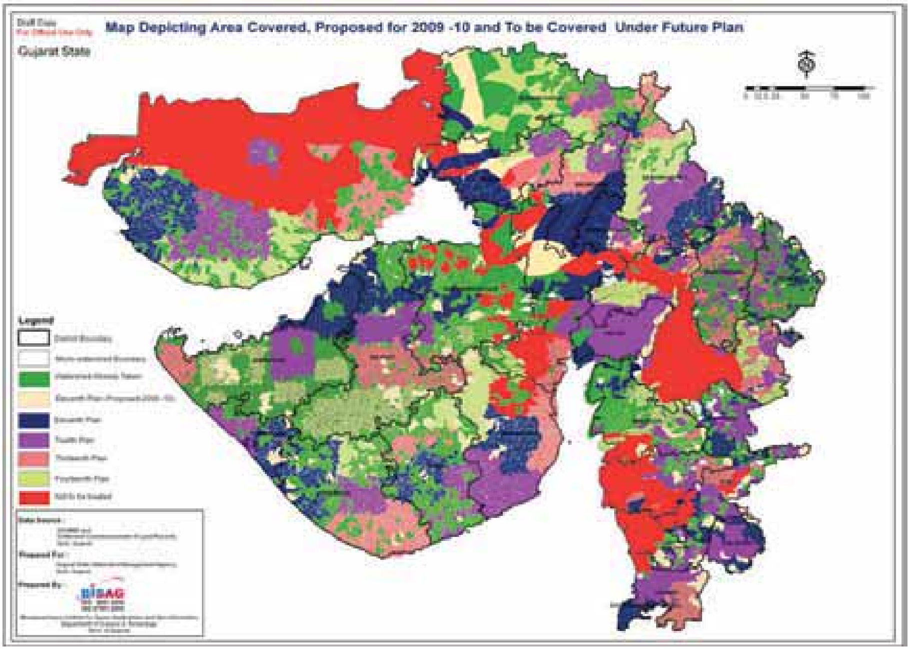


Figure 3. Final prioritization.

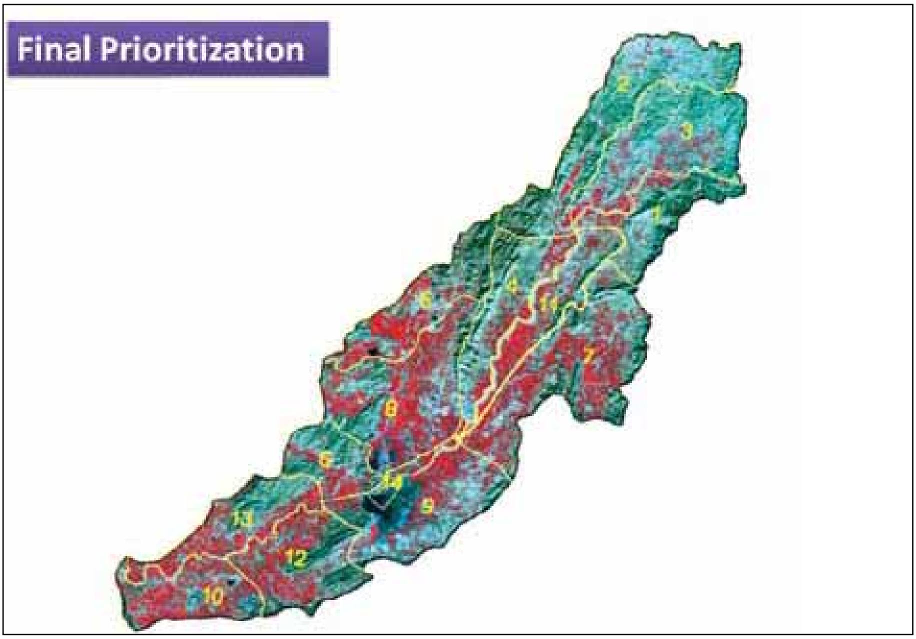


Figure 4. Map depicting the planned areas for the whole of 18 years.

4. the state was able to plan for the next 18 years; the GIS based plan for the 18 years is given in the map (Fig. 4):

The flow chart below summarizes the process of prioritization.

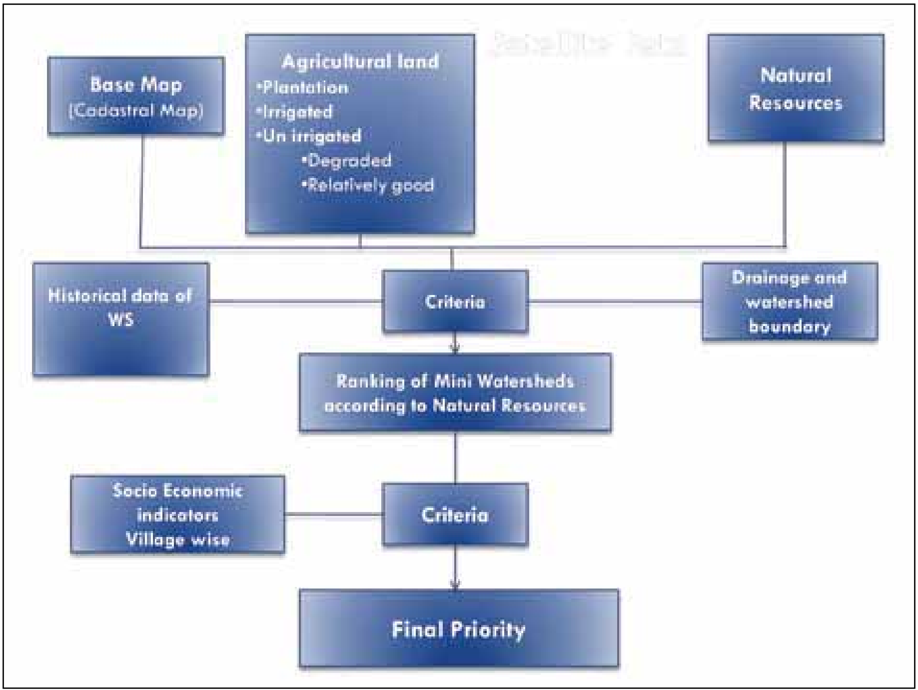


Figure 5. The prioritization model of watershed management.

Developmental Planning

A Developmental Action Plan Matrix was developed by GSWMA in collaboration with BISAG for various land forms (viz., Forest, Wasteland, Agriculture) which involved the parameters of land use and land cover, slope percentage, soil depth, soil texture, erosion as given in Table nos. 3, 4 and 5. The treatments recommended in the Action Plan Matrix were based on the technical guidelines and published literature.

After analyzing the above parameters for various landforms, an activity chart was prepared, which involves various activities related to soil moisture conservation, forestry and agriculture development as mentioned in Table 6.

Table 3. Action plan for forest land.

						Action plan
Forest	Slope %	Soil depth	Soil texture	Erosion	Landform	Measures
Degraded forest	15-35%, 35-50%	Shallow	Coarse Loamy	Moderate	Structural Hill, Residual Hill	Staggered Contour Trenches + Plantation
	10-15%	Moderate	Coarse Loamy Fine Mixed	Moderate	Buried pediment Shallow, Residual Structures, Structural hill	Contour Trenches + Plantation
			Fine Mixed			Small Gradonies + Plantation
	5-10%		Coarse Loamy	Moderate	Structural hill, Alluvial plain	
	0-1%,	Moderate to deep	Coarse Loamy	Moderate	Alluvial plain, Burried Pediment Shallow, Pediment	Pits and plantation+ plantation

DPR Preparation

The exercise of developing detailed planning reports (DPRs) is therefore assisted by the prepared GIS maps and indicative action plan generated using the matrix. These provide accessible scientific tools to the watershed committees or the watershed development teams to take decisions to be carried out in different survey numbers. The DPR will be summed up in a Logical Framework Approach (LFA). DPR will be part of the overall MIS. A special software is being developed to monitor the progress of the projects by monitoring the DPR. This will be done by integrating the DPR with the MIS and GIS. Besides, the DPR prepared will also be made available online.

Table 4. Action plan for wasteland

Wasteland	Slope %	Soil depth	Soil texture	Erosion	Landform	Action plan
						Measures
Barren rocky	35-50%	Shallow, moderate	Fine, mixed loamy	Moderate	Structural hill, dyke, linear ridge	Staggered contour trenches+ plantation
	15-35%	Shallow, moderate	Mixed loamy	Severe	Structural hill, pediment	Contour trenches+ plantation
	10-15%					
	5-10%	Moderate		Severe	Structural hill, BPM, buried pediment shallow	Contour trenches+ plantation
Land Without Scrub	0-1%,	Moderate to deep	Coarse loamy	Moderate	Alluvial plain, buried pediment shallow, pediment	Pits and plantation+ plantation
	1-3%		Fine			
	3-5% 5-10%	Shallow , moderate	Loamy	Moderate	Structural hill, residual hill, buried pediment shallow	Contour trenches+ plantation
	35-50%	Shallow, moderate	Fine, mixed loamy	Moderate	Structural hill, dyke, linear ridge	Staggered contour trenches+ plantation
Land with scrub	0-1%,,	Shallow, moderate	Mixed loamy, coarse loamy	Severe	Buried pediment shallow, residual hill, structural hill	Protect natural vegetation+ protection
	1-3%			Moderate		
	3-5%		Fine mixed			Small gradonies+ protection
	5-10%		Coarse loamy	Moderate	Structural hill, Alluvial plain	
	10-15%	Moderate	Coarse loamy		Structural hill, Alluvial plain, pediment	Contour trenches+ protection
	15-35%		Fine mixed			
	35-50%	Shallow, moderate	Loamy skeleton	Severe to moderate	Structural Hill, buried pediment shallow	Staggered contour trenches+ protection

Table 5. Action plan for agriculture land

Agriculture	Slope %	Soil depth	Soil texture	Erosion	Landform	Action plan
						Measures
	0-1%, 1-3%, 3-5	Deep, moderate	Fine	None	Buried pediment shallow	Bench terraces, agro-horticulture+organic farming
	5-10%, 10-15%				Structural Hill, Alluvial Plain, Valley Fill	Bench terraces, Agro-forestry with farm bunding+organic farming
	15-35%, 35-50%		Fine, mixed loamy	Slight, moderate		
	0-1%, 1-3%		Fine, mixed and coarse loamy	Slight		Farm bunding, farm pond nearer to village+organic farming

Table 6. Planned activities for watershed development under IWMP.

SMC measures	Forestry works	Agriculture development
• Plugs/trenches/bunds • Check dam • Boribandh • Farm pond • Renovation of village pond • Percolation tank	• Nursery raising • Farm forestry • Community plantation • Silvi-pastoral	• Terracing • Land levelling • Agro-forestry • Horticulture • Organic farming • Drip irrigation • Allied dairy/poultry/fisheries

Convergence

The State has mandated convergence of programs and resources available under different government-funded programs at the planning stage itself to ensure focused development in watershed areas and to enhance the livelihood security of the rural people.

Different possibilities for convergence are shown in Fig. 6.

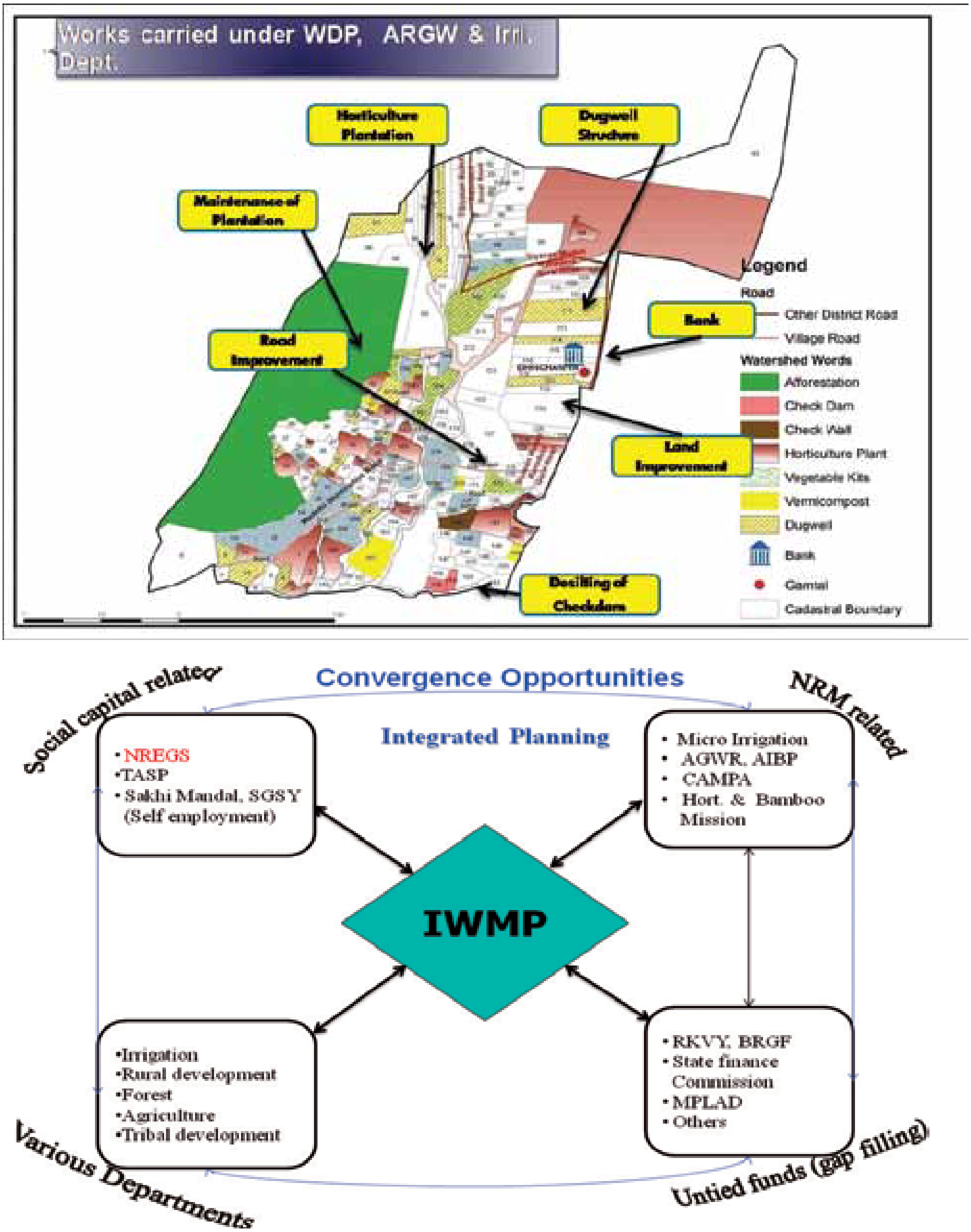


Figure 6. Possibilities for convergence.

Geographic Information System can also be used as a tool to identify different areas of convergence of IWMP with various departmental schemes. This would help in generation of Watershed Annual Action Plan map with the consent of *gram sabha* and optimization of village level resources.

Case Study: Convergence

GSWMA had undertaken a pilot project in Dhinchaniya village of Idar *taluk* in Sabarkantha district. Using different data and thematic maps from BISAG convergence planning has been carried out. Following is the pre-convergence action plan map. On the basis of above map, different opportunities to converge with other departments and schemes surveyed. Following is the final action plan map which includes the aspect of convergence. The map shows different planned activities that can be carried out.

Implementation

Extensive capacity building of different stake holders on how to use the technical knowledge and scientific tools are planned to ensure that technical personnel and local population have a better understanding of each other and conflicts are minimized. WDT members would be equipped with the tools like GPS machines, GIS based geohydrology and geomorphology maps to enable them to take informed and technically correct decisions.

Monitoring and Evaluation

Use of GIS has been planned for the purpose of monitoring and evaluation of IWMP projects. Customized mobile based software is being developed in collaboration with BISAG which will enable updating maps through mobile text messages received from WDT's & incorporating GPS coordination. Each WDT member of PIA will be allotted a unique code for their respective districts. Timely updating of the data regarding the project implementation on GIS maps will help in generating regular summarized and specialized reports for the decision makers. Data will be translated at state level onto GIS maps through which monitoring before, during and post implementation will become possible. For example, if a check dam is constructed at a certain place, sending a text message containing the details of the structure and the longitude and latitude will ensure that the check dam is marked on the map. Pre-monsoon and post-monsoon images of the area will reflect whether the structure has been effective in water storage. Such mapping of structures periodically will reflect whether the ridge to valley approach is being followed or not during the implementation of the project. Also, if the need for some changes in the sites selected is realized during the works phase, an informed decision can be made based on the maps depicting the work done so far and their implications reflected in the pre- and post-monsoon images. In all, such a mechanism where the progress of the work phase can be monitored on a map with coordinates can reveal whether the work is being undertaken according to the plan and schedule, the ridge-to-valley approach. Moreover, the need for changes in the plan can also be detected early.

Often, it has been observed that water storage structures are constructed in the downstream valley areas without treating the upper ridges. This often results in damage to the structures and in some cases, the entire structure gets washed away. While the ridge to valley approach has been adopted at the planning phase, implementation in the same sequence is to be ensured. A GIS-based monitoring system will help in better implementation of the ridge-to-valley approach.

One of the institution building activities under IWMP is formation of user groups. The members of user groups will be those farmers who will benefit the most from the construction of a water harvesting structure. The user group will also be responsible for maintenance of the structure and appropriate use of water. A GIS based monitoring mechanism will ensure that members of user groups are actually only those farmers whose land plots lie in proximity to the water harvesting structure and that no potential beneficiary is excluded from the user group.

Thus a GIS-based monitoring mechanism will not only help in site selection in planning phase and scheduling of works phase, but will also strengthen the institutions that are visualized to sustain development in the consolidation phase of IWMP.

Impact Assessment

On completion of the project, impact assessment becomes essential. GIS will be used to map the environmental as well as social impact, resulting from implementation of IWMP. Natural parameters such as ground water recharge, forest cover, salinity ingress, soil erosion and biodiversity will be studied through remote sensing and GIS. Also parameters such as crop pattern and irrigated area, which have a direct impact on society, can be studied. Analysis of data available from satellite images at regular intervals will help in generating an idea of the changes occurring in the baseline data due to implementation of IWMP. Detection of changes in forest cover may be possible only after a certain duration but IWMP is to continue over a long period.

Collection and analysis of data at regular intervals along with the mapping of project activities before, during and after implementation will create a very useful database, which is at the core of any impact assessment process.

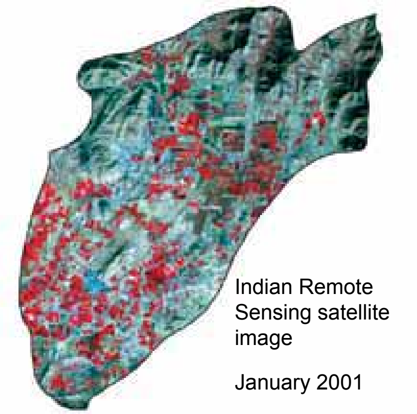
Based on the impact of IWMP on environmental and social factors inputs for future planning of the projects will be generated. This will help in continual improvement in the scientific planning process that is essential to the successful implementation of IWMP.

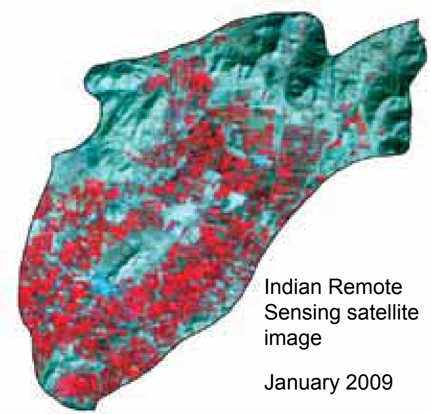
Conclusion

The New Common Guidelines, 2008 for the IWMP program have envisaged a new and holistic approach to natural resource management. The factor of convergence and use of high science tools has resulted in comprehensive planning, implementation, monitoring and evaluation. The significance of the new approach lies in extending technology to enhance rural livelihoods. This has resulted in imparting transparency and efficiency in implementing these projects. Use of GIS for planning that integrates convergence with NREGS and other government schemes strengthens coordination among departments. This helps in reducing duplication of watershed development activities. Blending of traditional knowledge with scientific process helps in planning and development of the integrated watershed management program in a sustainable manner.

Box-2: Case Study: Impact assessment of watershed development in Idar *Taluka* (Code: 5F2D4b4)

Sabarkantha is a tribal-dominated district situated in the north east of Gujarat. It is a hilly area with very little irrigation. There are mainly small and marginal farmers who depend on rain-fed agriculture and the main crop is maize. Sabarkantha receives an average rainfall of 500 to 1000 mm. There are hardly any other livelihood options available to farmers locally due to which farmers are forced to migrate to other prosperous districts in Gujarat. Canal irrigation through large dams was possible only up to a limited extent. Harvesting rainwater would be the best option available to increase the area under irrigation. After the introduction of watershed development projects in Sabarkantha district, a number of water harvesting structures were constructed. Construction of water harvesting structures ensured that the runoff decreased and availability of water for irrigation increased. The two images are of Mini Watershed 5F2D4b4 as recorded by Indian Remote Sensing Satellite. One image dates back to January 2001 and another image dates back to January 2009, i.e. before and after the implementation of watershed development projects under Hariyali Guidelines. An increase in the irrigated area is clearly visible from the images. Thus, GIS mapping is effective in impact assessment of watershed development activities.





Acknowledgement

This paper has tried to share the experience of GSWMA in applying GIS in Integrated Watershed Management Program in the state of Gujarat. We must acknowledge the fact that this paper is born from a team project undertaken by the GSWMA, Gujarat team. We owe a great sense of gratitude to all those people who have been associated with GSWMA for planning and implementation of IWMP. BISAG and particularly TP Singh, its Director has been a great source of inspiration in this effort. We recognize the spadework done by various departments of the Government of Gujarat in preparing GIS data sets for their departments.

We thank the professional experts at GSWMA, district watershed development units and their respective project managers and technical experts who support us in this endeavour.

We also recognize the effort of the interns from Dhirubhai Ambani Institute of Information & Communication Technology (DA-IICT) who actively took part in the discussions while this paper was being written.

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Use of Modeling in Watershed Planning

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Abstract

Integrated watershed management has emerged as a powerful concept in development planning for agriculture and rural development in India. Importance of integrated planning of natural, animal and social resources for enhanced productivity and livelihood is evident from the increased outlay of watershed programs in the XIth *Five Year Plan. Comprehensive Assessment of Watershed Programs in India by the ICRISAT-led consortium has clearly shown the benefit of scientifically planned and systematically implemented watershed projects. Now all the watershed programs of different ministries/departments are being implemented following the new Common Guidelines for Watershed Development Projects effective from April 2008. The guidelines emphasize using new science and technology inputs, including Remote Sensing (RS), Geographic Information System (GIS) and modeling to bring about a paradigm shift in preparing detail project reports (DPRs) for implementation of the watershed development programs.*

Integrated watershed planning is done on the basis of its resource inventory, which includes the analysis of the present status or conditions (i.e., bench mark analysis) of its natural resources (soils, topography, drainage, land use, water resources, forest, vegetation, etc.), animal/ livestock resources, socio-economic and livelihood conditions and human resources and the type/extent of problem and needs of the watershed area and the community. Modeling application requires spatial data at watershed scale. Creation of a spatial database is therefore the first and very important step in watershed planning to put maps and baseline data in place, followed by spatial analysis using analytical tools to help identify special features, problems, needs and critical areas and, finally, prepare action plan or DPR for development of the watershed.

The advances in remote sensing in collecting spatially variable data at higher resolution, GPS and capabilities of GIS in storing, retrieving and *manipulating data have shown tremendous potential in circumventing problems of the conventional and time-taking techniques in watershed planning. Integrating and collating data from multiple sources, conventional and/or remote sensing and others, with GIS, can lead to important operational applications including better opportunities for use of modeling in watershed planning.*

Use of modeling as a tool in conjunction with spatial data manipulation in GIS for estimating runoff, soil erosion and sedimentation, land capability classification, land use planning, identifying critical areas needing treatment within the watershed for optimized investments, planning, location and design of various soil and water conservation, water harvesting and other such interventions, and analysis of best management practices (BMPs) in preparing watershed plan, has been presented in the paper. Opportunities of using data from free sources in watershed planning have also been presented. Use of distributed modeling to address issue of upstream–downstream conflicts and complementarities of watershed development projects are also discussed. Need for identifying and integrating the analytical biophysical and socio-economic models to GIS through user interface in a modular modeling frame work to develop decision support systems (DSS) and web-enabled system is emphasized to help automate the watershed planning process and simulate the effects of various watershed intervention scenarios.

Introduction

Watershed management has emerged as a new paradigm for planning, development and management of land, water and biomass resources with a focus on social and environmental aspects following a participatory approach. Watershed management is more a philosophy of comprehensive integrated approach to natural resources management. It aims at integration of social resources management with natural resource management. The approach is generally preventive, progressive, corrective and curative. Watershed management involves the judicious use of natural resources with active participation of institutions, organizations, in harmony with the ecosystem. It is a complex process with multiple objectives and multi disciplinary multiple functions. It generates multiple benefits aggregated as productive, protective/reclaimable, environmental, social and livelihood security. Planning plays a pivotal role in preparing detail project reports and action plans to derive a sustainable outcome from a watershed management program.

Common Guidelines for Watershed Development Projects-2008 (Anonymous, 2008 a) emphasize use of new science and technology inputs including Remote Sensing (RS), Geographic Information System (GIS) and modeling to bring about a paradigm shift in preparing Detail Project Reports (DPRs) for implementation of the watershed development programs. Integrating and collating data from multiple sources, conventional and/or remote sensing and others, with GIS can lead to important operational applications including watershed planning. The paper presents the intricacies of planning process, encompassing watershed management and use of high science tools such as GIS/RS/GPS and modeling in watershed planning and development. A centralized national watershed database system has also been discussed along with mechanism to disseminate information to watershed planners and end users.

Watershed Planning

A watershed plan recommends how watershed resources are to be protected, managed and improved, and also prescribes planning at a micro-level within the watershed. Therefore, micro-level planning requires a wide array of information and data and a variety of tools. The Common Guidelines for Watershed Projects effective from April 2008 (Samra and Sharma, 2009) has emphasized – (a) clustering of small watersheds in the range of 1000-5000 ha areas to optimize transaction cost; (b) multi-tier ridge to valley planning and implementation; (c) focusing livelihoods through integrated farming systems; (d) scientific planning using new science and technology inputs including RS, GPS, GIS and modeling to bring a paradigm shift in watershed planning. To address these, greater emphasis has been laid on planning with one per cent allocation for DPR preparation in the Common Guidelines.

Some of the basic steps envisaged for watershed planning are (Anonymous, 2008b):

- Selection of watershed as a manageable unit;
- Benchmark/baseline information of the region/ watershed;

- sensitizing the watershed community and existing organizations;
- participatory Rural Appraisal (PRA) to identify potential problems, perception, baseline information collection, etc;
- institution and capacity building and training to facilitate decentralized planning;
- inventorying of existing watershed resources;
- preparation of a land capability classification (LCC) information
- developing an area specific intervention/management plan;
- implementation plan;
- identifying and promoting livelihood activities;
- post-execution monitoring and evaluation;
- exit plan, maintenance of watershed assets and follow-up plan to achieve sustainability.

Requisite Information for Watershed Planning

Planning being an information intensive process needs to be carefully executed with collecting baseline information either from primary or secondary sources including PRA. A major listing as follows:

A. Resource inventory: present condition (bench mark)
  - Climate
  - Physiography: topography, slope, drainage
  - Natural resources: Soils, geology, land use, forest, hydrology
  - Animal/ livestock resources
  - Socio-economic details and human resources
  - Livelihood conditions

B. Status of resource management
  - Land and crop management conditions/soil conservation practices
  - Forest management (natural / manmade)
  - Water harvesting, drainage line treatment measures
  - Infrastructural facilities
  - Type/extent of problems, needs and constraints.

Modeling in watershed planning requires the following:

- higher resolution data at the intended watershed scale;
- creation of spatial data base of watershed information system;
- basic data layers used to obtain derived data layers for thematic maps; topographic (i.e., slope), soils (i.e., texture, depth, hydrologic soil groups), soil erosion and land degradation, etc;
- higher resolution RS data, GPS and GIS capabilities have potential in circumventing problems of conventional and time taking techniques in planning;
- multi-data approach of integrating and collating data from conventional and/or RS and other sources with GIS now provide good opportunity for use of modelling;
- Critical area delineation using advance modelling tools (Lahlou et al. 1997) for prioritizing intervention areas

A general approach to watershed planning is illustrated in Fig 1.

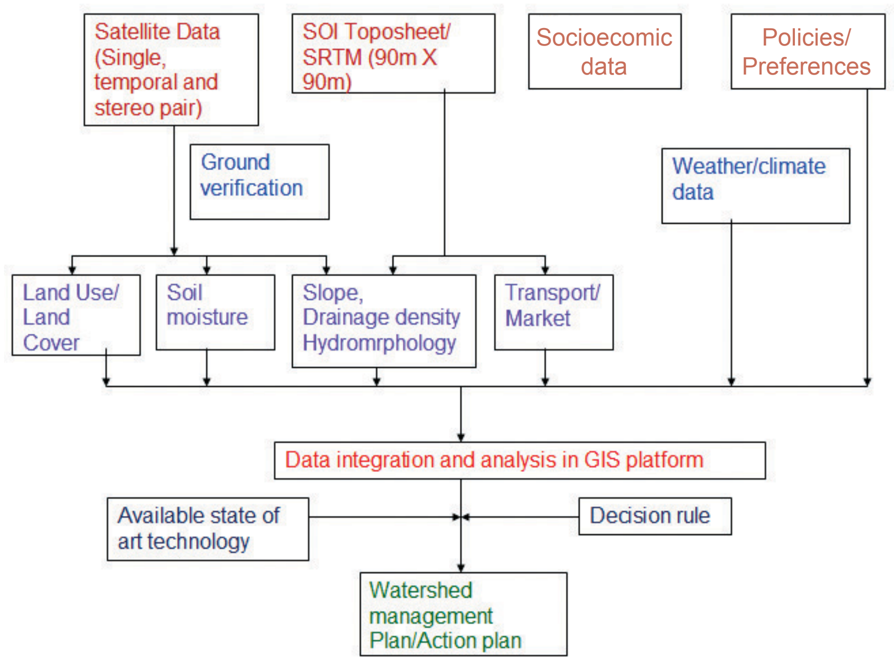


Figure 1. A schematic of watershed management planning process.

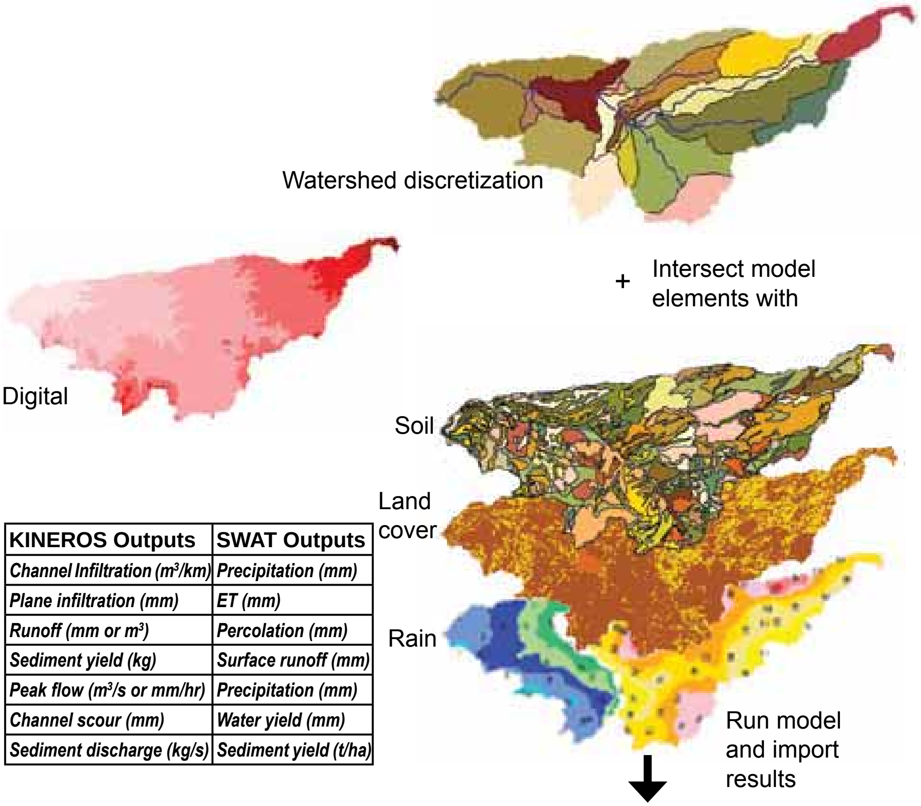
Watershed Modeling as a Planning Tool

Often lack of a reliable database and scientific planning is reflected in too general strategies or prescriptions in a DPR and inappropriate selection as well as placement of interventions leading to ineffective implementation of a plan. This is attributed to various reasons such as (a) insufficient critical baseline information at the level of watershed, (b) difficulty in integration of multiple databases and their spatial manipulation, (c) lack of using scientific tools, and (d) poor capacity building at the level of the field functionaries, the actual watershed managers. Therefore, scientific planning using modern tools and techniques together with PRA have been emphasized to overcome these shortcomings (Lahlou et al. 1997). Recent advances in remote sensing, GIS-based modeling and visualization capabilities, coupled with the growth of Internet and the World Wide Web (Jin-Yong et al. 2005) have significantly improved analytical capabilities of landscape data in a watershed to collate the data, understand the processes and use modelling in the watershed planning. GIS application in watershed management has changed from operational support (e.g., inventory management and descriptive mapping) to prescriptive modeling and tactical or strategic decision support system.

The concept of watershed management involves holistic development of land, water, biomass, human and animal resources for sustainable production system and livelihood improvements of the inhabitants of the watershed. Development and management of the natural resource base; soil and water, therefore remains the core of watershed planning. To manage soil and water, it is imperative to understand their relationship with the land use and transition within the confine of the hydrological boundary i.e. the watershed. Runoff estimation, soil erosion, land capability analysis are basic to planning watersheds.

Runoff can be estimated by determining land use/cover and CN for each cell or element by partitioning a watershed into parcels of land use/cover or hydrologic response units (HRUs). Each HRU or cell can be assigned curve numbers and then area weighted CN is determined for the watershed to estimate runoff with the input of rainfall data. Identification and distribution of watershed into land capability classes (LCCs) is needed to help plan conservation measures. Data layers of soil texture, depth, drainage, slope and erosion hazard can be used in GIS to divide watershed into LCC. This can be achieved by successive overlays of different data layers in an interactive graphic mode or writing a program or module in GIS to manipulate and automate this process. LCC map so derived can be verified and supplemented with sample field survey including resource maps derived from PRA exercise.

Besides simple hydrologic tool of estimating runoff, process based hydrological modelling tools, offer a promising prospect to achieve this goal. GIS integrated with hydrologic models like SWAT (Arnold et al. 1994)/ KINEROS2 (Burns et al. 2004; Semmens et al. 2005; Woolheiser et al., 1990)/PRMS/HSPF/AGNPS (Bingner and Theurer 2009; Chnaseng He et al. 2001) (Fig. 2) can help in estimating runoff, soil loss



KINEROS Outputs	SWAT Outputs
Channel Infiltration (m^3/km)	*Precipitation (mm)*
Plane infiltration (mm)	*ET (mm)*
Runoff (mm or m^3)	*Percolation (mm)*
Sediment yield (kg)	*Surface runoff (mm)*
Peak flow (m^3/s or mm/hr)	*Precipitation (mm)*
Channel scour (mm)	*Water yield (mm)*
Sediment discharge (kg/s)	*Sediment yield (t/ha)*

Figure 2. Schematic of popular modeling environments SWAT and KINEROS2 to determine various watershed functions essential for watershed planning (Burns et al. 2004).

and sedimentation, LCC, land use planning, planning and designing of SWC interventions, assessing watershed conditions through modeling impacts of various management scenarios and identify best management practices (BMPs) as well as critical intervention areas and focusing on these efforts on the targeted priority areas, instead of enforcing them uniformly in the watershed (Fig. 3).

There is a need to prioritise critical areas needing interventions within a watershed in order to optimise investments while reasonably achieving the desired goals. Modeling provides great opportunity in this endeavour. A study conducted in CSWCRTI, Research Centre, Ooty in a watershed (KG-4-1), using universal soil loss equation (USLE) in a distributed parametric modeling by partitioning watershed into erosion response units (ERUs), suggests that by treating only 14% of the area (where soil loss is >20 t ha^{-1} yr^{-1}), 47% decrease in soil loss can be brought about and by treating 28% of the area (where soil loss is > 10 t ha^{-1} yr^{-1}), nearly 68% decrease in soil loss can be obtained (Fig 4). This demonstrates the use of modeling to identify and prioritize critical intervention areas within a watershed for optimized investments (Sikka and Paul 2005).

Decision Support Model for Alternate Management Strategies

The watershed plan should also reflect a long term management process keeping view of any irreversible land use management or unsustainable management concurrent to exit of the watershed project. Optimization models help in creating a sustainable plan to maintain the resources unaffected once restored under a watershed plan. These necessitate post project monitoring plan to keep track of the rejuvenated resources and impose curbs through regulatory means. By applying some GIS integrated models like L-THIA (Long-term hydrological impact assessment) (Lim et al. 1999), actual and planned (zoned) watershed development, and the long term effects of past, present and future land use can be determined. Hydrological models coupled to evaluation models such as WEAP (Yates et al. 2005) helps plan water resources through optimisation process allocating to various environmental services.

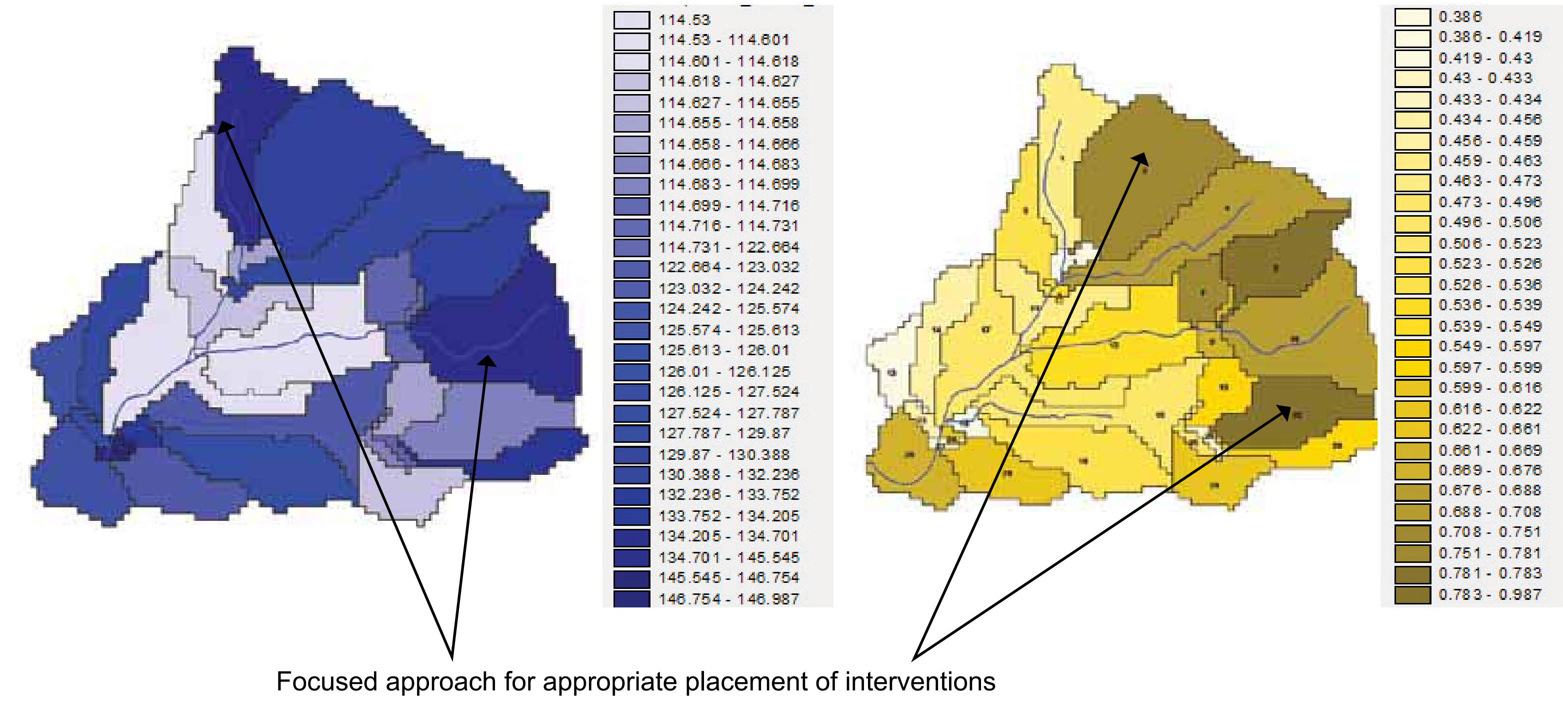


Figure 3. Process based modeling for identifying critical areas for intervention (e.g. a model SWAT output).

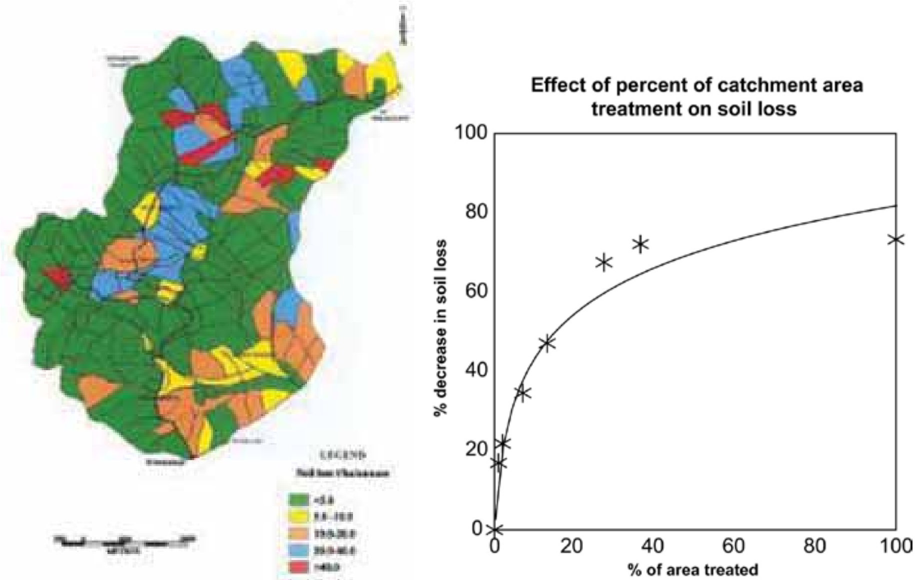


Figure 4. Treatment of partial (critical) area and its effect on soil loss in KG-4-1 watershed of Nilgiris.

Upstream-Downstream Relationship

Upstream-downstream implications of watershed development projects have long been a debatable issue (Sunday and Mallavam 2003). Well intentioned and scientifically planned watershed projects not only conserve land and water resources locally but also enhance their pereniality in downstream through reduced peak flows and increased dry season flow. Use of distributed modeling with nested watersheds approach provides a great opportunity to examine upstream-downstream interactions with a balanced view of both conflicts as well as complementarities. Tradeoff amongst water allocation to different users/uses and environmental services may be addressed though hybrid optimization modeling.

Watershed Information System (NWIS)

The information/data relevant to watershed planning, monitoring and evaluation is either insufficient/absent, or not readily available or is under-utilized because it is scattered among many agencies and not available in the required form. There is lack of a co-ordinated centralised database with easy access for a decentralised planning of watershed projects. The linkage between GIS, the Internet, and environmental databases is especially helpful in watershed planning, monitoring and evaluation studies where information exchange and feedback on a timely basis is very crucial and more so when different agencies and stakeholders are involved. This requires massive input/output manipulation including weather data arrangement using databases, menu-driven and graphical user interfaces for the user's convenience and data transfer through the Internet.

There is a long felt need for National Watershed Information System (NWIS) where a centralised database system may be created (Table 1) (Sunday and Mallavam 2003). A thin client server unit like internet browser may be used to access the information (Jin-Yong et al. 2005). This will not only enhance the effectiveness of the watershed management programs, but also help in keeping track of watershed development and reduce the probability of a watershed being treated more than once. The system may also provide options of using/linking various kinds of models as discussed above to help planners properly plan and prioritize their interventions within the watershed.

Opportunities for Watershed Planning Using free Resources

In the context of available resources at the watershed/local and national level, preparation of DPR in a small time span becomes difficult, as it is a time bound activity of the watershed program. Detailed survey of the watershed becomes time consuming, difficult, expensive and exhaustive. Preparation of contour maps at the level of watershed becomes difficult. Survey of India toposheets at the designated contour interval may not serve the purpose, especially if the watershed lies in plain areas (sometimes within the confine of watershed of interest no contour lines are available). Land use maps generated from LISS-III data also become costly. One of the alternatives is, therefore, to prepare those baselines quickly using GIS (open source software like Map Window, GRASS and many others) and free resources such as Google earth interface (Fig. 5.). CSWCRTI, Research Centre, Vasad,

Table 1. Conceptual framework for National Watershed Information System

Spatial database (*Pooled information at appropriate scale of operational size watershed*)	**Assessment/derivation/ database management/ data mining tools**	**Modeling tools**	**Decision support system**
Cartographic data ▶ SOI toposheet ▶ Cadastral maps **DEM/ Elevation data** ▶ SRTM data (90 m) ▶ ASTER (30 m) ▶ Survey of India toposheet (digitised)	a) Derivation of slope from DEM maps. b) Model dependent soil parameter derivation tools c) Derivation of LCC	● **Hydrological simulation models.** ▶ SWAT (daily time step) ▶ KINEROS2 (event based modeling) ▶ PRMS ▶ HSPF ▶ AGNPS etc. ▶ SW+GW coupled models	● **Critical area assessment** ▶ Appropriate interventions ▶ Focused strategies based on critical area assessment. ● **Resource management** ▶ Nutrient management ▶ Surface and ground water resources management
National hydrographic drainage network. **Land use/ land cover data** (*referably at 1: 4000 scale*) ▶ Satellite imageries ▶ Google earth framework	d) Meteorological parameter derivation tools e) Derivation of watershed characteristics	● **Evaluation/ optimization models** ▶ WEAP ▶ Hybrid optimization models	▶ Agronomic management ▶ Forest management ▶ Livestock management ● **BMP assessment** ▶ Alternative management option
Watershed boundary at operational level ▶ GIS + elevation data **Meteorological data** ▶ Digital maps derived from model acceptable format **Soil database** ▶ Digital maps derived from model acceptable format ▶ A digital format with various parameters acceptable to various models **Socio-economic database**	f) Watershed boundary delineation from DEM data (if the watershed of intent is not delineated)	● **Socio-economical models**	● **Long-term assessment** ● **Conflict management** ▶ Allotment quota for various environmental services. ▶ Upstream-downstream conflict ● **Socio-economic management**
Dependency			
INFORMATION ZONE		**MANAGEMENT ZONE**	
(Centralised database)	**(Decentralised planning)**		

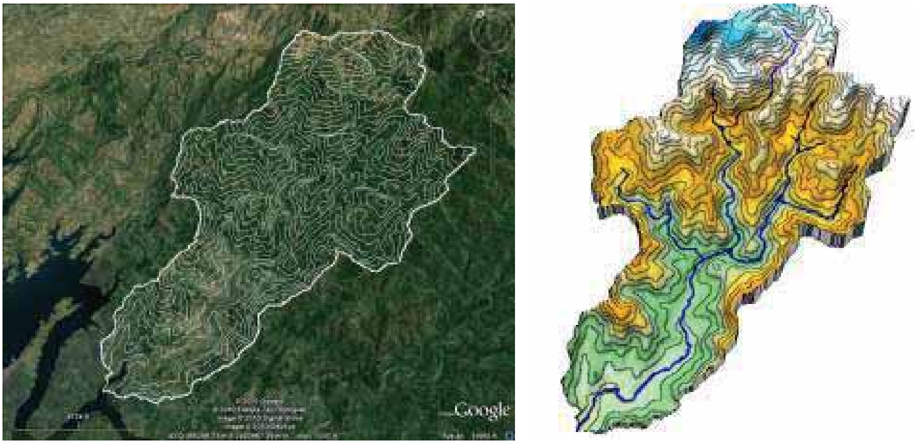


Figure 5. GIS (free open source) delineated contours derived from ASTER data draped in Google earth and a 3D DEM derived from it. (Prepared by D R Sena as an example).

Gujarat, has demonstrated use of Google earth together with elevation data at 30m resolution (ASTER) and 90m resolution (SRTM) to generate useful information required for preparation of DPR for Vejalpur Rampura watershed in Gujarat (Fig. 6).

Conclusions

The core issue in watershed planning still remains the sustainable and holistic management of natural resources and its integration with production and livelihood system that affect stake holders and environment of the watershed. Scientific planning of watersheds requires use of advances in using high science tools such as GIS/RS to derive thematic and secondary information related to watershed, modeling and production/livelihood interventions. Modeling techniques, integrated with GIS and mind-boggling internet connectivity, have vast untapped potential in watershed planning. Hydrological modeling tools need to be applied to understand the watershed functions and their transition within the confines of the hydrological boundary and plan appropriate and cost effective interventions. It is suggested to promote consortia approach evolving modular modeling framework to develop DSS and web-enabled system integrating hydrologic, agronomic and socio-economic models to GIS interface to automate or semi-automate

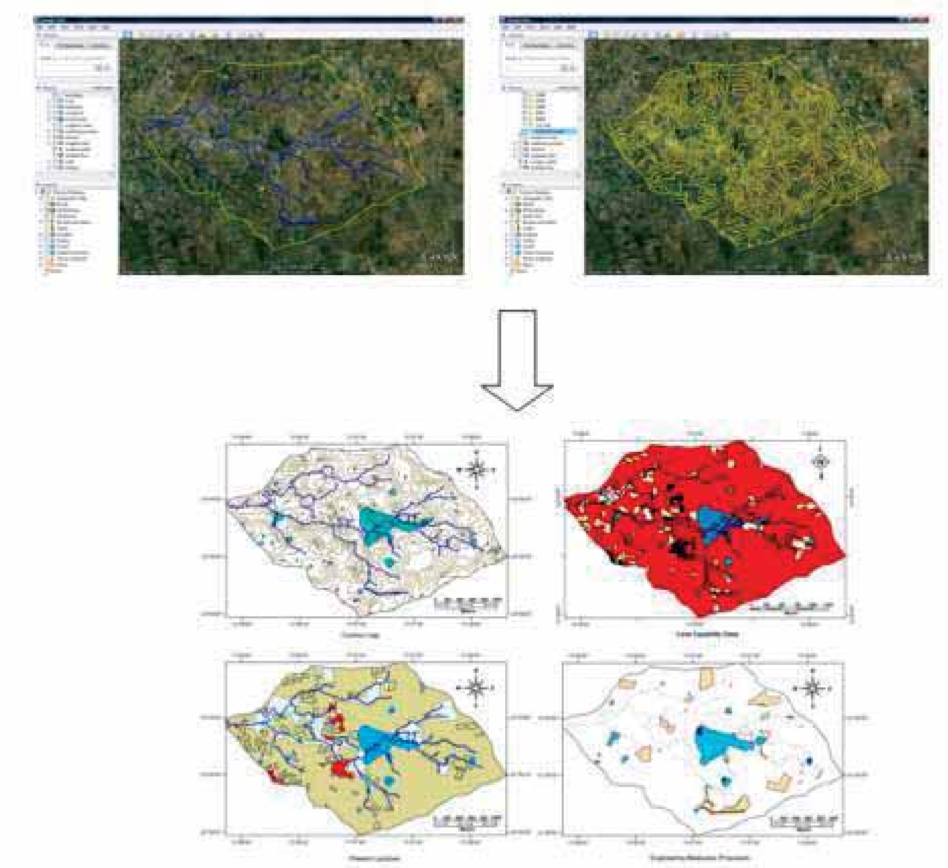


Figure 6. Google resources translated into useful baseline information for DPR preparation (CSWCRTI, 2008).

watershed planning process. A national level watershed Information System is essentially needed to help in effective watershed planning. Promoting use of high science tools and modeling in watershed planning has to be strongly supported with carefully planned capacity building and skill development programs at different levels in the country.

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Application of Econometic Methods for Assessing the Impact of Watershed Programs

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Abstract

Watershed programs in India are contributing to water resources development, agricultural production and ecological balance. Impact assessment of watershed development project includes: (i) developing a framework to identify what impacts to assess and (ii) developing a framework to look after the indicators together and assessing the overall impact of the project. The nature of watershed technologies and their impact on different sectors pose challenges to the evaluation process. More specifically, major challenges include (i) choice of methodologies, (ii) selection of indicators, (iii) choice of discount rate, (iv) quantifying benefits in upstream and downstream, (v) defining the zone of influence, and (vi) extent of natural and artificial recharge conventional methods using financial measures attempt to quantify the impacts in an isolated manner. In order to evaluate the impacts of watershed programs in a holistic manner, the Economic Surplus (ES) approach has been applied. The economic surplus incorporates both consumer surplus and producer surplus. The consumer surplus is the amount that consumers benefit by being able to purchase a product for a price that is less than they would be willing to pay. The producer surplus is the amount that producers benefit by selling at a market price mechanism that is higher than they would be willing to sell for. In the case of watershed programs, producers are mainly the farm households who produce the goods using the benefits of the watershed interventions such as soil and moisture conservation, water table increase and livestock improvement activities and consumers are mainly the other stakeholders in the region, viz. non-farm households representing the labourers, business people and people employed in non-agricultural activities. The ES method is demonstrated using the data from a cluster of 10 watersheds in the Coimbatore district of Tamil Nadu. The distributional effects of watershed programs are also captured through the ES method. The results of the conventional method had indicated that the BCR is 1.23, IRR is 14% and NPV is Rs 567912. The results of the ES method had indicated that the BCR is 1.93, the IRR is 25 % and the NPV is Rs 2271021. The conventional *evaluation method had thus underestimated the watershed impacts. Hence, possibilities of using the ES methodology in the future watershed evaluation programs could be examined.*

Introduction

The overall objectives of the watershed programs, by and large, are three fold, viz. promoting economic development of the rural area, employment generation, and restoring ecological balance (Department of Land Resources 2006). The watershed development program assumes importance in India where nearly two-third of the cropped area is under rain-fed, characterized by low productivity, degraded natural resources and widespread poverty, particularly in the rural areas. Under such situation, understanding the nature and extent of impact of these watershed development programs on various domains in the rural economy is crucial for the development personnels/specialists, economists and policymakers. It would guarantee more food, fodder, fuel, and livelihood security for those who are on the bottom of the rural income scale.

A watershed is a geographical area that drains to a common point, which makes it an attractive unit for technical efforts to conserve soil and maximize utilization of surface and sub-surface water for crop production (Kerr *et al.* 2000). Different ministries like Ministry of Agriculture (MoA), Ministry of Rural Development (MoRD) and Ministry of Environment and Forest (MoEF) are involved in the implementation of watershed development programs in the country. Watershed development has been conceived basically as a strategy for protecting the livelihoods of the people inhabiting the fragile eco-systems, experiencing soil erosion and moisture stress. Different types of treatment activities are carried out in a watershed. They include soil and moisture conservation measures in agricultural lands (contour/field bunding and summer ploughing), drainage line treatment measures (loose boulder check dam, minor check dam, major check dam, and retaining walls), water resource development/management (percolation pond, farm pond, and drip and sprinkler irrigation), crop demonstration, horticulture plantation and afforestation (Palanisami and Suresh Kumar 2003). Training in watershed technologies and related skills is also given periodically to farmers in watersheds. In addition, members are also taken to other successful watershed models and research institutes for exposure. These efforts appear to be contributing to groundwater recharge. The aim has been to ensure the availability of drinking water, fuel wood and fodder and raise income and employment for farmers and landless labourers through improvement in agricultural production and productivity (Rao 2000). Today watershed development has become the main intervention for natural resource management. Watershed development programs not only protect and conserve the environment, but also contribute to livelihood security.

As an important development program, watershed development has received much attention from central and state governments. Up to Xth Five Year Plan (till March 2005), an area of 17.24 million ha was treated with a total budget of Rs 9368.03 crore under Ministry of Agriculture, 27.52 million ha with an outlay of Rs 6855.66 crore under Ministry of Rural Development and an area of 0.82 million hectares with an outlay of Rs 813.73 crore under Ministry of Environment and Forest. A total of 45.58 million ha has been treated through various programs with an investment of Rs 17,037 crore. The average expenditure per annum during the Xth Five Year Plan comes to around Rs 2300 crore (Department of Land Resources 2006). As millions of rupees are being spent on the watershed development programs, it is essential that the programs become successful.

With programs so large and varied, it is important to understand how well they function overall and which aspects should be promoted and which to be dropped. However, despite this importance, little work has been done to assess their impacts. This paper partially fills this gap by examining both social and environmental outcomes. In particular, it tries to answer the questions: (i) What impacts the watershed development activities have on rural areas? and (ii) How do watershed development activities impact on groundwater resources, soil and moisture conservation, agricultural production and socio-economic conditions? It would help the policymakers in up-scaling and mainstreaming watershed development programs in the country.

To successfully implement the watershed development activities, the Government of India has issued various guidelines. The GoI guidelines were first issued in 1995. In order to make more participation of people in the watershed development and management, the GoI guidelines were further revised and issued in 2001. Subsequently, to involve Panchayati Raj Institutions more meaningfully in the implementation of watershed development activities, the popular Haryali guidelines were introduced in 2003. In addition to all these guidelines, the guidelines for NWDPRA watershed development programs, CAPART, NABARD and NGO implemented watershed guidelines were released separately over the period. Though these guidelines have, by and large, been successful in the implementation of various watershed development activities, they have some lacuna particularly in the context of institutional issues, post-project maintenance and sustainability and monitoring and evaluation of watershed development activities. Recently, the GoI has issued Common Guidelines 2008 for the effective implementation of watershed development programs in the country.

In spite of the guidelines, the implementation aspects normally deviate due to local demand. Several studies have indicated that the watershed structures are not maintained after completion and benefits may decline over years (Palanisami and Sureshkumar 2006). Also, to push up the implementation of the watersheds at other locations, the evaluation of the existing watersheds has been conducted positively. But, it is always mentioned that the benefits and costs are based on several assumptions. Impact analysis of an area-based program like watershed development has inherent difficulties. Apart from the benefits accrued from different technologies, the impact of watershed development should be looked into three major dimensions, viz. scales (household level, farm level and watershed level) temporal and spatial. The dimensions of impact of watershed technologies further complicate the impact assessment.

Different studies have developed a variety of indicators for impact assessment. These indicators cover watershed development activities including soil erosion, groundwater recharge and water resources potential, agricultural production, socio-economic conditions and overall impact incorporating the extent of green cover. These indicators have been compared with before and after the watershed treatment activities with that of the control village where watershed treatment activities are not taken up. The other methodologies, such as Total

Economic Valuation (Logesh 2004) and bio-economic modelling have also been employed by the researchers. However, still the researchers face challenges in quantifying the impacts of watershed development activities.

The problem of impact assessment of watershed development project includes the following aspects: (i) developing a framework to identify what impacts to assess, where to look for these impacts and selecting appropriate indicators to assess the impacts, and (ii) developing a framework to look after the indicators together and assessing the overall impact of the project. The nature of watershed technologies and their impact on different sectors pose challenges to the project monitoring and evaluating agencies, economists, researchers and policymakers. More specifically, major challenges include (i) choice of methodologies, (ii) selection of indicators, (iii) choice of discount rate, (iv) quantifying benefits in upstream and downstream, (v) defining the zone of influence, and (vi) extent of natural and artificial recharge (Palanisami and Suresh Kumar 2006).

Since the watershed development technologies benefit not only the participating farm households, but also non-participating farm and other rural households in the watershed village, the economic surplus method has been used to study the impact of the watershed programs using data from sample watersheds in Coimbatore district of Tamil Nadu state.

Methodology

Economic Surplus Approach

The Economic Surplus (ES) approach is widely followed for evaluating the impact of technology on the economic welfare of households (Moore *et al.,* 2000; Wander et al. 2004; Maredia et al. 2000; Swinton, 2002). The economic surplus method measures the aggregated social benefits of a research project. With this method it is possible to estimate the return to investments by calculating a variation of consumer and producer surplus through a technological change originated by research. Afterwards, the economic surplus is utilized together with the research costs to calculate the net present value (NPV), the internal rate of return (IRR), or the benefit-cost ratio (BCR) (Maredia et al. 2000). The model can be applied to the small/large open/closed economy within the target domain of production environment. The term surplus is used in economics for several related quantities. The consumer surplus is the amount that consumers benefit by being able to purchase a product for a price that is less than they would be willing to pay. The producer surplus is the amount that producers benefit by selling at a market price mechanism that is higher than they would be willing to sell for. In the case of watershed programs, producers are mainly the farm households who produce the goods using the benefits of the watershed interventions such as soil and moisture conservation, watertable increase and livestock improvement activities and consumers are mainly the other stakeholders in the region, viz. non-farm households representing labourers, business people and people employed in non-agricultural activities.

Theoretical Framework

The model is based on the Marshallian theory of economic surplus that stems from shifts over time of the supply and demand curves. In Figure 1, the rightward shift (S_1) of the original supply curve (S_0) generates economic surplus for producers and consumers. Such a shift can stem from changes in production technology, in the present case watershed development intervention. Given that the demand function remains constant, the original market equilibrium a (P_0, Q_0) is transferred by the effect of technological change to b (P_1,Q_1).

Consumers gain because they are able to consume a greater amount (Q_1) at a lower price (P_1). The area P_0abP_1 represents the consumer surplus. The watershed development intervention affects agricultural producers in two ways: (i) lower marginal costs (according to the theory, the supply curve corresponds to the curve of marginal costs as of the minimum value of the curve of average variable costs), and (ii) lower market price (P_0 reduced to P_1). Thus, the producers' surplus is defined as the Area P_1bl_1 - Area P_0al_0.

The mathematical model used was based on the scheme proposed by Pachico et al. (1987), in which supply and demand functions were

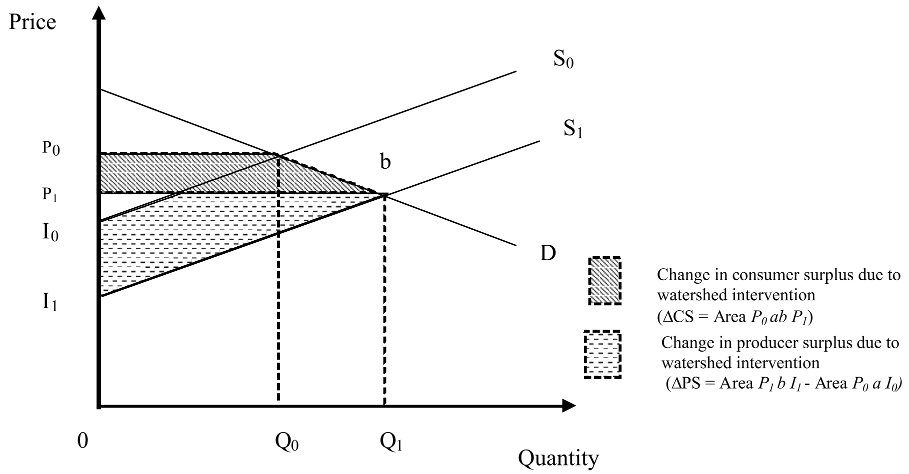

Figure 1. Graphical representation of economic surplus method.

nonlinear with constant elasticity, i.e. log-linear. The supply function for a product market was assumed that supply curves of the following functional form:

$$s_0 = c(P_0 - P_{lo})^d \quad (1)$$

where, s_0 = Initial supply before watershed intervention,
c, d = Constants,
P_0 = Price of product, and
P_{lo} = Minimum price that producers are willing to offer.

Typically, the watershed development programs involving the entire community and natural resources influence different aspects such as agricultural production system, environment and socio-economic conditions of the watershed villages. By virtue of its nature, watershed is an area-based technology cutting across villages comprising both private and public lands. Thus, the benefits from watershed development activities not only limited to the users/beneficiaries but also to the non-participating farmers. For instance, the watershed development technologies are expected to have positive impacts on groundwater recharge, soil and water conservation, maintaining ecological balance, increased fodder availability, increased crop yield, etc. Similarly, the increased agricultural production favours the non-farming community like labourers, rural artisans and other rural households. Thus, the watershed development brings benefits not only to the producers (farmers) but also to the consumers (farmers, labour households and other households in the watershed village). In this context, the economic surplus approach captures the total benefits accrued due to watershed development intervention in the rural areas.

The advantage of the economic surplus approach lies in the fact that the distribution of benefits to different segments of the society could be estimated. The watershed development could be treated as a 'public good' and covers both the private and public lands. Moreover, the benefits due to watershed development activities are not restricted to the producers alone. Increased supply and hence changes in price of the agricultural products will also benefit the consumers positively. In this context, the economic surplus approach captures the impact of watershed development activities in a holistic manner.

Application of Economic Surplus Method to Watershed Evaluation

Watershed programs play a dual role of safeguarding the interest of the producers as well as consumers, as in several locations, the drought-proofing aspects of the watershed programs are easily felt (Palanisami and Suresh Kumar 2007). In the case of producers, they can change the crop pattern due to increased water levels in their wells, moisture conservation in the soil, increase water use for the existing crops, increase the number of livestock and fodder production. There is also a change in the cost of production of the commodities in the watershed. Over the years, there is an increase in technology adoption due to watershed programs. In the case of consumers, the increased crop production in the watershed results in availability of produce at lower prices. Consumption levels also get increased among the consumers. Labour employment is increased due to increased land and crop production and processing activities in the watershed. Evidences show that the production levels have increased as a result of watershed interventions and the consumers have started enjoying the benefits of localized production in the regions. Hence, for the purpose of the analysis, it was assumed that, the output supply curve shifts gradually over time when the benefits from the watershed developmental activities start benefiting the agricultural sector through water resource enhancement. The supply shift factor due to technological change, in our case, watershed intervention, is known as K. This factor varies in time depending on the dynamics of the rainfall, adoption, dissemination of soil and moisture conservation technologies and maintenance activities undertaken in the watershed. The supply shift factor (K) can be interpreted as a reduction of absolute costs for each production level, or as an increase in production for each price level (Libardo et al. 1999).

Micro economic theory defines consumer surplus (individual or aggregated) as the area under the (individual or aggregated) demand curve and above a horizontal line at the actual price (in the aggregated case: the equilibrium price). Following IEG, World Bank, 2008, the demand curve is assumed to be log-linear with constant elasticity. Thus, the demand equation for this demand function can be written as:

$$P = gQ^{\eta} \tag{2}$$

where, η is the elasticity and g is a constant. Once, the parameters η and g are estimated, then consumer surplus could be estimated by equation (3):

$$CS = \int_{Q_0}^{Q_1} gQ^{\eta} dQ - (Q_1 - Q_0)P_1 \tag{3}$$

Combined, the consumer surplus and the producer surplus make up the total surplus.

Estimation of Benefits

Following the theory of demand and supply equilibrium, economic surplus (benefits) as a result of watershed development intervention is measured by equation (4):

$$B = K * P_0 * A_0 * Y_0 * (1 + 0.5\, Z * \varepsilon_d) \tag{4}$$

where, K is the supply shift due to watershed intervention.

The supply shift due to watershed intervention can be mathematically represented by equation (5):

$$K = \forall * \rho * \psi * \Omega \quad (5)$$

where, K represents the vertical shift of supply due to intervention of watershed development technologies and is expressed as a proportion of initial price. $\forall$ is net cost change which is defined as the difference between reduction in marginal cost and reduction in unit cost. The reduction in marginal cost is defined as the ratio of relative change in yield to price elasticity of supply (ε_s). Reduction in unit cost is defined as the ratio of change in cost of inputs per hectarpe to (1+change in yield). ρ is the probability of success in watershed development implementation. Ψ represents adoption rate of technologies and Ω is the depreciation rate of technologies.

Z represents the change in price due to watershed interventions. Mathematically, Z can be defined by equation (6):

$$Z = K * \frac{\varepsilon_s}{(\varepsilon_d + \varepsilon_s)} \quad (6)$$

where, P_0, A_0, and Y_0 represent prices of output, area and yield of different crops in the watershed before implementation of watershed development program. If we use the with and without approach, then these represent area, yield and price of crops in control village.

Cost of Project

The analysis considered cost towards watershed development investment during the project period and maintenance expenditure incurred in the project. For watershed development projects with multiple technologies or crops, incremental benefits from each technology and crop were added to compile the total benefits. The worthiness of the watershed development projects was then evaluated at 10 per cent discount rate. Using above estimates of returns and costs, net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) were computed.

Study Area and Data Collection

The study was conducted in Coimbatore district of Tamil Nadu, India. The predominant soil types are red soil, laterite, clay loam, sandy clay loam, and black cotton soil. Differences in soil types have differential impact on the water resources and agricultural production and productivity. The success of the watershed development programs critically depends on rainfall in the region. The major crops grown were: sorghum, cotton, sugarcane, maize, coconut and vegetables. Of the total cropped area, the area irrigated accounted for 56.82 per cent.

The chief source of irrigation in the district was through wells. Over the years, there has been a general decline in the water level in the whole of Coimbatore district, which is attributed to indiscriminate pumping of groundwater. The groundwater resource degradation has in turn

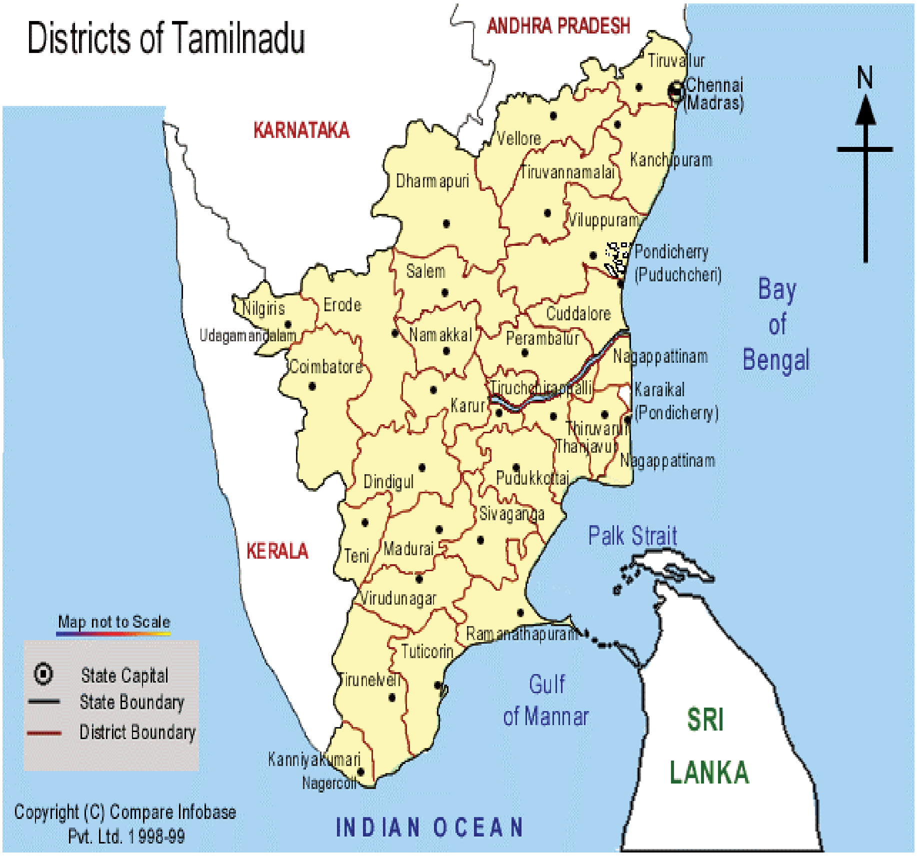

Figure 2. Map of the study area.

resulted in changes in crop patterns, well deepening, and an increase in well investments, pumping costs, well failure, and abandonment and migration of farmers (Palansami and Suresh Kumar 2007). It is in this context that groundwater augmentation by artificial recharge through watershed development programs gained momentum.

Data

The major data were derived from the recently completed study on Comprehensive Assessment (CA) of Watersheds Programs in India implemented by the ICRISAT team (Wani *et al*. 2008). For the purpose of our study, the data were drawn from a cluster of 10 watersheds implemented in Coimbatore district of Tamil Nadu. The details of all these watersheds with area treated are given in Table.1. A variety of indicators were developed and used for the impact assessment. The indicators of impact of watershed development activities covering soil erosion, groundwater recharge and water resources potential, agricultural production, socio-economic conditions and overall impact including the extent of green cover were developed. To make a comparative study, one control village where no watershed treatment activities were carried out, was selected for each watershed. The control villages were selected so as to have similar agro-climatic conditions. The select indicators were compared with before and after the watershed

Table 1. Details of watersheds covered for the study in Coimbatore district of Tamil Nadu.

Name of the Block	Name of watershed	Area (ha)
Annur	Kattampatty I	460.0
	Kattampatty II	467.5
	Kuppepalayam	672.5
Avinashi	Naduvenchery	767.5
	Karumapalayam	752.5
	Chinneripalayam	524.8
Sulur	Arasur I	605.0
	Arasur II	590.0
	Rasipalayam	560.0
Palladam	Kodangipalayam I	455.0

treatment activities and also with that of the control village. Thus, the data pertaining to 10 watershed villages and 10 control villages were gathered. The information on price elasticity of demand and supply of various farm products was obtained from the published sources.

Results and Discussion

This section presents the key results and findings from the field experience of impact assessment of watershed programs implemented under Drought Prone Area Program (DPAP) in Coimbatore district of Tamil Nadu. The general characteristics of the sample farm households in the study watershed were analysed and have been presented in Table 2. It could be seen that the average size of the holding worked out to be 1.28 ha and 1.75 ha, respectively for watershed and control villages. It is evident from the analysis that the average number of workers was 2.5 and 2.1 out of 4.07 and 4.2 for watershed and control villages, respectively.

The labour force participation rate came out to be 61.48 per cent and 50.79 per cent. The higher labour force participation was due to better scope for agricultural production, livestock activities and other off-farm and non-farm economic activities. It is evidenced from the analysis that the labour force participation rate among farmers in watershed villages was higher, implying that the enhanced agricultural production was due to watershed treatment activities. Construction of new

Table 2. General characteristics of sample farm households.

Particulars	Watershed village	Control village
Farm size (ha)	1.28	1.75
Household size	3.31	3.34
Land value (Rs/ha)	230657	153452
No.of wells owned	1.35	1.20
Average area irrigated by wells (ha)	1.48	1.80
Value of household assets (Rs)	261564[1]	184385
No.of persons in the household	4.07	4.2
Number of workers	2.5	2.1
Labour force participation (%)	61.48	50.79

[1]indicates that value was significantly different at 10 per cent, level from the corresponding values of control village

percolation ponds, major and minor check dams and the rejuvenation of existing ponds/tanks had enhanced the available storage capacity in the watersheds to store the run-off water for surface water use and groundwater recharge. The additional surface water storage capacity created in the watersheds ranged from 9299 m^3 to 12943 m^3. This additional storage capacity further helped in improving the groundwater recharge and water availability for livestock and other non-domestic uses in the village. On the basis of the data collected from the sample farmers, it was found that the water level in the open-dug wells had risen in the range of 0.5-1.0 metre in watershed villages. The depth of the water column in the few sample wells was recorded both in watershed and control villages for comparison. The depth of the water column in the wells was found to be higher in the watershed villages than in control villages. For instance, depth of the water column in the wells in Kattampatti watershed village was 3.53 m compared to 2.16 m in the control village leading to a difference of 63.43 per cent.

Information related to duration of pumping hours before well went dry (or water level depressed to a certain level) and time it took to recuperate to the same level were collected from the sample farmers across villages. Due to watershed treatment activities, groundwater recuperation in the nearby wells had increased. The increase in recuperation rate varied from 0.1 $m^3\ hr^{-1}$ to 0.3 $m^3\ hr^{-1}$. It was also observed that the recharge to wells decreased with their distance from the percolation ponds and check dams and the maximum distance where the recharge to the wells had occurred was observed to be 500-600 m from the percolation ponds.

The area irrigated in watershed villages registered a moderate increase after the watershed development activities in most of the watersheds, whereas in control village it declined slightly over the period. The irrigation intensity was found higher in watershed treated village than in untreated village. This shows that watershed development activities helped increase the water resource potential of a region through enhanced groundwater resources, coupled with soil and moisture conservation activities. In the case of control villages, the watertable in the wells had declined due to continuous pumping. It is one of the reasons why farmers in most of the villages demand watershed programs in their villages.

Table 3. Cropped area, cropping intensity and crop diversification.

Particulars	Watershed villages		Control villages	
	Before	After	Before	After
Net area irrigated (ha)	1.08	1.10[1]	1.68	1.62
Gross area irrigated (ha)	1.25	1.35[2]	1.84	1.62
Irrigation intensity	115.74	122.73[2]	109.52	100.00
Net cropped area (ha)	1.15	1.28[2]	1.78	1.62
Gross cropped area (ha)	1.38	1.88[2]	2.43	2.16
Cropping intensity (%)	120.00	146.88	136.52	133.33
Crop Diversification Index (CDI)	1.0		0.97	

[1] and [2] indicate that values were significantly different at 1 and 5 per cent levels from the corresponding values of control village

Crop diversification index (CDI) was worked out by employing Composite Entropy Index (CEI) based on the proportion of different crops in the farm. The Composite Entropy Index for crop diversification was worked out as:

$$C.E.I = -\left(\sum_{i=1}^{N} P_i . \log_N P_i\right) * \{1 - (1/N)\}$$

where, CEI = Composite Entropy Index,
P_i = Acreage proportion of i^{th} crop in total cropped area, and
N = Total number of crops.

The analysis also revealed increase in net cropped area, gross cropped area and cropping intensity in both the watersheds (Table 3). For example, the cropping intensity worked out to be 146.88 per cent in the watershed village, which is higher than in the control village (133.33 per cent). The composite entrophy index (CEI) was used to compare diversification across situations having different and large number of activities. The CEI has two components, viz. distribution and number of crops or diversity. The value of crop diversification index (CDI) increases with the decrease in concentration and rises with the number of crops/ activities. In general, CDI is higher in the case of watershed treated villages than control villages, confirming that watershed treatment activities help diversification in crop and farm activities.

The details regarding livestock per household and per hectare of arable land have been furnished in Table.4. The livestock income has been a reliable source of income for the livelihood of the resource-poor farmer households. Cattle, sheep and goats were maintained as important sources of manure and were the liquid capital resource. It could be seen that nearly 46.67 per cent and 93.33 per cent of the households

Table 4. Livestock per household and per hectare of arable land.

Particulars	Watershed village	Control village
Per cent of households	46.67	93.33
Herd size (number)	2.57	2.64
Per hectare of gross cropped area (number)	2.01	1.63

in watershed and control villages maintained cattle. Access to grazing land and fodder had made the farm households to maintain livestock in their farms to derive additional income. But, the analysis revealed that relatively more number of households in control villages maintained livestock. It was mainly due to the fact that inadequate grazing land and poor resource-base for stall feeding persuaded them to feed their livestock with green leaves and fodder obtained from crops and crop residues. The farm households in control villages maintained mainly milch animals to derive additional income for their livelihood.

Application of Economic Surplus Method

The impact of watershed development activities on yield of crops and hence the cost was estimated and has been presented in Table 5. The change in yield due to watershed intervention across crops varied from 31 per cent in maize to 36 per cent in cotton. It was the maximum change in yield due to watershed intervention. Reduction in marginal cost due to supply shift ranged from 32.8 per cent in vegetables to

Table 5. Impact of watershed development intervention on yield and cost.

Crops/ enterprises	Change in yield (%)	Reduction in marginal cost (%)	Reduction in unit cost (%)	Net cost change
Sorghum	33	63.6	3.76	59.8
Maize	31	39.9	2.29	37.6
Pulses	36	41.0	1.47	39.6
Vegetables	32	32.8	0.76	31.9
Milk	28	27.3	7.81	19.5

Note: The reduction in marginal cost was the ratio of relative change in yield to price elasticity of supply (ε_s). Reduction in unit cost was the ratio of change in cost of inputs per hectare to (1+change in yield). Ci was the input cost change per hectare.i.e., C_u = Ci/(1+change in yield;. The net cost change ($\forall$ was the difference between reduction in marginal cost and reduction in unit cost, ie., $\forall$ Cm-Cu.

63.6 per cent in sorghum. Net cost change varied from 32 per cent in vegetables to 59.8 per cent in sorghum.

The change in total surplus due to watershed development activities was estimated and has been presented in Table 6. The change in total surplus was higher in sorghum and maize than crops like pulses and vegetables. Being the major rain-fed crops, these two crops benefited more from the watershed interventions. The change in total surplus due to watershed intervention was decomposed into change in consumer surplus and change in producers surplus. It was evident that the producers surplus was higher than the consumer surplus in all the crops. For instance, in sorghum, the producers surplus worked out to be 61.2 per cent whereas the consumers surplus was only 38.8 per cent. Watershed development activities benefited the agricultural producers more. It was interesting to note that unlike in the crop sector, the milk

Table 6. Impact of watershed development activities on the village economy.

Crops/enterprises	Total benefits due to watershed intervention (B)		
	Change in total surplus (ΔTS)	Change in consumer surplus (ΔCS)	Change in producer surplus (Δ PS)
Sorghum	293177.3 (100.0)	113636.3 (38.8)	179541.0 (61.2)
Maize	177774.2 (100.0)	85424.0 (48.1)	92350.2 (51.9)
Pulses	25777.5 (100.0)	12580.3 (48.8)	13197.2 (51.2)
Vegetables	29663.6 (100.0)	10627.5 (35.8)	19036.1 (64.2)
Milk	176878.5 (100.0)	105974.1 (59.9)	70904.4 (40.1)

Note : The change in total surplus in the village economy due to watershed intervention was decomposed in to change in consumer surplus and change in producer surplus. The decomposition of total surplus was as follows:

$\Delta TS = \Delta CS + \Delta PS = P0Q0K(1+0.5Z\eta)$

$\Delta CS = P_0Q_0Z(1+0.5Z\eta)$

$\Delta PS = P_0Q_0(K–Z)(1+0.5Z\eta)$

Table 7. Results of economic analysis employing economic surplus method.

Particulars	Economic surplus method	Conventional method
Benefit-cost ratio	1.93	1.23
Internal rate of return (%)	25	14
Net present value (Rs)	2271021	567912

production had different impacts on the society. The decomposition analysis revealed that watershed development activities generated more consumers surplus in milk production. The overall impact of different watershed treatment activities was assessed in terms of net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR). The NPV, BCR and IRR were worked out using the economic surplus methodology assuming 10 per cent discount rate and 15 years life period.

The BCR is worked out to be more than one, implying that the returns to public investment such as watershed development activities were feasible. Similarly, the IRR worked out to be 25 per cent, which is higher than the long-term loan interest rate by commercial banks indicating the worthiness of the government investment on watershed development. The NPV worked out to be Rs 567912 for the entire watershed. The NPV per hectare worked out to be Rs 4542 (where the total area treated was 500 ha) implying that the benefits from watershed development were higher than the cost of investment of the watershed development programs of Rs 4000 ha^{-1}.

Conclusions and Policy Recommendations

The study has concluded that the watershed impact assessment should be given due importance in the future planning and development programs. The study has demonstrated that the economic surplus method captures the impacts of watershed development activities in a holistic manner and assesses the distributional effects, and therefore it would be a fairly good methodology to assess the impacts of watershed development. The watershed development activities have been found to have significant impact on groundwater recharge, access to groundwater and hence the expansion in irrigated area. Therefore, the policy focus must be on the development of these water-harvesting structures, particularly percolation ponds wherever feasible. In addition to these public investments, private investments through construction of farm ponds may be encouraged as these structures help in a big way to harvest the available rain water and hence groundwater recharge.

Watershed development activities have been found to alter crop pattern, increase crop yields and crop diversification and thereby could provide enhanced employment and farm income. Therefore, alternative-farming system combining agricultural crops, trees and livestock components with comparable profit should be evolved and demonstrated to the farmers.

Once the groundwater is available, high water intensive crops are introduced. Hence, appropriate water saving technologies like drip is introduced without affecting farmers' choice of crops. The creation and implementation of regulations in relation to depth of wells and spacing between wells will reduce the well failure, which could be possible through Watershed Association. The existing NABARD norms such as 150 metres spacing between two wells should be strictly followed.

People's participation, involvement of Panchayati Raj Institutions, local user groups and NGOs along side institutional support from different levels, viz. the central and state government,,district and block levels should be ensured to make the program more participatory, interactive and cost effective.

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Recent Developments in Vadose Zone Hydrology: Opportunities and Challenges for Sustainable Utilization of Water and Nutrients for Enhancing Productivity

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Abstract

Declining total land area under cultivation, increasing demand for land for non-agricultural use, demand for food grains, large gap between actual and potential yields, and recent trends in weather anomalies call for an urgent action to identify ways and means for improving agricultural productivity. Efficient and intelligent use of water and nutrients has a potential opportunity to improve agricultural productivity inasmuch as their prevailing use efficiencies are low. For example, both the use efficiencies for water and nitrogen for a major crop such as rice are in the order of 25%. For the past two decades, several developments in vadose zone hydrology have opened opportunities to improve water and nutrient use efficiencies. Specifically, low-cost sensors and user-friendly simulation models are becoming reliable aids for making informed agricultural decisions on how much and how frequently both water and nutrients have to be applied to specific crops, making precision farming a reality. A summary of these two products are discussed in this document with the objective to identify opportunities and research needs specific to Indian agriculture.

Introduction

Declining arable land since mid eighties (FAOSTAT, 2010) in the country, is a great concern not only in view of the increasing demand to produce more food grains for rising population, but also for various conflicts arising out of the requirement for more land for non-agricultural purposes. As per the national agriculture policy papers, India must achieve 3-4% growth in agricultural sector and increase its food grain production from the current level of about 218 million t to 307 million t by 2020. This shortfall of about 90 million t must come from the expansion of irrigated areas, productivity enhancement and better performance of the rain-fed areas. It is projected that the expansion in irrigated areas could contribute to about 35% of this shortfall and about 25% could emerge from the productivity enhancement in irrigated areas. The remaining 40% must be gained in rain-fed areas through intensive watershed interventions and productivity enhancement. Whether it is irrigated or rain-fed, a major issue in our production systems is the poor factor productivities, which trail far behind yield potentials of several crops. Management of production systems with productivity enhancement has a large potential to bridge this yield gap and has the potential to contribute to the total food grain production of the country in a large way. Rightly, Swaminathan (2006) has labelled productivity enhancement as the single most important option to increase food grain production in countries like India. Of particular importance is the productivity enhancement for water and nutrients. For both these inputs, the partial factors of productivity are quite low. Moreover, while good quality water is slowly becoming a limited commodity, poor management of nutrients has become a major environmental concern.

Roughly 50% of the total rainfall enters through soil surface as infiltration. As the infiltrated water passes through the soil and reach the groundwater system, the thin layer of soil between the groundwater table and the soil surface (also called as the vadose zone) temporarily stores almost 60% of this water. As early as 1930s, R. E. Horton identified the infiltration component of the water cycle as the sole source of water for the vegetation as well as the sole source of clean water for the groundwater system. With a large body of work on how different chemicals move through soil pores (generally referred to as Solute Transport in soil literature), it is also established now that the cleanliness of water is much to do with the filtering and scavenging functions of soil for pollutants. The shallow layer of the vadose zone directly plays these two vital functions in the terrestrial system. Yet, being a temporary water storage system, the vadose zone is by far one of the most-overlooked components of the entire hydrologic system. In fact, because the vadose zone is not considered as a resource (water) reservoir, it is not 'an explicit part of regulatory or planning guidelines that protect or control its water' (Harter and Hopmans 2004).

Soils in the vadose zone are opaque, heterogeneous, variably aggregated, variably saturated and consist of multiple phases. Generally, such a medium does not allow typical measurement signals to pass through it or even if it does, the reflected signal is too weak to be comprehensively detected. In addition, processes in vadose zone are typically non-linear, hysteretic, coupled and discontinuous (Nimmo, 2008). The availability of an inexpensive yet accurate non-invasive or even an intrusive measurement method for such processes has remained nearly elusive. However, a few breakthrough technologies have been developed over the last few decades, which have created new opportunities in vadose zone hydrology. We view these technologies in terms of three distinct perspectives. The capability to ascertain the exact position of a location on earth surface through satellite tracking has been the century's one of the most significant technologies. The Global Positioning System (GPS) is a key component of the precision management of agricultural inputs. The second perspective we chose is the capability of proximal sensing, which in our view would benefit the farming community in coming years in a greater way. Finally, the capability to measure many land surface processes and parameters through remote sensing techniques has a large potential. Although a comprehensive treatment of all these three components is beyond the scope of this document, we emphasize that each of these capabilities must be used in an integrative mode to tackle the complexity that come across in Vadose zone.

A second important challenge is the lack of suitable instrumentation to measure processes and parameters at the desired scale in real time in a non-invasive and non-intrusive manner. For instance, if one would intend to measure the wetness of a soil or the energy status of soil (gradient of which typically drives the rate of water movement in soil), the available technologies are expensive, prone to measurement errors, and are generally invasive in nature. This precludes monitoring of soil processes in the same location for a desired time frame. The last two decades have passed through a resurgence in computing as wells as sensor development. There are several opportunities to "Borrow, Adapt, Steal, and Dream" technologies and concepts to exploit vadose zone as a vital natural resource (Nimmo 2008).

A third component of the challenge is how plants utilize water and nutrients from the top of few centimetres of the vadose zone (also called as root zone or the rhizosphere). A large body of work exist in the agricultural community as to how plants utilize water and nutrients from the root zone. Yet, typical use efficiencies for water and nutrients in for many crops are abysmally low. For instance, rice being a very prominent crop with a lion's share in acreage and research, both water and nitrogen use efficiencies continue to be in the order of just 25%. For instance, the water use efficiency (WUE) for transplanted rice is only 20-30% (Tuong and Bhuiyan 1999). Similarly, N use efficiency (NUE) is 20-40% (Raun and Johnson 1999). As estimation of water and nutrient contents in soil continues to be difficult and expensive, the management of these two vital inputs is usually done following a general recommendation (blanket application) rather than matching the true crop requirement. Because of such a practice, often application is made when there is no requirement by the crop leading to the loss of these inputs. Environmental pollution arising out of excess application of chemicals, depleting groundwater resources arising out of excess pumping of water, and the reduction in crop yield are some of the adverse shortcomings of such blanket application of agricultural inputs. The ability to measure water and nutrient contents in situ instantaneously is important to provide not only a better and sustainable crop yield but also to maintain greater use-efficiency of agricultural resources and hence improved environmental quality.

A synergy among a) how best water, nutrients, or carbon cycles may be assessed in appropriate scale of observation, b) how best processes or parameters in the hydrologic system may be monitored, and c) how crop plant systems may be exploited to ensure sustainable and economic return is all required if we are to make a headway in ensuring the food security. Synergy is critical. Without comprehensive studies natural systems will hardly be tuned to our requirement. An immediate synergy need is to have human resources capable of both 'measuring' and 'modeling' if we are to achieve productivity enhancement. This document outlines a few emerging measurement techniques and a few comprehensive models that may be utilized for productivity enhancement. As a working example, we show how integration of technology may be useful in enhancing the productivity.

Conceptual Developments in Flow and Transport Modeling

Limited and less efficient solutions for the challenges in vadose zone stem from the inherent complexity of the vadose zone itself. Depending upon the specific conditions, soils in the vadose zone may remain saturated or unsaturated. Two of the most daunting challenges in such systems are the heterogeneity and spatial variability of soils and soil processes. With a large variation in soil pore size, flow and transport processes in vadose zone are generally not ideal. It is increasingly shown that water and chemicals do not pass through the soil matrix alone; for most soils, there are evidences of preferential flow wherein much of water and chemicals bypass the soil matrix and very quickly reach the deeper layers uninhibited and unfiltered. With almost a decade-full of research, a clear understanding of preferential transport is yet to emerge.

Traditionally, hydrologists have adopted a top-down approach to segregate components of water balance at large catchment or watershed scales, albeit the recent trends in distributed hydrologic modelling, ignoring small details and specific mechanisms. Soil physicists on the other hand characterize flow and transport processes at very small (a few grams of soil to soils in a plot) scale in a bottom-up approach. Most measurements used in hydrology (at least, those concerning the soils in a catchment or watershed) in either of these approaches are limited to small spatial extents. It is well recognized now that the processes characterized in small scales fail to describe the large-scale scenarios and approaches and fail to be predictive and portable to new areas and new conditions. Amid such shortfalls, there are efforts where small-scale processes are built into large-scale models such as those in MIKE-SHE among others (Abbott et al. 1986) during the last few years. In what follows, we list three distinct different modelling environments. HYDRUS Suite (Simunek et al. 1999) is a comprehensively mechanistic model and the Soil Water Assessment Tool (Arnold et al. 1998) is largely a physically based model with several empiricisms. MIKE SHE implements several mechanistic components much similar to HYDRUS while maintaining the main-stream hydrologic modelling approach.

HYDRUS Suite: HYDRUS Suite is a flow and transport modeling environment, which comes with the capability to have one-, two-, or three-dimensional flow domain. Mechanistic models of major flow and transport processes such as water, heat, and chemical transport as well as root water uptake are implemented in an adaptive finite element scheme within HYDRUS Suite with the capability to optimize model parameters from measured state variables of concerned processes. HYDRUS also has the provision to model preferential flow, nonequilibrium solute transport, multi-species chemistry of decay and production with mechanistic coupling among mass and energy transport processes.

All the transport equations implemented in HYDRUS are some form of the continuity equation derived from the conservation of mass and energy. In essence, all the governing equations are mechanistic in nature and are described by partial differential equations. Both fixed and variable boundary conditions with several models of constitutive relationships are built into this modelling environment. Newer versions of this modelling environment also have provisions for vapour flow, gas transport, root growth, and snow hydrology.

Soil Water Assessment Tool (SWAT): The watershed loading/water quality model SWAT is used by many users for simulating stream flow and sediment load. A detailed description of SWAT is given in Arnold et al. (1998). Briefly, SWAT is a physically based simulation model developed to simulate continuous-time landscape processes and stream flow with a high level of spatial detail by allowing the river/watershed to be divided into sub-basins or sub-watersheds. Each sub-basin is divided into several land use and soil combinations called hydrologic response units (HRU) based on threshold percentages used to select the land use and soil. This model operates on a daily time step and is designed to evaluate the impacts of different management conditions on water quality in large ungauged basins. Major components of the model include hydrology, weather, erosion, soil temperature, crop growth, nutrients, pesticides, and agricultural management.

The local hydrologic water balance in the HRU is made by dividing the control volume into four storage volumes: snow (stored volume until it melts), soil profile (0–2 m), shallow aquifer (typically 2–20 m), and deep aquifer (>20 m). Processes such as infiltration, runoff, evaporation, plant uptake, lateral flow, and percolation to lower layers are included in this model. Percolation from the bottom of the soil profile recharges the shallow aquifer (groundwater recharge). SWAT simulates the total groundwater recharge as: (a) water that passes past the bottom of the soil profile, (b) channel transmission losses and (c) seepage from ponds and reservoirs. Surface runoff from daily rainfall is estimated with a modification of Soil Conservation Service (SCS) curve number method. In the curve number method, the daily rainfall is partitioned between surface runoff and infiltration as a function of antecedent soil moisture condition. Green & Ampt infiltration method is also available within SWAT to simulate surface runoff and infiltration. SWAT has options to estimate the potential evapo-transpiration (PET) by different methods such as Modified Penman Montieth, Hargreaves, and Priestley-Taylor.

MIKE SHE: MIKE SHE is a fully distributed physically based model capable of simulating the entire land phase of the hydrological cycle over the model area (Abbott et al. 1986; Refsgaard and Storm, 1995). The model can perform numerical solutions of one-dimensional unsaturated, two-dimensional overland flow, and three-dimensional saturated flow and transport. The overland, drain and baseflow are coupled with the river model MIKE 11 – a sister module of MIKE environment. The unsaturated zone module of MIKE SHE has a built-in by-pass function that calculates a direct instantaneous groundwater recharge as a function of the rainfall of the net rainfall and the actual soil moisture condition in the unsaturated zone.

The model area in MIKE group of model is discretized by two analogous horizontal-grid square networks for surface and ground water flow components. A vertical column of nodes at each grid representing the unsaturated zone links these. A finite difference solution of the partial differential equations describing the processes of overland and channel flow, unsaturated and saturated flow, interception and evapotranspiration, is used for water movement modelling. The interception process is modelled by introducing interception storage, expressed as a function of leaf area index. The actual evapotranspiration is calculated based on the potential evapotranspiration using the Kristensen and Jensen model. The actual evapotranspiration rate, consisting of the sum of actual transpiration and soil evaporation, is further adjusted according to vegetation density and water content in the root zone. The overland flow process is simulated in each grid square by solving the two-dimensional diffusive wave approximation of the Saint±Venant equations. For stream network channel flow, the one-dimensional form of the equation is solved in a separate node system located along boundaries of the grid squares. Soil moisture distribution in the unsaturated zone is calculated by solving the one-dimensional Richards' equation. Extraction of moisture for transpiration and soil evaporation is introduced via sink terms at the node points in the root zone. Similarly, the ground water flow is modelled using an implicit finite difference solution of the two-dimensional non-linear Boussinesq equation for an unconfined aquifer. The interaction between the streamflow and groundwater system is calculated on the basis of water levels in the river system and the groundwater table.

Developments in Measurement Techniques

A comprehensive listing of different sensors is not the object of this exposition. We merely cite three prominent proximal sensing approaches, which we consider to have wide-spread application in coming future specifically in view of the management of water and nutrients needed to improve agricultural productivity.

Time-Domain Reflectometry (TDR): Over the last three decades, TDR has emerged as a reliable means to determine volumetric soil water content (Topp et al. 1980), bulk soil electrical conductivity (Dalton et al. 1984), ionic solute concentration (Risler et al. 1996) and nitrate concentrations in root zone (Das et al. 1999). The ability to simultaneously measure volumetric water content and solute concentration in the same sampling volume and the relative ease with which TDR sensors may be concurrently measured at multiple soil locations make TDR a potential technology to monitor soil wetness and nutrient loading directly in the root zone on a real time basis. Although initial acquisition costs are high, TDR may be less expensive than conventional techniques, considering the total cost of sampling and analyses.

The basic principle behind the TDR technology is that when an electromagnetic wave propagates through a medium, part of the energy is dissipated in polarizing the dipolar molecules present in the medium. Soil solids are very feebly polar with a dielectric constant (ε) of about

2-5, whereas amount of water present in soil provides a strong dielectric response. The water saturated soil could yield a dielectric constant as high as 40-50. The bulk dielectric constant of soil changes proportionally with the degree of unsaturation. The relationships between volumetric soil water content (θ) and ε are almost independent of soil type except for soils having very high organic matter contents of are high in iron and other magnetic materials. Thus, the polynomial relationships such as given by Topp et al. (1980):

$$\theta = -5.3\text{x}10^{-2} + 2.92\text{x}10^{-2}\varepsilon - 5.5\text{x}10^{-4}\varepsilon^{2} + 4.3\text{x}10^{-6}\varepsilon^{3} \qquad (1)$$

or that given by Ledieu et al. (1986):

$$\theta = 0.115\sqrt{\varepsilon} - 0.176 \qquad (2)$$

may be suitably used to estimate soil wetness. Similarly, the bulk electrical conductivity (σ_a) of a soil may be estimated from the loss component of the reflected electromagnetic signal, which is estimated using the Giese and Tiemann (1975) relationship:

$$\sigma_a = \frac{Z_0 f_T}{120\pi L Z_L} \qquad (3)$$

where Z_0 is probe impedance (Ω), L is probe length (m), Z_L is resistive impedance load across the buried TDR probe (Ω), and f_T is a correction factor (US Salinity Laboratory Staff 1954);

$$f_T = 1/[1 + 0.02(T - 25)] \qquad (4)$$

for measured soil temperature (°C) adjacent to TDR probes. The resistive impedance load across the TDR probe is calculated by subtracting the combined series impedance (Z_{cable}) of the multiplexer, connectors, and connecting cables from the total impedance (Z_{total}) measured with the cable tester (Heimovaara et al. 1995). The cable impedance is estimated using standard calibration procedure (Das et al. 1999). Once the bulk electrical conductivity is estimated, the solute concentration is estimated using a two-step calibration procedure. In the first step, soil solution electrical conductivity (σ_w) is first inverted from TDR-measured σ_a conceiving that the electrical conductivity of bulk soil is an integrated measure of contributions from ions on solid surfaces (surface conductance, σ_s), σ_w, and the tortuosity of electrical flow paths. Once σ_w is estimated, simple linear relationships may be used to estimate solute concentration such as nitrates (Das et al. 1999).

There have been several applications of TDR technology in estimating soil wetness and solute concentration simultaneously in the same location in almost a non-destructive manner. Reviews on details of TDR technology may be consulted for greater details (Robinson et al. 2003). Corwin and Lesch (2003) have recently outlined detailed methodology as to how the resistivity measurement technology may be useful in the precision management of nutrients.

Combined Heat Pulse and Resistivity Technology: This is a sensor-fusion technology in which, water content is measured using the heat pulse approach (Campbell et al. 1991) and the electrical conductivity is estimated using a four electrode resistivity bridge. In the heat-pulse method, the temperature response to a finite duration of heating (pulse heating) is analyzed using the models for conduction of heat through soil. Thermal diffusivity (k) and volumetric heat capacity (C) of soil can be determined if temperature response to a pulse heating is known. Campbell et al. (1991) assumed that the dual-probe configuration approximates instantaneous heating of an infinite line source embedded in an infinite medium and developed an inverse relationship between the maximum temperature rise (T_m) and C:

$$C = q / \left(e \pi r^2 T_m \right) \tag{5}$$

where q is the quantity of heat liberated per unit length of heater and r is the distance from the heater. Thus, C can be determined simply by obtaining measurements of q and T_m. Once the heat capacity is estimated, volumetric water content may estimated by rearranging the heat capacity relationship for a mixture of soil solids (minerals plus organic matter contents) and water:

$$\theta = \left(C - \rho_b c_s \right) / C_w \tag{6}$$

where C_w is the volumetric heat capacity of water, ρ_b is the soil bulk density and c_s is the specific heat of the soil solid (mineral and organic) constituents. Similarly, in the electrical conductivity measurement method, a four-electrode Wenner array may be used to measure bulk electrical conductivity (σ_a) of soil (Rhodes et al. 1989). The measurement involves measuring the resistance to current flow between the inner pair of electrodes while electrical current is caused to flow through the soil (or other porous media) between the outer pair of electrodes. Once the bulk electrical conductivity and soil wetness are assessed, the combined heat pulse and electrical conductivity probes may be used for estimating solute contents in soil similar to procedures followed in TDR approach. This combined technology is much cheaper than a TDR but has the disadvantage of requiring soil-specific calibration. It may be noted that the combined heat pulse and resistivity measurement principle was coupled with permittivity measurement in the Phoenix Mars Lander for detecting water in Martian crust.

Imaging Spectroscopy: Over the last decade, imaging spectroscopy (IS) in the visible, near-infrared and short wave infrared (VNIR-SWIR) region (350 to 2500 nm) has emerged as a rapid non-invasive technique for the estimation of soil properties (Ben Dor et al. 2009). The IS approach involves a prior establishment of relationships between target soil properties and soil reflectance values measured by a spectroradiometer, which are then used to transform measured reflectance into a target soil property. Spectral signatures of soil are due to electronic transition of atoms and vibrational stretching and bending of structural groups of atoms that form molecules and crystals. The fundamental vibration of most soil materials can be found in the mid-infrared (MIR) region (2500-20000 nm), with overtones and combinations found in the near-infrared (NIR) region (700-2500 nm). In the NIR region, reflectance spectra of soil show vibrational absorbances due to –OH functional group in minerals, and to –OH, –CH, and –NH organic functional groups in soil organic matter (Viscarra Rossel and McBratney 1998). In the VNIR-SWIR, the reflectance spectra also show prominent absorption peaking at 1400, 1900 and 2208 nm. Out of these three absorption peaks, first two are attributed to the OH- ions and bound water present in soil (Leone and Sommer, 2000) and the third one to clay mineral (Chabrillat et al. 2002). Nominal values of wavelengths for which absorption features are generally observed are given in different literature (Baumgardner et al. 1985). Full description on spectral reflectance of soil as influenced by different soil properties and its quantification through remote sensing was given in Baumgardner et al. (1985), Leone and Sommer (2000), and Ben-Dor et al. (2002) among others.

Several studies have shown that the IS approach may be used to estimate soil organic matter content (Galvão 2008), nitrogen content (Vagen et al. 2006), soil electrical conductivity (Shrestha, 2006), cation exchange capacity (Fox and Metla 2005), iron content (Galvão and Vitorello 1998), soil colour (Mathieu et al. 1998), soil moisture content (Carlson et al. 1995), soil carbonates (Lagacherie et al. 2008), and the mineralogical composition (Clark 1999). In addition to the assessment of specific soil properties, IS technology has also been used to monitor different soil processes. For example, Leone and Sommer (2000) discriminated between soil development and soil degradation using laboratory reflectance spectra in the VNIR region. Dematte et al. (2004) showed that laboratory reflectance spectra in the VNIR region can be used to describe the variation of parent material along a toposequence. They also showed that reflectance spectra may be used to group soils according to different tillage systems. Recently, studies have also shown that proximal spectral reflectance may be used for estimating soil hydraulic properties (Santra et al. 2009). The reflectance spectroscopy approach is rapid, non-invasive, and is best suited for in situ measurement although a spectroradiometer is currently very expensive (Ben-Dor et al. 2009).

Application of Measurement and Modeling Techniques for Productivity Enhancement and Resource Conservation – A Case Study at IIT Kharagpur

As stated earlier, lowland rice cultivation is notoriuous for poor use efficiencies of both water and nutrients – two key factors of production needing immediate attention (Swaminathan 2006). Over the last six years, a series of field-scale water and solute transport studies have been conducted at the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India (220 19’ N 870 19’ E) with a view to devise feasible solutions for improving use efficiency of water and nutrients. An integration of both modelling and measurement techniques is being adopted to reach this goal.

Lowland paddy was grown in 30 experimental plots (6 m x 5 m) each fitted with piezometers and soil solution samplers at multiple soil depths. All the 30 plots have 2 m wide bunds for preventing mixing of nitrogenous fertilizer among plots. The local climate is humid subtropical with an average rainfall 140-160 cm of which about 100 cm is distributed over the *kharif* months. Soil of the experimental site is acidic lateritic sandy loam (Haplustalf). Soils are generally low in organic carbon and cation exchange capacity (8.1-9.2 cmol+/kg). Detailed characterization of soils (Garg 2007, Patil 2007) showed the presence of distinct layers in the top one meter profile. A thin plow sole between 10-26 cm below soil surface and a discontinuous clay pan at about a meter soil depth (Garg et al. 2009) is a characteristic feature in these soils. Even with the presence of two compact layers in the top one meter of soil, experiments repeatedly showed very high water requirement exceeding 300 cm in a single growing season for this soil (Garg et al. 2009). Similar water requirement in paddy fields has also been observed by others (Wopereis et al. 1994). Large water requirement for paddy makes its water productivity substantially low compared to wheat or maize.

Systematic investigation of soil water regime showed the presence of large preferential flow paths, which was interpreted to yield low water productivity. Garg et al. (2009) showed that water regime in such soils may be suitably modelled using a dual-porosity modelling (DPM). The DPM approach assumes that water flow is restricted to the fractures (or inter-aggregate pores and macropores) and that water in the matrix (intra-aggregate pores) is immobile (Simunek et al. 2003). The total water content (θ) of a soil is thus the sum of the water present in the intra-aggregate pores (θ_{im}) and that present in the macropores (θ_m). The DPM formulation for water flow can be based on a mixed formulation of the Richards equation (Simunek et al. 2003):

$$\frac{\partial \theta_m}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right] - S_m - \tau_w \qquad (7)$$

$$\frac{\partial \theta_{im}}{\partial t} = -S_{im} + \tau_w \qquad (8)$$

$$\tau_w = \omega(h_m - h_{im}) \qquad (9)$$

where S is the sink term and ω is the mass transfer rate (h^{-1}) for water from the inter to intra-aggregate pores. Subscript m denotes the macropore (mobile) domain and im denotes the matrix domain. In this modeling approach, total eight parameters (θ_{rim}, θ_{rm}, θ_{sm}, θ_{sim}, n, α, K_s, and ω) are needed. The parameters θ_{rm} and θ_{rim} are the residual water content for mobile and immobile region, respectively; θs_m and θ_{sim} are the total pore volume for mobile and immobile phases, respectively; and K_s, n, and α are the fitting parameters of water characteristic curve for mobile phase. It was further observed that a dual-porosity modelling framework for water flow substantially improved the prediction of solute profiles. Once parameterized, the DPM approach provides a way to predict the amount of water or urea needed to maintain specific levels of saturation or nitrogen contents in soil. Such a capability prevents excessive application of inputs and, in turn, reduces environmental loading of nitrogen.

Knowledge gained in these investigations also led to the development of simple solutions to improve water and nutrient use efficiency. For instance, we observed that application of less water has a positive effect on nitrogen use efficiency (Patil et al. 2010). It was also possible to use 40% less water by adopting a novel conservation treatment.

Implications for Productivity Enhancement

The requirement for productivity enhancement in agriculture is beyond doubt. The contention is how to identify and how to implement the best possible approach. The answer to this is not a simple one. We argued that a conscientious mix of measurement and modelling approaches may be one of the solutions to identify a feasible approach. Similar to Nimmo (2008), we also argued that new technologies and new concepts have to be developed or borrowed from related disciplines without inhibition. The investment in technology development may not appear cost effective. But one needs to look at the totality. Sixty eight per cent of 38 developing countries spend large sums on fertilizer subsidies. In India, it amounts to several thousand crores. At about 100 kg nitrogen per hectare application over 160 million hectares of land and less than 50% use efficiency, the environmental loading of nitrogen is beginning to be substantial. Environmental risks and less input efficiencies combined together must bargain for large investments on researching how best to improve factor efficiencies in agriculture.

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Use of Agroclimatic Datasets for Improved Planning of Watersheds

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Abstract

Maximizing agricultural production from rain-fed areas in a sustainable manner is the need of the day to feed the ever-increasing population. Integrated watershed management with focus on productivity enhancement and livelihood improvement is one of the high priority areas identified and promoted for producing both tangible and non-tangible benefits to the individuals as well as for communities as a whole. Reliable and long-term data on agroclimate, soils, crop varieties and crop production at taluk/block/district-level for several years are needed for undertaking climatic analyses and to understand variations in agricultural productivity and changes in the cropping patterns. Data on crop phenology, growth and yield characters are needed to quantify crop-weather relationships and for validating crop-growth simulation models. Agroclimatic datasets need to be developed at individual watershed level and climatic analyses help in assessing rainwater harvesting potential, efficient land use planning, determining suitability of crops, risk analysis of climatic hazards, adoption of farming methods and choice of farm machinery. In this paper, results of climatic analysis of selected watersheds in India with respect to water balance and length of rain-fed crop-growing period, yield gap analysis of some important crops are presented and discussed. Use of agroclimatic datasets goes much beyond agroclimatic analysis of watersheds. Current issues like end-of-the-season crop yield forecasting, climatic change impact assessment, crop insurance to farming community, maintaining quality of produce to compete with international market, sustainability of the yield and environment are also to be addressed. Enhancing climate awareness among the rural stakeholders using new IT tools is the need of the hour.

Introduction

The importance of weather assumes greater importance in rain-fed regions where moisture regime during the cropping season is highly variable and 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, favourable weather is a must for good harvests (Rao et al. 1999). Even in irrigated agriculture, the thermal and radiation regimes influence the choice of crops, cropping patterns, and the optimum dates of sowing for achieving better crop yields.

It is imperative that the vast potential of rain-fed agriculture needs to be realized, as irrigated agriculture alone cannot meet the total foodgrains requirements of the country. High rainfall variability, severe land degradation, poor soils, frequent droughts, high population density and low investments lead to poverty and fragile livelihoods. These factors characterize the rain-fed areas. Growing scarcity for water and fodder has become a sad reality in these areas. In rain-fed areas, rainwater management at watershed/catchment scale is used as an entry point for increasing agricultural productivity (Wani et al. 2003b). Agroclimatic analyses helps in devising suitable management practices for watersheds to conserve, harvest and efficiently use rainwater for increasing agricultural production.

Agroclimatic Datasets and Database Management

Reliable and long-term agroclimatic data are needed for undertaking any climatic analyses along with data on soils, crop varieties and production at *taluk*/block/district-level for several years to understand the variations in agricultural productivity and changes in the cropping patterns. Data on crop phenology, growth and yield characters are needed to quantify crop -weather relationships and validating the crop-growth simulation models.

Several organizations like India Meteorological Department IMD), Indian Council of Agricultural Research, state agricultural universities maintain meteorological and agrometeorological observatories in the country have long-period of data. Data need to be collected from those stations which are nearby to the watersheds. The conventional method of handling data is to store it in a “file”. Application programs are needed to quality check and analyze the data stored in files. Database management following the conventional method requires application programs or software to: (i) add new stations and related data, (ii) calculate means, sums etc., on weekly and monthly basis, (iii) compute derived parameters and indices, and (iv) generate various reports

A database management system or DBMS is a set of application programs that act as layers between the physical database and its users. All the requests from users for access to the database are handled by the DBMS. Though there are several models, the Relational Database Management System (RDBMS) is most suitable for agroclimatic data. RDBMS eliminates explicit parent-child relationships and there are no pointers maintained and records are logically connected by key values. Hierarchical and network models deal with one record at a time while relational model reads and writes data in units of a set of records. In RDBMS, data is organized in the form of tables comprising rows and columns. Any row is identified by a column or set of columns that form a primary key. Development of agroclimatic database is thus a pre-requisite for climate analysis and the DBMS includes:

- computer hardware and software
- data acquisition, entry, storage, quality control and archiving
- designing an appropriate agroclimate DBMS with scope for scalability,
- data access and application software development, and
- data administration, monitoring and policy on data sharing.

In addition to collecting the historic agroclimatic data, weather needs to be monitored at the watersheds to assess the impacts of interventions made during the development phase by establishing a manual agromet station or by installing an automatic weather station (AWS). Manual agromet station is to be established by following the standard procedures prescribed by the IMD and the observer or the volunteer has to be trained thoroughly in recording the data and maintaining the instruments. AWS is a system to record the changes in the weather continuously without any human intervention. The AWS consists of a datalogger, set of sensors, power supply, solar panel, mounting stand and other accessories. The AWS should be located in such a place that it represents the general agroclimatic conditions of the watershed area. Datalogger program should be optimised for power and memory usage and checked thoroughly for any bugs. Proper protection against theft and damage is to be ensured for the instruments. Weather data monitored at the watersheds need to be quality checked and datasets developed.

Agroclimatic datasets once developed would lead to various agroclimatic analyses based on the concepts of rainfall probability, water balance, length of growing period, dry and wet spells, droughts, crop-weather modelling, climate variability and change at the watersheds. Development of software for quality check of weather data and various agroclimatic analyses including water balance was taken up by ICRISAT. Results of the analyses help in assessing rainwater harvesting potential, efficient landuse planning, determining suitability of crops, risk analysis of climatic hazards, production or harvest forecasts and in adoption of farming methods and choice of farm machinery.

Water Balance

In selected watersheds in the semi-arid Andhra Pradesh, water balance analysis indicated that between the wet and dry years, variation in the water surplus was much higher compared to the water deficit (Kesava Rao et al., 2007). Climatic water surplus accrued contributes to runoff, which could be harvested and stored for use during the intra-seasonal dry periods as well as for partially meeting the crop water requirements of the second crop season. Analysis indicated that runoff water that could be harvested and stored for a watershed area of 500 ha is 0.3 to 0.6 million m^3 water during normal years. In the wet years, this potential may go up to about 1.72 million m^3.

Length of growing period (LGP) is defined as the length of the rainy season, plus the period for which the soil moisture storage at the end of rainy season and the post-rainy season and winter rainfall can meet the crop water needs. Soil depth in a toposequence can alter the LGP across the watershed, being highest in the low-lying regions and lowest in the upper reaches of the watersheds. Weekly water balance indices are mostly used to delineate the LGP and such analyses done over several years help to determine the assured begin and end of the rain-fed growing period based on probability of occurrence. It was observed that at selected watersheds in Andhra Pradesh (Kesava Rao et al.

2008) start and end of the crop-growing season varied across years; however, begin was more variable compared to the end. There was no definite relationship between the start and length of growing period.

Climate Change Impacts on LGP

Solapur in southwestern Maharashtra is under hot dry semi-arid ecological sub-region with shallow and medium deep loamy black soils. Available water capacity is about 100-200 mm. Normal length of growing period (LGP) is about 150 days. Sorghum, groundnut, pigeonpea, chickpea, wheat and sugarcane are major crops. Daily agroclimatic dataset of Solapur for the period 1975-2004 was used in the study. Reference crop evapotranspiration was estimated following the FAO-Penman-Monteith method (Allen et al. 1998) and water balances were computed based on modified water balance (Thornthwaite and Mather 1955). LGP was delineated for all the years based on the Index of Moisture Adequacy (ratio of actual evapotranspiration to reference crop evapotranspiration) for the present and imposed conditions. Considerable variation exists in both start and end of growing period, however, no definite relation between beginning and end could be established. Growing period starts by 25 June and ends by 25 November with a growing period of about 150 days. At 75% probability, season starts by 10 July and ends by 15 November with a duration of 130 days. In certain years, growing season started as early as 01 June or as late as 30 July. End of the season could be as early as 30 September or can extend up to 31 December. The longest (220 days) season occurred in 1978 and shortest (85 days) occurred in the year 2003. In general, dry spells occur more at vegetative stage. LGP might shorten by 10-20 days (delayed begin and early end) due to climate change projections of temperature increase by 2°C and rainfall decrease by 20% (Fig. 1). End-season dry-spells are likely to increase.

Time series analysis indicated that the average annual maximum and minimum temperatures increased by 0.5°C in the past 30-years from 33.5°C to 34.0°C and from 19.5°C to 20.0°C, respectively. No trend could be seen for rainfall. Highly erratic rainfall distribution in the growing season is seen and crop yields are highly variable. Climate change is likely to increase variability in rainfall. Monsoon cropping

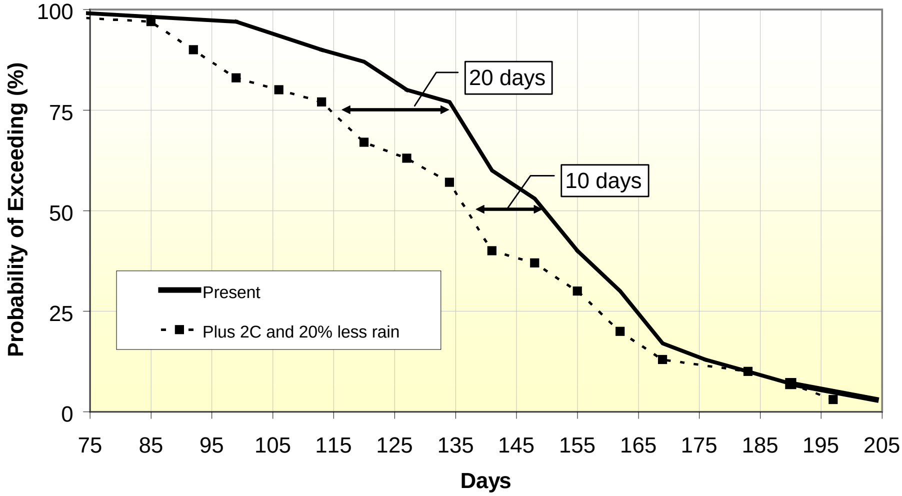

Figure 1. Projected climate change impact on LGP at Solapur.

is fairly undependable, particularly with long-duration crops. Crops that are sensitive to rain aberrations at vegetative and at maturity have greater risk. Drought-hardy crops are more suitable for rain-fed cultivation. Short-duration crop of pearl millet or grain legume followed by a sorghum grown on conserved moisture could be successful. Agroclimatic analysis coupled with crop-simulation models, and better seasonal and medium duration weather forecasts, help build resilience to climate variability/change at watersheds.

Yield Gap Analysis

Based on the agroclimatic datasets, yield gap analysis of selected major rain-fed crops was carried out, which showed that substantial yield gaps exist between current (farmers') and experimental or simulated potential yields. Simulated rain-fed potential yield in different production zones of India ranged from 3,210 to 3,410 kg ha^{-1} for *kharif* sorghum, 1,000 to 1,360 kg ha^{-1} for *rabi* sorghum and 1,430 to 2,090 kg ha^{-1} for pearl millet. Total yield gap (simulated rain-fed potential yield – farmers' yield) in production zones ranged from 2,130 to 2,560 kg ha^{-1} for *kharif* sorghum, 280 to 830 kg ha^{-1} for *rabi* sorghum and 680 to 1040 kg ha^{-1} for pearl millet. These gaps indicate that productivity of *kharif* sorghum can be increased 3.0 to 4.0 times, of *rabi* sorghum 1.4 to 2.7 times and of pearl millet 1.8 to 2.3 times from their current levels of productivity (Murty et al. 2007).

Large spatial and temporal variation in yield gap was observed for the four legumes. The yield gaps for the production zones ranged from 850 to 1,320 kg ha^{-1} for soybean, 1,180 to 2,010 kg ha^{-1} for groundnut, 550 to 770 kg ha^{-1} for pigeonpea and 610 to 1,150 kg ha^{-1} for chickpea. The results showed that on average the productivity of legumes and oilseeds can be increased 2.3 to 2.5 times their current levels of productivity under rain-fed situations. Supplemental irrigation would further increase these yields (Bhatia et al. 2006). Yield gaps of selected legumes, sorghum and pearl millet are presented in the Figure 2.

Extensive land degradation and unfavourable climate are the major abiotic constraints limiting crop production in the rain-fed areas of India. Erratic rainfall results in frequent droughts and water-logging in the rainy-season crops. Both low and high temperatures and drought limit the productivity of post-rainy-season crops, especially legumes. Most of the soils in the rain-fed regions of India have low soil fertility caused by soil erosion, continuous mining of nutrients by crops with inadequate nutrient inputs by the farmers. Biotic constraints are also the major yield reducers of rain-fed crops. High-yielding improved cultivars resistant to some of these biotic constraints have been developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the national institutes in India and are being promoted for adoption by farmers.

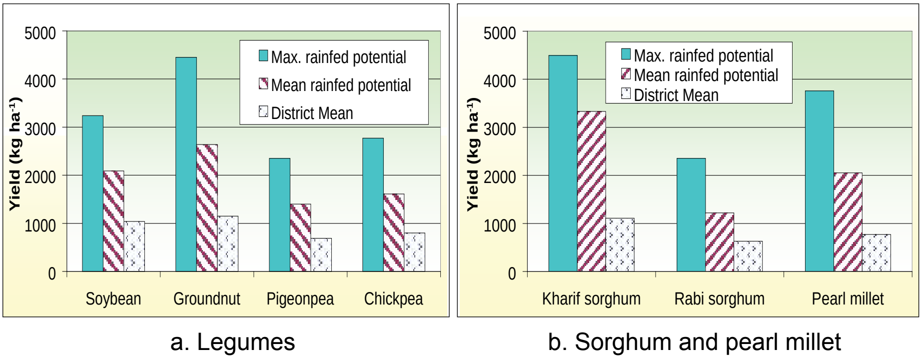

Figure 2. Rain-fed potential yields and yield gaps of selected crops in India.

An integrated genetic and natural resource management (IGNRM) approach in the watershed framework is needed to enhance the productivity of rain-fed crops in the rain-fed areas. Integrated watershed management, comprising improved land and water management, integrated nutrient management including application of micronutrients, improved varieties and integrated pest and disease management, has been evaluated by ICRISAT in several states of India. Substantial productivity gains and economic returns have been obtained by farmers (Wani et al. 2003a, b). Widespread deficiency (80-100% of fields) of micro- and secondary nutrients (zinc, boron and sulfur) has been observed in the farmers' fields in Andhra Pradesh, Gujarat, Rajasthan and Karnataka. Application of micronutrients resulted in a 20-80% increase in yield of several crops, which further increased by 70-120% when micronutrients were applied with adequate amounts of nitrogen and phosphorus (Rego et al. 2007). Thus, improved varieties along with improved management of natural resources have the potential to increase crop production in rain-fed areas of India, which need to be promoted and scaled up by the promotion and adoption of the existing 'on-the-shelf' technologies presently available.

Several studies indicate that global warming is likely to reduce 'days to maturity' resulting in crop yield reduction. ICRISAT's Integrated Genetic and Natural Resource Management (IGNRM) philosophy is to help farmers mitigate the challenges and exploit the opportunities that are posed by climate change through (i) the application of existing knowledge on crop, soil and water management innovations, and (ii) through the re-deployment and re-targeting of the already available germplasm of ICRISAT's mandate crops viz., sorghum, pearl millet, pigeonpea, chickpea and groundnut.

Simulations on sorghum at Aurangabad, Maharashtra using DSSAT software considering treatments of low input farming, improved practices, enhanced temperature and better variety have indicated encouraging results (Cooper et al. 2009) as shown in Figure 3.

A temperature increases of +3^{O}C had very little impact (145 kg ha^{-1} reduction) on the sorghum yield under low input fertilizer use as nutrient limitation remained a strongly limiting factor. Even under climate change, the adoption of improved fertilizer use (column 3) resulted in

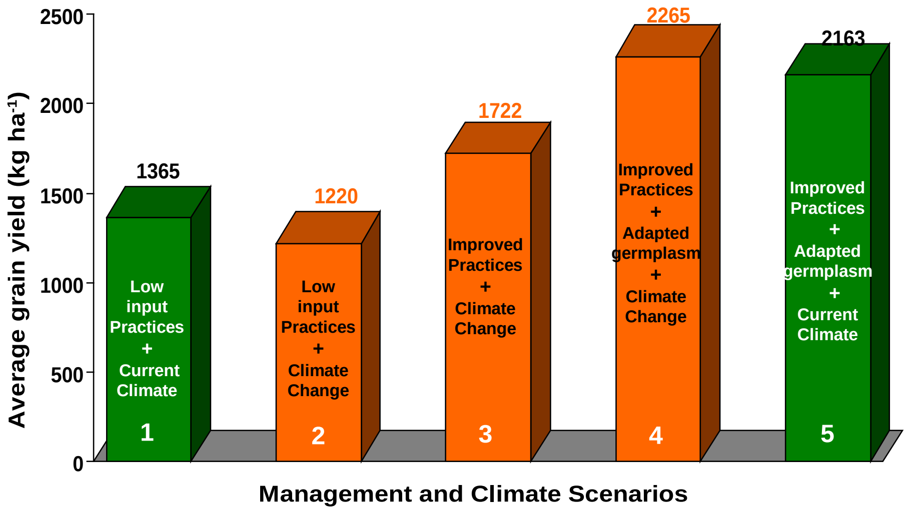

Figure 3. Sorghum yield simulations at Aurangabad, Maharashtra.

yield gains of 357 kg ha^{-1} over what farmers are currently getting under low input practices and today's climatic conditions (column 1). Perhaps the most notable result in this case is that growing the longer duration variety (Brandes), better suited to grow in a warmer world (column 4) resulted in farmers being able to achieve yields 5% higher than they could under "improved practices" with today's climate (column 5). The simulations show that the impact of climate change on the yields of low input agriculture is likely to be minimal as other factors will continue to provide the overriding constraints to crop growth and yield. The adoption of currently recommended improved practices, even under climate change, will result in substantially higher yields than farmers are currently getting. The adaptation of better 'temperature adapted' varieties could result in the almost complete mitigation of climate change effects.

Weather Forecasting and Advisories

Many a times, a great proportion of crop and livestock losses are due to direct weather effects such as droughts, flash floods, untimely rains, hail, strong winds and storms. Crop losses due to pests/diseases and in harvest and storage are highly influenced by the weather.

Agrometeorological methods have great potential in providing practical solutions when specifically tailored weather support is readily available to the needs of agriculture. They contribute towards making short-term and long-term adjustments in agricultural operations to minimize losses in agricultural production. Based on the NOAA satellite imageries received at ICRISAT in near real-time and forecasts issued by the India Meteorological Department, experimental weather advisories during southwest and northeast monsoon seasons of 2007-2009 were prepared for selected watersheds in India and shared among the watershed team at ICRISAT and watershed field personnel. It was observed that majority of these were successful in prediction and were useable.

Current issues like end-of-the-season crop yield forecasting, global warming and climatic change impact assessment, crop insurance to farming community, maintaining quality of produce to compete with international market, sustainability of the yield and environment are to be addressed. Bringing climate awareness among the rural stakeholders using new IT tools is the need of the hour.

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Advances in Geospatial Technologies in Integrated Watershed Management

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Abstract

Management and utilization of natural resources - land and water have assumed the prime importance in the wake of increasing pressure on them. In this context, the watershed approach has gained momentum all over the world for addressing environmental issues and implementing various developmental programs. Though watershed represents a hydrological unit of an area, it is also considered as a bio-physical and socio-economic unit for efficient planning and management of natural resources. These developmental activities in any watershed, focuses not only on management of rain water, reducing soil loss, runoff and increasing productivity but also focuses on social and financial upliftment of the watershed community. For an efficient execution of any activity, efficient planning is foremost.

To accomplish efficient planning, geospatial technologies like remote sensing, GPS and GIS are being increasingly used to address various aspects of watershed developmental programs namely preparation of base maps, natural resource inventory at different scales, identification of critical issues with respect to soils/water/crops, generation of action plans and impact assessment. Several studies were conducted on watershed planning with reference to natural resources and cropping systems planning. Stereo data obtained from aerial and satellite platforms play an immense role in obtaining terrain height information in the watershed. Essentially the height information thus extracted is represented in the form of Digital Elevation Model (DEM). When clubbed with drainage information, hydrological DEM can be generated which inturn is useful to delineate watersheds automatically as well as hydrological modeling of watershed. Besides, high spatial resolution data are increasingly being used to monitor various soil conservation activities, and to assess watershed performance.

During recent years, with the development of communication technology, techniques have emerged for real time field data collection and transmission, which will be of immense use for real time monitoring of watershed activities. A large network of Automatic

Weather Stations across India is being created with state-of-the-art communication tools to serve the data on web in almost real time. The revolution in electronic circuits made it possible to attach a radio to almost any electronic device and remotely communicate with it. This has ushered new ideas of developing sensor web where these sensors can communicate with each other and use the information intelligently as a single system. The sensor network can function independently and collaboratively to provide parameters need to measure in the field. By adding machine intelligence, these networks can perform important field decisions automatically. The developments in micro/ nano satellites and their networking with ground based sensors; the data can be used for real time applications in watershed management. Further, Geoinformatics and web GIS tools can bring major impact on the watershed management.

Introduction

In recent years the watershed has become a practical planning unit for transfer of rain-fed agricultural technology from lab to land and for formulating the various developmental programs to improve the crop productivity, conserve soil and water resources and minimize land degradation (Bharadwaj, 1982; Bonde, 1985). The watershed approach is more rational because the resources of land and water have optimum interaction and synergistic effect. The advances in technology front like remote sensing, GIS, portable devices, instrumentation and communication devices play a very crucial role in providing base information as well as for day-to-day management in watersheds.

Watershed management has been defined as 'the integrated use of land, vegetation, and water in a geographically discrete drainage area for the benefit of its residents, with the objective of protecting or conserving the hydrologic services which the watershed provides and of reducing or avoiding negative downstream or groundwater impacts'. It has played a prominent role in rural development efforts in many countries in the last several decades, helping to increase rural incomes, augment usable water resources, improve productivity and mitigate droughts (Wani et al. 2008). It 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 like control of soil erosion and land degradation or reclamation and rehabilitation of waste/degraded lands or landuse revisions consistent with land capability or management of croplands, grasslands and forests or management of water resources.

Watershed is an entity consisting of various stakeholders like farmers, land owners, scientists, administrative officials at various levels of village, district, state and central government, local business personal, water authorities, home owners, pollution authorities, environmental activists, NGOs, conversationalists, mass media, civic self-help groups, etc. Each of the stakeholders has a definite and responsible role to play in the overall development of watershed. For a balanced approach in the watershed development, all these stakeholders have to be involved at planning level for the smooth and efficient execution of the work in a timely manner. After understanding the requirements of these 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 citing of 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 on natural resources, physiography and socio-economic data to assess the problems and prospects of the watershed. For this, the role of modern technologies like remote sensing, Geographic and Information System (GIS), internet, portable electronic devices, electronic sensors and communication devices are vital in the total program planning and execution. The role of these technologies in the sphere of watershed management is discussed in this article.

Modern Tools for Watershed Management

Remote Sensing

Satellite remote sensing started in the early seventies, has undergone significant improvements in sensors spatial spectral, temporal and radiometric resolutions. The satellite images resolution increased from

80 m (coarse resolution- Landsat-MSS) in seventies to 20 - 36 m (medium resolution - SPOT-MLA / Landsat-TM / IRS-LISS II) in mid eighties to 0.68 – 5.8 m during late nineties (high resolution - Quick Bird – PAN, MLA / IKONOS / IRS-PAN, LISS-IV,Cartosat-1,2). Commiserating with these developments, the application of satellite data has changed from watershed level (to sub-watershed and micro-watershed level (Table-1).

Table 1. Suitability of various IRS sensors in watershed studies.

Sl. No	Level of study	Suitable spatial resolutions	Sensors	Application potential
1	Basin level (1:250000 scale)	50 to 150m	IRS-WiFS, AWiFS, LISS-1	Deriving overall base information on natural resources and land cover; large scale monitoring of changes.
2	Watershed level (1:50000 scale)	20 to 50m	IRS-LISS-III, SPOT-MLA, TM, ETM,	Deriving natural resources information for watershed prioritization, planning, monitoring
3	Sub / micro-watershed level (1:10000 or larger)	0.5 to 20m	IRS-LISS-IV, SPOT-PLA, Cartosat-1 / 2, IKONOS, Quick Bird, Worldview-2.	Execution planning, monitoring watershed developmental activities, detailed account on changes happened. Stereo data for DEM generation.

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 (DEM) models for the watersheds which include indispensable 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 HRS imagery are absolute planimetric accuracy 15 to 30 m and absolute elevation accuracy 10 to 20 m (Annon.2004). In Cartosat-1 DEM 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 the development of watersheds. The geometric accuracy and information content of ortho-images and DEM provided by the CartoSAT-1 Mission can be used for delineation of watersheds boundaries at 1:25,000 and 1:50,000 scales, generation of contours at 10m interval 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 enable generation of DEM with centimeters accuracy under ideal condition. This sort of data is being used for canal and other fine spatial alignment planning works.

The high-resolution (< 6 m spatial resolution) satellite imagery (IRS-LISS IV/ Cartosat-1&2 /IKONOS/quick bird) will be very useful for sub-watershed/micro-watershed level applications like mapping infrastructure (roads/drainage network), natural resources inventory (crops/soils/ground water potential), water resources (water bodies/ natural springs/ponds), land use (single cropped areas/double cropped areas/waste lands/ fallow lands/forest cover at level 4), etc. They can be employed for disaster management at block/village level like drought or flood damage 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 agro-climatic zones in our country.

Advancements also took place in spectral resolutions ie., 4 spectral bands (Landsat– MSS/ IRS-IA/1B, SPOT) to 7 bands (Landsat-TM) to 14 discrete spectral bands (ASTER). Simultaneous developments in ground based observations realized the importance of recording data in numerous narrow spectral bands and led to the development of satellite based hyperspectral remote sensing (Hyperion/HySI). The hyperspectral data will provide unique capabilities to discern physical and chemical properties of natural resources otherwise not possible using broadband multispectral sensors. Some of application areas in agriculture are crop stress (moisture/pest/nutrient) detection, yield prediction, soil quality and agro-environmental health assessment.

Geographic Information Systems (GIS)

Watershed level planning requires a host of inter-related information to be generated and studied in relation to one another. Remotely sensed data provides valuable and up-to-date spatial information on natural resources and physical terrain parameters. Geographical Information System (GIS) is a very powerful tool for arranging and storing spatial and tabular data in a structured way. This is a very useful and essential tool in the planning and development of watersheds embracing all natural and socio-economic facets. GIS has been used in the development of digital database, assessment of status and trends of the resources of the areas 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.

During the initial phases of development, GIS has been extensively used for data conversion/ digitization of paper maps, storing and generating map prints with little focus on spatial analysis. With the advent of time, the scenario changed drastically wherein the spatial analysis took the pivotal role in watershed planning. GIS also facilitates modelling to arrive at locale 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. Now the present GIS technology enables 'map any where and serve any where'. With recent developments, there is a leap in the development of spatial analysis tools and logical processing methods. This enabled the development of numerous spatial algorithms, spatial modelling techniques and better display and visualization of data. One such application that harnessed the benefits is watershed planning, where in these techniques were efficiently used for land resources as well as water resources planning, watershed prioritization and monitoring.

Besides, generation and spatial analysis of data, the important facet of this information is public outreach. Till recently, this spatial information was limited to cupboards of a few people. Now with the availability of RAID/BLADE servers, gigabit data transfer capabilities and Mbps internet speeds data can be served at faster rates. The out reach to outside world has improved tremendously. Now the spatial data with on-the-fly spatial analytical capabilities is being served over internet. One such initiative by NRSC/ISRO is **Bhoosampada**, where in the natural resources information along with base details and the latest thematic information is being served though internet GIS. It has a provision to spatially analyse 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.

Field Sensors and Data Communication Devices

In watershed management, one of the important components is the collection and sharing of field data or ground information and integrating it into the processing; and the analysis of spatial data in real time helps in timely decision making and taking up appropriate corrective measures. The collected field data represents the actual ground situatio nvery accurately in real time as well as in the temporal context as well. Field data collection typically consists of recording geographic location, photographs of the area at the sample points, notes on soils/crops/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 quite 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 complete before starting to use the 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:

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

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 alternative to get detailed weather information in the area of interest. AWS records data on parameters like 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 and housed in a portable and self contained package. The AWS system consists of a compact data logger, data transmitter, antenna, GPS, solar panel and sensors. The power requirements are minimum and hence do not pose any operational problems. The sensors on AWS collect data on specified time interval and store the data in its memory. The logged weather data will be transmitted in its prescribed time slots, through geostationary communication satellite systems. The transmitter, data logger, power supply and battery are housed in a weather-proof enclosure.

The AWS data find extensive applications in agricultural monitoring – drought / crop condition assessment, crop management, disaster management – flood forecasting and in other fields like transport. Almost real time information on meteorological parameters and crop parameters like soil temperature, leaf wetness allows the calculation of water requirements of crops and hence invaluable for in season drought management. Incidentally, it is also planned to integrate the relevant spatial and non-spatial information of natural resources and socio-economic aspects related to agricultural drought towards generation of a spatial decision support system. Data from AWS is expected to contribute towards value addition of the drought assessment in the current season in a near real time mode.

Mobile devices that are of interest to the field data collection process are - Personal Digital Assistants (PDAs) and cell phones. PDAs are basically palm-size devices that 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 like Windows adapted to these devices. Thus, desktop applications (word processing, spreadsheets, email clients, web browser, etc) have been made available on PDAs also. Thus, this forms a handy device to record and store field information in an organized way.

Cellular phones*,* on the other hand evolved form being primarily wireless voice communication devices to encompass various features like organizer, messaging, camera, music player and Bluetooth connectivity. Over time, with many other features like larger screen, custom applications deployment and web browser, they became powerful tools. The integrated mobile devices are also commonly equipped with a digital camera, which can be used to capture necessary field photographs also from the same device and store them on the device. 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 very 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 to input data ina convenient way. With these powerful configurations, it is possible to deploy rich GUI applications, which would have been difficult a few years ago.

Data Storage and Dissemination

Latest development in ***Server technology*** enabled availability of blade servers with RAID capabilities at a very cost effective price. These servers act as store houses for storing the data in a safe and efficient way, and can serve to clients via network sharing and World Wide Web, in almost real time.

Internet is 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 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.

Spatial Technologies in Watershed Management

Baseline Studies

Accurate delineation of a watershed plays an extremely important role in its management. The delineated boundaries form the nucleus around which the management efforts such as land use, land change, soil types, geology and river flows are analyzed and appropriate conclusions drawn. Digital elevation models (DEM) provide good terrain representation from which the watersheds can be derived automatically using GIS technology. There are various data sources for generation of DEM. Usually, the height contours mentioned in topomaps 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 direction, satellites like IRS-1D and SPOT acquired data across the path leading to temporal variation in terrain radiometry, which leads to poor DEM accuracy. 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 have greatly improved throughout 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-eighties and have been implemented in various GIS systems and custom applications (Garbrecht and Martz 1999). Fig-1 portrays the Cartosat-1 data and the DEM derived there from along with LISS-IV multispectral data. In this figure the perspective view generated from the above DEM draped with LISS-IV multispectral data is also presented. 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 need to be filled for sinks such that the runoff should be accumulated as a concentric flow and should pass through one of the outlets.

Watershed characterization involves inventorying and assessment of natural resources, which are essential pre-requisites of any watershed management activity. For example, watershed mangers need timely and reliable information on soils, crops, ground water potential and land use. Similarly, an assessment of the properties of the soils and their response to management is required in agricultural 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).

Prioritisation of watersheds helps in focusing the implementation activities on a few watersheds that urgently need attention. Watershed

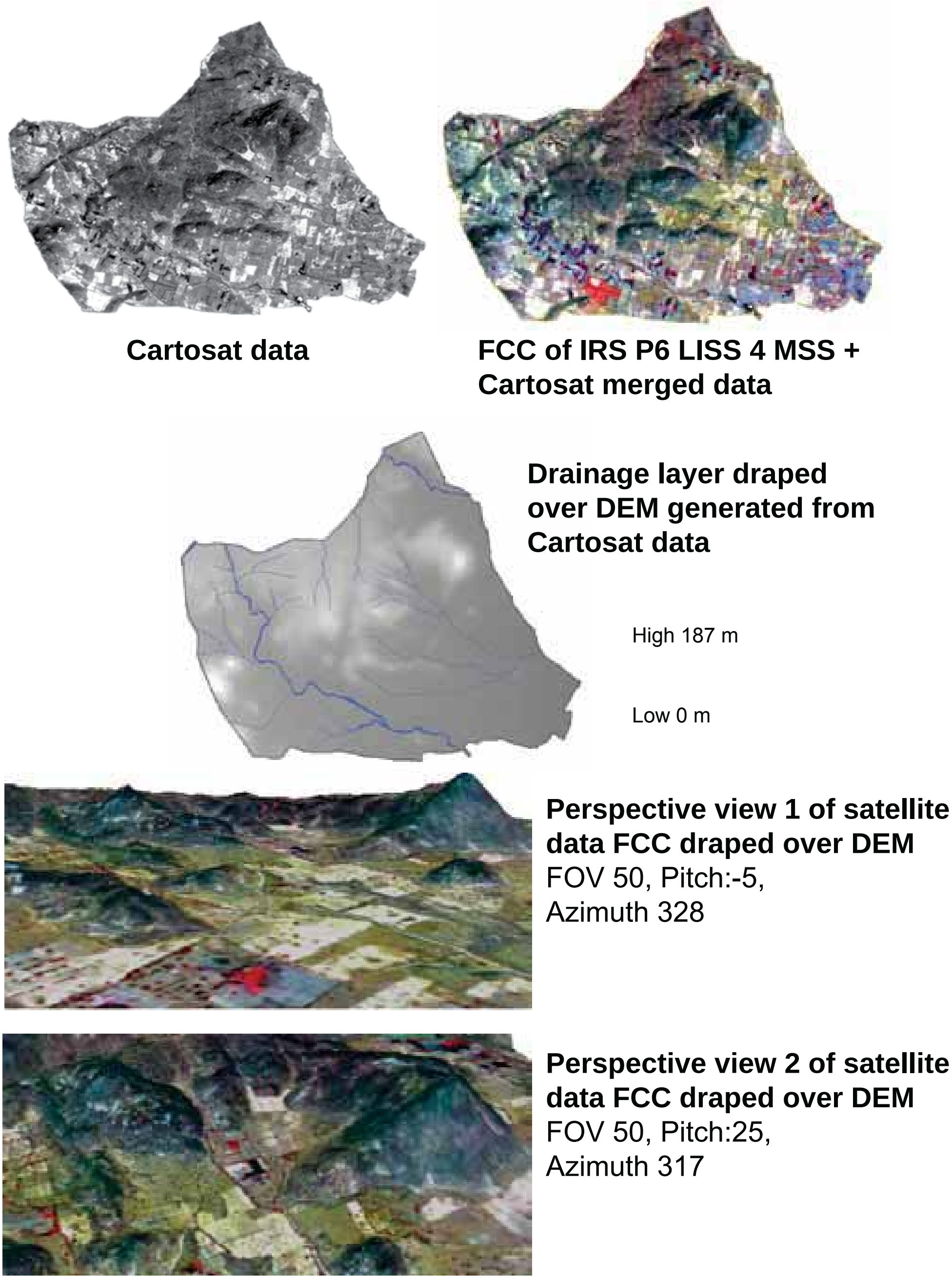

Figure 1. Satellite data and DEM for perspective view of watershed in part of Nalgonda district, Andhra Pradesh.

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 by the limited financial resources available for implementation over the entire area. Remote sensing derived inputs were considered for prioritising the watershed when it is based on natural resources limitations or potentials in a watershed (Sharma 1997, Khare et al. 2001, Sekhar and Rao 2002, NRSC,2006 ; Rao et al. 1998, Saxena et al. 2000).

The prioritization of watersheds in India is on the basis of natural resources status, socio-economic, biophysical and other criteria. During the 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 modelling (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 socio-economic conditions (agricultural laborers/SC, ST population/distribution of BPL families) were considered for prioritization. Geospatial data and multi criteria based prioritization of watersheds helps 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 has been successfully used to establish a strong baseline information system and prioritization (Khan et al. 2001, Thakkar and Dhiman 2007, Diwakar and Jayaraman 2007).

The success of the 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 Geographic Information Systems have really enhanced potential of remotely sensed data in identifying suitable locations for conservation measures. The repetitive nature of satellite data enables change monitoring and assists in understanding the effect of the management activity undertaken. Projects like Integrated Mission for sustainable Development (IMSD), National Agricultural Technology Project" (NATP), and Sujala demonstrated the operationalization of remote sensing in the sphere of watershed management, ranging from resource appraisal to implementation and monitoring (NRSA, 1995; NRSA, 2002). Remotely sensed data acquired from satellite has been used as a tool to detect, monitor and evaluate changes in the treated watersheds. The satellite images of watersheds acquired during pre and post treatment periods have offered a rich source of information about the status and conditions of the resources on the watershed landscape. Remote sensing change detection processes involving digital analysis of satellite data and its comparison has given insight into the land use/land cover changes in the watersheds over time. The analysis of landscape elements and its spatial structure in the watershed reveals information on the process of land cover changes (Chakraborty et al. 2001). The parameters have been considered for monitoring and evaluation purpose, which can be derived from satellite data are cropped area, cropping pattern, plantations, change in areal extent of wastelands, changes in land use, change in number and areal spread of water body and biomass (canopy cover/productivity).

Watershed Monitoring

Temporal resolution of spaceborne sensors enables to repetitively cover the same watershed at regular time intervals to detect, monitor and evaluate the changes in the treated watersheds. The satellite images of watersheds acquired during pre- and post- treatment periods have a rich source of information about the process of the implementation of the program and its impact. Changes like increase in crop land, clearing of natural vegetation, change in surface water spread/levels, afforestation, etc., could be monitored using temporal satellite images.

Technology Integration

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

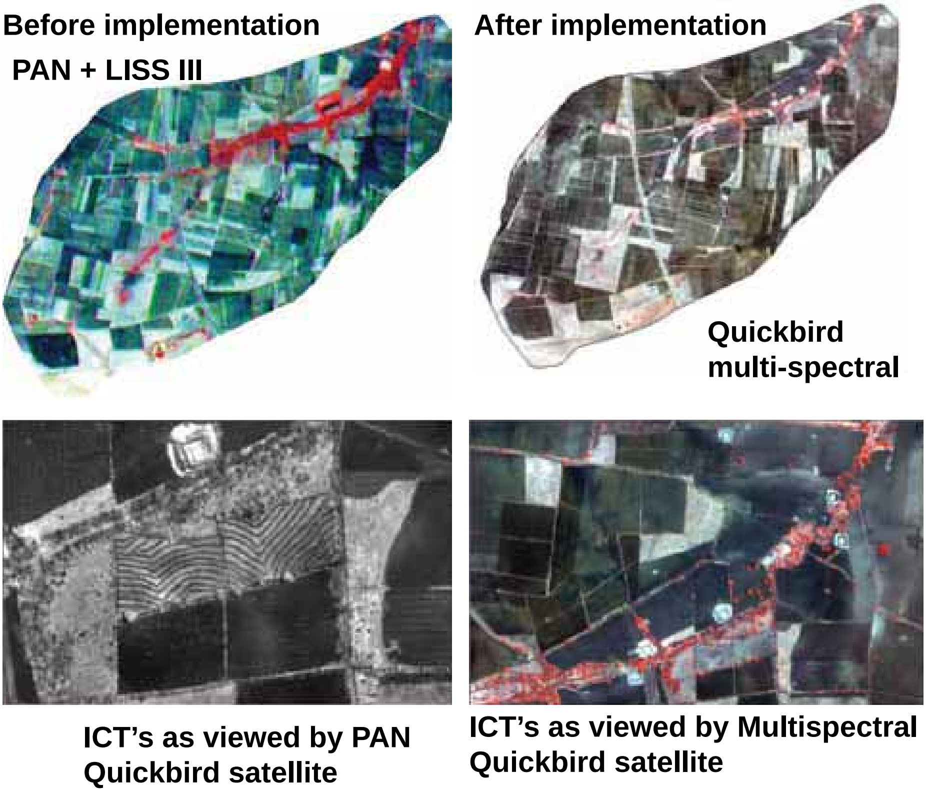

Figure 2. Monitoring microwatershed using high resolution satellite data.

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

Field Data Transmission

Even though the field data collection methods make use of IT (information technology) 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 revolution in technology front, 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 (Fig. 3).

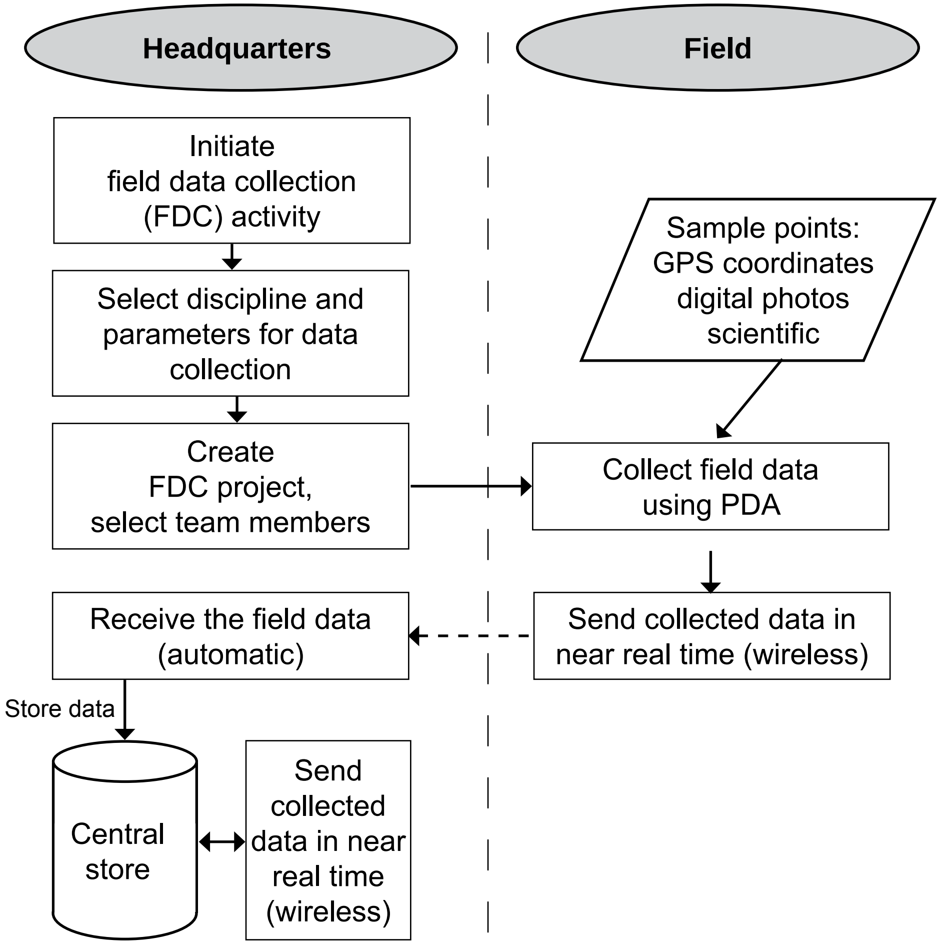

Figure 3. Total solution to field data collection system.

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 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.

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 in 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 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 with sensor web is that, the sensors could be placed in very remote and harsh environments, where it could be very difficult to collect data under direct human supervision. Further, the data could be collected in a continuous way and could be delivered to 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 the 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 for the 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.

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 above goals. They can enhance the impacts of agricultural research in watershed development. Simulation modeling using the surface and ground water 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 the long-term impacts of various management options on carbon sequestration, environmental balance, land degradation, etc. could be assessed using simulation modeling approaches, which otherwise is not possible using conventional approaches on a routine basis (Sreedevi et al. 2009).

Temporal satellite data acquisition during crop growing season enables to monitor the crop growth with the help of biophysical parameters like LAI (leaf area index), soil/crop moisture, NDVI, etc., and when coupled with spatio-dynamic modeling facilities in GIS scenarios generation, it is quite possible to use them for crop intensification and but also enhanced the sustainability of the systems. There is a need to incorporate these dynamic parameters in refining prioritized watersheds for effective utilization of resources.

The 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), Soil 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, potential evapotranspiration (PET), radiation, temperature, wind velocity, length of growing period), 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. In this aspect the Sensor Web, GPS and communication networks have greater role to play.

Intelligent Watershed Information System

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

To achieve this, initially a semantic network could be generated keeping the goal and objectives of 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 scheme towards achieving an Intelligent Watershed Information System (IWIS) for effective watershed management has been appended as Fig 4. The decisions generated from above system have to be communicated to the stakeholder (farmers/extension staff) in a reasonable time frame.

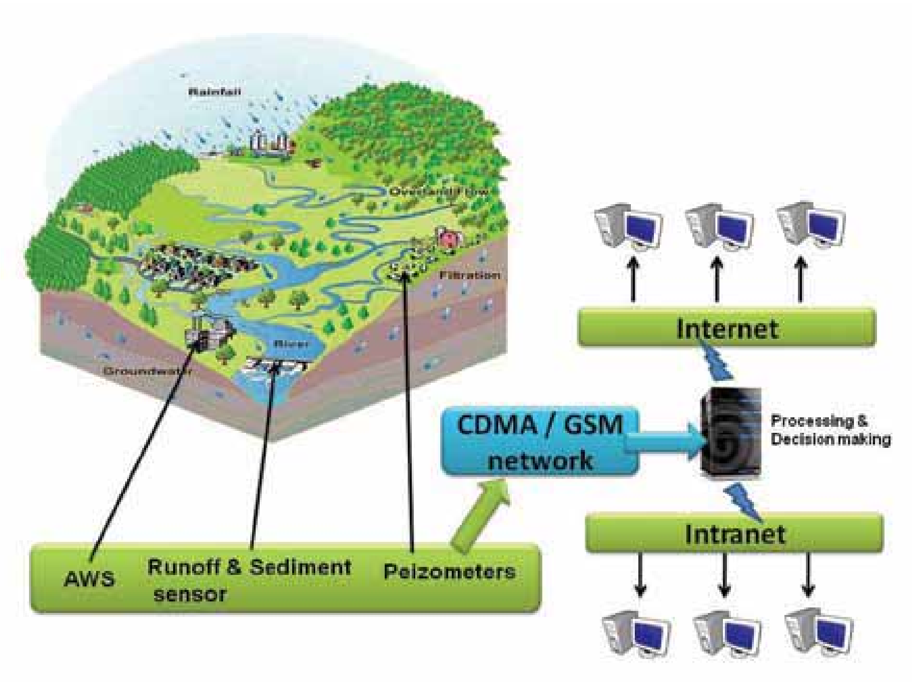

Figure 4. Technology integration for watershed management.

Conclusion

The remarkable developments in space technology currently offers 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. Further, such data could be of immense help in tracking the implementation, apply 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 complementary 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 though collaborative efforts between various line organizations.

A lot of developments taking place in technology front help greatly in making a leap forward in the direction of effective watershed management per se. Advancements in various technological, scientific, modelling, communication and data dissemination fronts should be integrated on to a seamless platform to develop an Intelligent Watershed Management System (IWMS).

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GIS-based Monitoring Systems for Integrated Watershed Management

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Abstract

Integrated Watershed Development (IWD) has been in practice for a very long time and it has received special attention in the recent past with the advent of technological tools for planning, implementation, monitoring and impact studies. IWD itself has gone through varieties of changes in the approaches for development and implementation and so is the case with respect to the possible use of technologies. Of late, the use of space based inputs from remote sensing and Geographic Information System (GIS) technology have helped IWD directly. Satellite remote sensing is particularly of significant use in characterizing the terrain, understanding the existing landuse, generating soil maps, estimating ground water/water resource potential and finally integrating all these under the geospatial domain with base layers and other infrastructure layers. Such an integration of multi-thematic GIS layers with socio-economic data and ground knowledge helps in deriving action plans, which could be a guiding factor for further implementation at grass roots. With the availability of very high resolution satellite images and hence large scale thematic mapping possibilities, it is even possible to address developmental aspects at farmers' field level through cadastral overlays. Such attempts have been made not only for providing locale specific action plans for IWD, but also for systematic monitoring and management. The advantage of using such techniques is in bringing about greater transparency amongst implementers and other stakeholders, which in turn helps in better execution, thus resulting in optimal benefits to the farming community.

Close monitoring of IWD programs need many parameters/indicators to be studied in detail throughout the project lifetime. While some of the parameters/indicators are amenable through Management Information System (MIS) databases, the others are obtained through GIS technology. With the availability of connectivity from the field level (villages) through taluk, district and state level users, it is possible to establish web-based information and decision support systems

for closer and effective monitoring of such developmental programs. Specific software tools and techniques for locale specific action plan preparation (also popularly known as DPR preparation at sub-district level in a state), web based GIS and MIS tools for on-line project monitoring and multi-temporal remote sensing data for impact assessment have been successfully used as in watershed development programs of Karnataka. Considering the success achieved in this program, similar attempts are being extended to a few other states in the country. Innovative use of space inputs, information technology and GIS has helped in successfully testing such technologies under operational scenarios. It is now required to emulate more such projects and also integrate such tools and technologies at national level programs like Integrated Watershed Management Program of DoLR, MoRD and other Central and state ministries to improve the efficiency and derive better results while helping in providing rich benefits to the grass root level farming community.

Introduction

Conservation of Natural resources, particularly in the rural areas, is of priority for addressing various issues in a developing country like India, which hosts one of the largest human populations of the world. Such conservation measures could be successful by suitably adopting watershed development programs, particularly in arid, semi-arid and dryland farming areas, with active participation by local communities through many government-sponsored schemes. Many attempts are made to implement such programs by adopting typical conventional methods across the country in the past. Such participatory approaches are focused on mobilizing the farming community to collectively take up measures to conserve the soil and water resources in their respective watersheds. The idea here is to adopt control mechanism to limit the runoff potential of the soil, based on terrain conditions, that ultimately drains to a common point by designing locale specific approaches through community participation. The green revolution that transformed agriculture in India did not significantly impact rain fed agriculture in the arid and semi-arid tropical regions, which experience low agricultural productivity, degraded natural resources and have poor people. The rain fed areas experience high degree of land degradation and suffers from low and uncertain rainfall, poor soil fertility, sparse vegetation cover, low productivity, lack of infrastructure. Majority of the people of these areas have limited access to primary education, basic health care, clean drinking water, poor food and livelihood conditions. Present day world has a special focus on optimal management of land and water resources with an approach of integrated mission of economic development, equity and environmental soundness, evolving multi-pronged strategy of sustainable development with special focus on poorer sections of the society and regenerating the eroded natural resource base. Watershed development is gradually evolving into a comprehensive program with simultaneous pursuit of biophysical and rural development objectives that promote rural livelihoods.

To make such programs more acceptable, simple and adaptable, a set of innovative methods have been devised and field-tested with significant success. Use of EO data with respect to pre-specified time frame, image analysis, new software tools and geospatial databases for participatory watershed development program is demonstrated using a watershed development project of Karnataka Government. Attempt has been made to use an optimal combination of earth observation inputs, field observations and Information Technology for planning in implementation, monitoring and impact assessment.

Community Participation in Watershed Development

Community based organizations, their activities, involvement in various local level processes and societal issues have recently become important subjects of GIS research (Obermeyer 1998). Watershed development is a well-accepted method of treating land through scientific means for sustainable development of natural resources (Diwakar et. al. 2004). Watershed is a typical polygon, in GIS terms that connects similar elevation points or ridge tops towards a common pour point or water body depending the slopes and gradients of the terrain, which is amenable for conservation and protection from erosion and runoff. Different methods, suitable to locale specific conditions, have been practiced for ages across the world, which involves treating land on a ridge-to-valley basis to restore equitable use of soil and water resources in a given terrain. Typical parameters that are important and needs consideration for watershed development are land belonging to farming community, common land or government land or others sharable by the village community, livestock, fuel and fodder areas, tanks and water bodies, waterholding structures, socio-economic conditions of landless labourers, infants and so on.

Newer techniques involving space imaging, extraction of natural resources information, GIS for data integration and modeling, providing extract of such processing in the form of land and water resources plans, tools from Information Technology for monitoring and impact assessment could make significant difference in successful implementation of watershed development. Such techniques have been successfully been implemented with specific customization efforts to adapt to the local context with significant impacts.

Study Area

The proposed space imaging and GIS techniques are successfully tested under project Sujala, a participatory watershed development program of Government of Karnataka with World Bank assistance in five districts, viz., Kolar, Tumkur, Chitradurga, Dharwad and Haveri. The project was implemented across 77 sub-watersheds covering an area of about 0.51 million ha and benefiting about 400,000 households for a span of about seven years.

The major objective of the project was to improve the productive potential of degraded watersheds in dry land areas and poverty alleviation. The project being a community driven program, the village people were involved in participatory planning and decision making including implementation and maintenance of assets.

Geomatics as a Solution

Space imaging from Remote Sensing platforms, GIS technology and near real-time Management Information System embedded with GIS solutions are developed and used for participatory planning process. There are the core areas of technology utilization for resource mapping, database generation, analysis and information extraction for watershed planning, implementation and monitoring. High resolution satellite data with a spatial resolution of 6 meter has been utilized to generate maps on 1:12,500 scale for varieties of themes. Typical areas of technology utilization under the project are:

- watershed prioritization;
- resources inventory and mapping;
- land and water resources action plan;
- sSite selection for implementation;
- web based management information system (MIS) solution;
- GIS based action plan development;
- implementation monitoring;
- impact assessment;
- post project evaluation;
- run off estimation by imperial methods;

Remote Sensing for Planning

Data from Indian Remote Sensing satellite proved to be effective in capturing varieties of field realities during various stages of project implementation, including the pre-project phase. With the availability of high resolution space images, RESOURCESAT and CARTOSAT, there has been a significant shift in the way the technology is used for monitoring. LISS 4 multispectral images (5.8 m) and high spatial resolution CARTOSAT 1 PAN (2.5 m) could be effectively used to carry out an on-line tracking of the various developmental works on a near real-time basis. High resolution image data are used, not only for facilitating the farming community to take up technically sound decisions for watershed development, but also for monitoring such implementations. The usage of data from space was facilitated by generating special products through image fusion, natural color composites, landuse classification, change detection and other GIS layers to aid in locale specific action plan preparation (Chen and Tsai 1998). Geospatial layers at high resolution was created and integrated with parcel data to aid in scientific planning of watershed interventions in private and common land developments. In addition, such high-resolution data from EO satellites was also used for bringing out short term and long-term impacts at local level. Availability of such high spatial resolution data from IRS satellites has brought about required transparency and unbiased field-level assessments in a cost-effective manner. The unique combination of sensors available from IRS P6 satellite has brought about unique possibilities of providing geospatial information on the field realities as required under the project. While AWifs sensor with 55 m spatial resolution could help in faster repitity and wide coverage of the entire area, LISS 3 could be used for thematic mapping at 1:50,000 scale for establishing medium scale database for study area at district level. However, LISS 4 and Cartosat 1 data was further used in combination at better than 1:10,000 scale for providing specific decision making capabilities at locale level.

Sampling Strategy for Baseline

It is essential to identify the indicators and create baseline information system, which involves both natural resources information and parameters related to socio-economic situation at village level. This would be a good reference for subsequent evaluation and other monitoring works. Simple GIS and IT tools at microwatershed level has been successfully used to establish a strong baseline information system and database elements under the project. Also, the sampling procedure and strategy for obtaining regular data from the field has also been well thought of. A well defined field data collection procedure, to establish baseline database for the study area, has been adopted through multistage sampling approach (involving stratification criteria, randomization, area based sampling with probability proportion to size) that uses criteria which is an optimum mix of natural resources and socio-economic parameters. The sub-watersheds are randomly selected based on their agro-climatic conditions, status of land use and soil. Within each sub watershed, micro watersheds are selected at random, representing ridge, middle and valley portions. Households are further selected and randomly sampled based on land holding class, i.e., marginal, small, big and landless using Probability Proportion to Size (PPS) criteria. To achieve acceptable accuracies of estimates, a 10% sampling intensity is considered for data collection and analysis (Fig.1).

Benchmark survey is carried out to collect data and information on

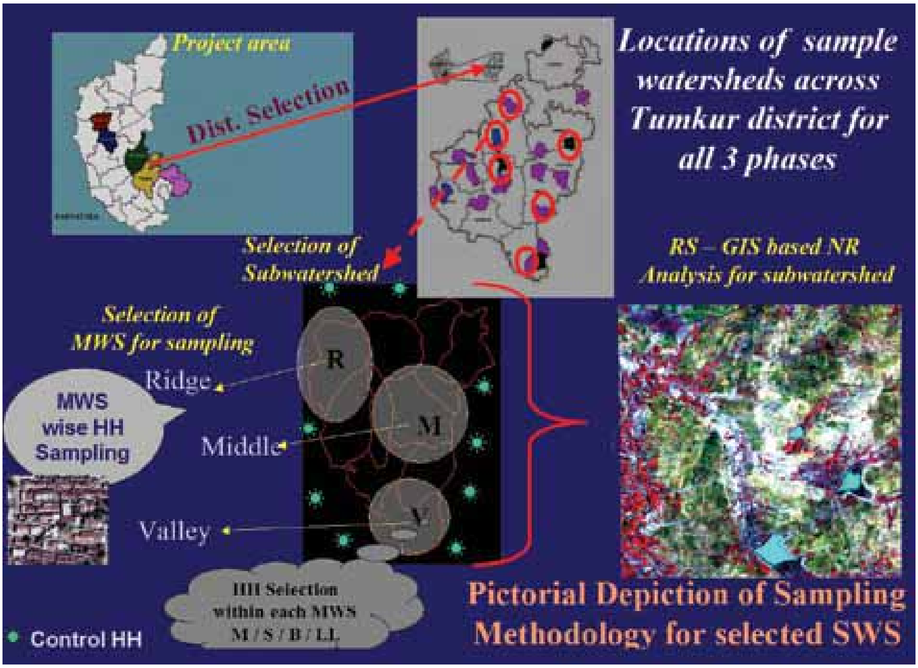

Figure 1. Pictorial view of data collection and analysis.

the pre-project status of the community and natural resources. This information helps in monitoring the project at various stages and to assess the changes in the project area (Sander 1997). A combination of conventional and remote sensing approaches are utilized to generate benchmark data.

Geoinformatics for Natural Resources Information

The technique based on EO inputs has tremendous potential to not only establish a strong baseline on natural resources but also to provide critical inputs for on-line monitoring of the implementation works. This type of possibility has given a big boost in the area of project monitoring by bringing about transparency in project implementation and peoples' participation at grass roots.

High-resolution satellite images have been processed and provided at large scale to the village communities involved in watershed development to help them understand the locale specific nature of the terrain for better planning and management of natural resources. Image fusion and natural color composite based product generation techniques were successfully employed to make the basic satellite images community-friendly. Image fusion is extensively used to take full advantage of high-resolution geometry of the pixel and the optimum spectral mixing of the multispectral component to produce best possible output. It was discovered that for preserving spectral characteristics, one needs a high level of similarity between the panchromatic image and the respective multispectral intensity (Andreja and Kristof 2006).

Varieties of image fusion methods have been used in the present study amongst some of the popularly used techniques, such as, IHS, PCA, Broovey's method, Discrete Wavelet Transforms, adaptive linear band combination and so on. However, these techniques depend on the inter-band correlation existing amongst the multispectral channels to appreciate the results. Multispectral transformation techniques are adopted to generate natural color composite images by establishing a relationship between the spectral bands producing false color composite with that of true color composite.

These images and other ancillary data have been analysed and integrated under GIS to generate various types of resource maps, viz., land use/land cover, soils, slope, hydro-geomorphology, drainage, transport network, settlements, land parcels, etc., at the micro-watershed level. These maps play an important role in understanding the spatial nature and interrelationship that exists between different resources. From a practical point of view, a high-resolution satellite image depicting terrain in true color could be the most comfortable one for conventional interpretation and visualization (Chen and Tsai 1998). Locale specific action plans for sustainable development of land and water resources are generated on micro watershed basis by integrating thematic information from the resource maps, peoples' aspirations and socio-economic inputs with special emphasis on community needs (Fig. 2).

Such action plans, prepared through community participation, basically address private lands (the land belonging to individuals in the villages) and common lands (the government land utilized by the village community). These plans are basically the recommendations

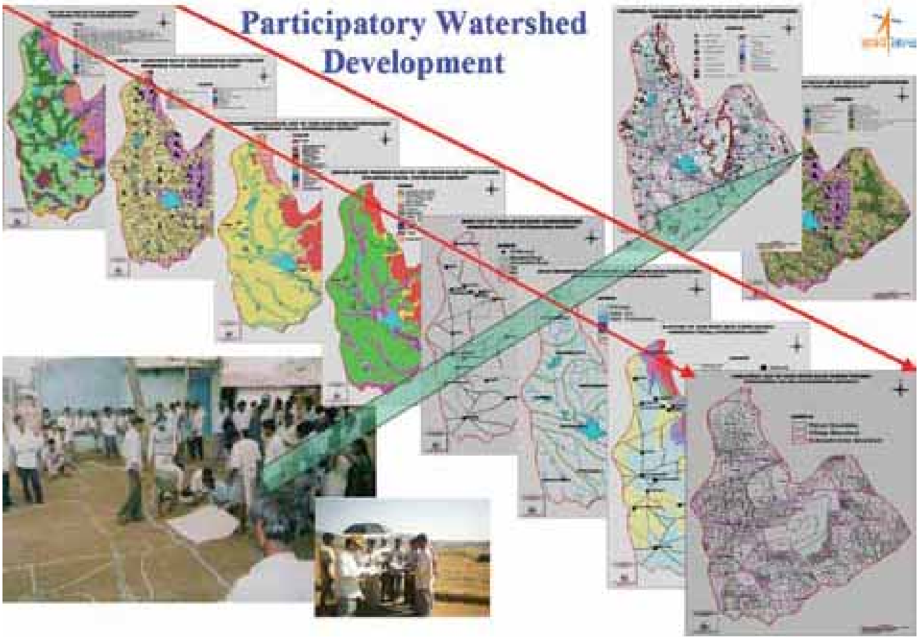

Figure 2. Geospatial data layers for participatory action plan preparation.

towards improved soil and water conservations for ensuring enhanced productivity, while maintaining ecological/environmental integrity of the micro-watershed. The action plans also address the identification of sites/areas for surface water harvesting, ground water recharge, soil conservation measures through check dams, vegetative bunding, sites, etc. It also specifies sites for improved/diversified farming systems with fodder, fuel wood, agro-forestry, agro-horticulture, etc. These action plans are generated jointly by watershed department experts (agriculture, horticulture, animal husbandry and forestry) field NGOs and beneficiaries. While all the land-based activities under such plans address the marginal, small and big farmers, the landless people get the benefit of the income generation activities (IGA) mostly focused on self help groups (SHGs). District resources group (DRG) scrutinizes the action plans technically before the approval of zilla panchayat (local body for decision making) for implementation.

Keeping these points in view, it was decided to customize specific GIS and IT tools in a simple-to-use form for the community to adopt at the local level. A simple GIS tool to help prepare parcel-level watershed

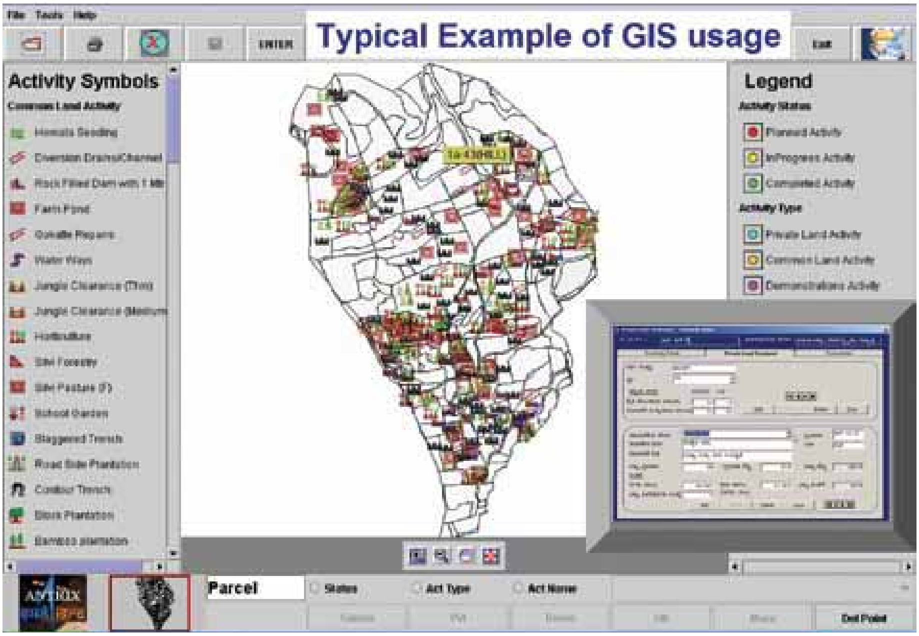

Figure 3. Community level GIS Technology for PRA and action plans.

development plan through a participatory rural appraisal (PRA) process is developed and at the same time an MIS engine is also customized to capture details at beneficiary level on all aspects of watershed development in local language (Fig.3).

The impact of such a tool has been quite significant at the village level, and also for the project implementing agency. It has brought about transparency in the project as these databases serve as the basic information for wall-paintings in the villages, the entire community know the contribution of the project and their share for implementation, NGOs facilitating such an activity at the community level find it easy to monitor all activities with ease, the project authorities are able to quickly prepare the yearly logical action plans for monitoring, conduct enables many technical evaluations like, equity, inclusiveness, gender sensitivity, environmental and social assessment of action plans, etc., before approving the action plan for implementation.

Web-based Solution for Monitoring

The project is implemented at about 742 microwatersheds across five districts in Karnataka. Concurrent information on the status of implementation at each microwatershed is required on a continuous basis for monitoring and management of various resources under the project. This calls for a systematic compilation of information at each microwatershed and made available at Subwatershed, district and state level for management at different levels of hierarchy. Such a requirement is facilitated by adopting simple web-based MIS, which enables data flow across the different stages of decision making. The web-based MIS–GIS tool enables data capture on implementation of action plan, social aspects, and income generation activities. This model of data compilation and synthesis has proved to be highly successful and facilitates smooth monitoring of the project at regular fixed intervals. The package is browser based customization on the client side with server component handling the computational load. Following illustrations provide details of the working MIS-GIS model (Fig. 4a).

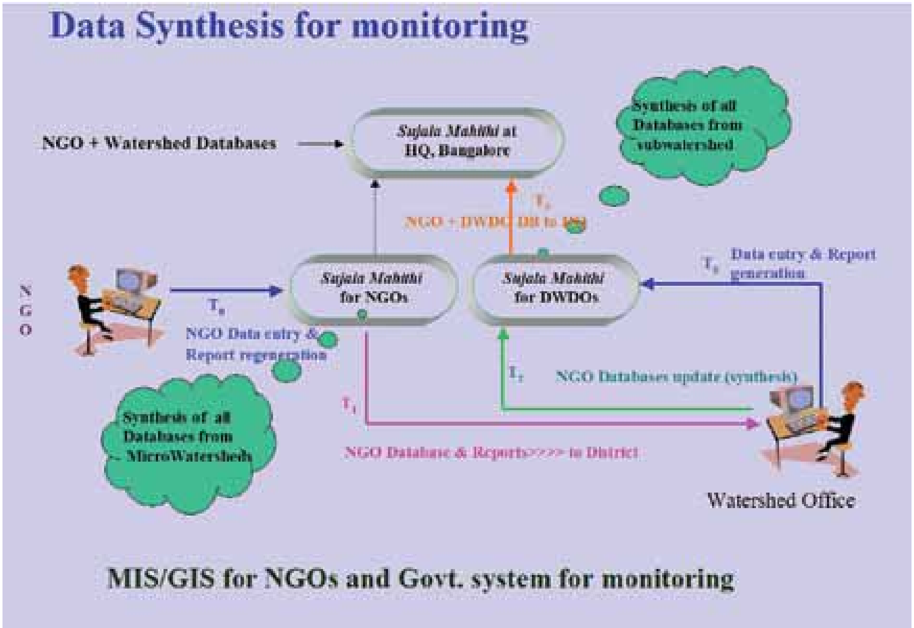

Figure 4a. Package architecture and database synthesis - web-based model.

A wealth of data exist from the field for effective monitoring and carrying out specific analysis with respect to the key performance indicators of the project. The data flow from the field level is regularized with respect to weekly inputs and the same is used at all levels for online interactions through audio conferences. A typical example of how proper data flow could empower planners and managers to effectively carry out monitoring for administering midcourse corrections are well demonstrated (Fig. 4b).

The package enables wide variety of report generation on all aspects of the processes undertaken in the project and also provides variety of graphics and analysis functions as value added tool. Other unique feature of the package is the possibility to have access to GIS maps through WebGIS technology with MIS reports and graphs to provide a spatial dimension for monitoring and management of the project more efficiently (Fig. 5).

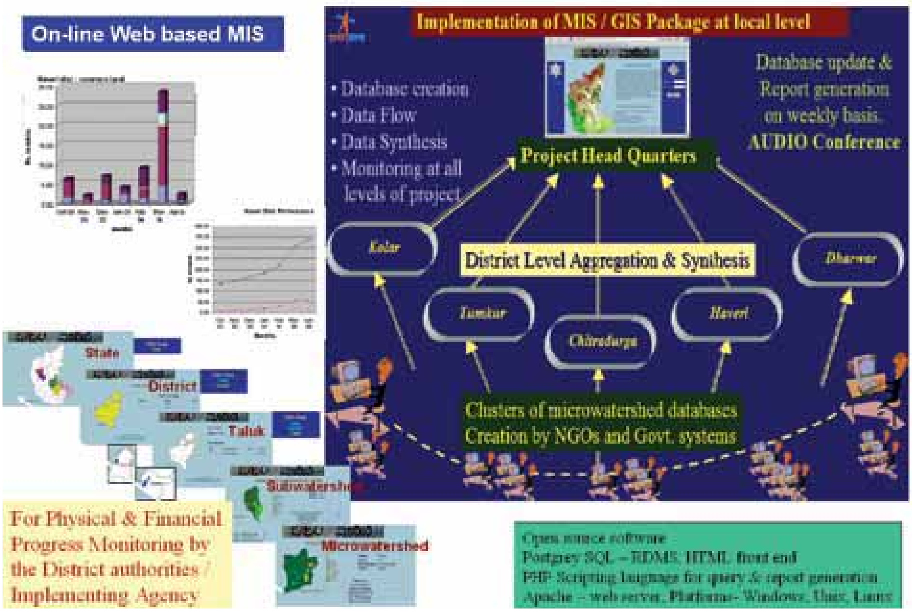

Figure 4b. Hierarchical organization of query engine and data flow

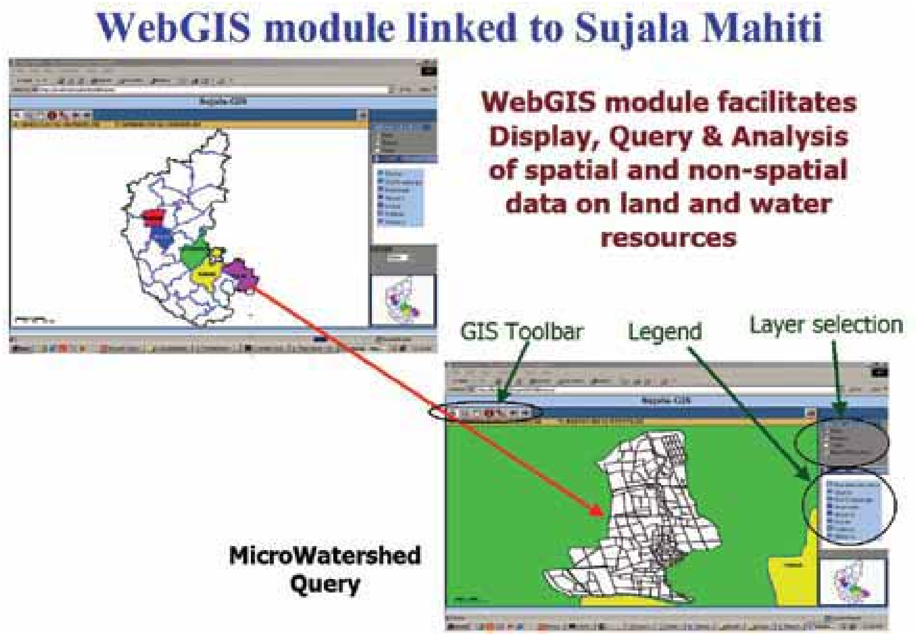

Figure 5. WebGIS tools for online monitoring.

Impact Assessment - Space Imaging and Geospatial Analysis

Space technology is of much importance in generating the base line information on land and water resources and in monitoring the progress and success of watershed development that has been substantiated from various studies carried out so far (Diwakar et al. 2004). Impacts by various interventions are monitored through a combination of remote sensing data, GIS, MIS data, process monitoring data and farmers/household surveys. Through a scientifically designed monitoring mechanism, impact assessment is done at pre-determined time intervals to establish the net contribution of the project to poverty alleviation and natural resource regeneration (Fig.6). Impact is evaluated using a variety of qualitative and quantitative indicators with respect to baseline, midterm and post-project status. Impacts are also analysed based on observations made in the project and control areas. A comprehensive benchmark data has been established through judicious combination of conventional and remote sensing data to facilitate monitoring and impact assessment.

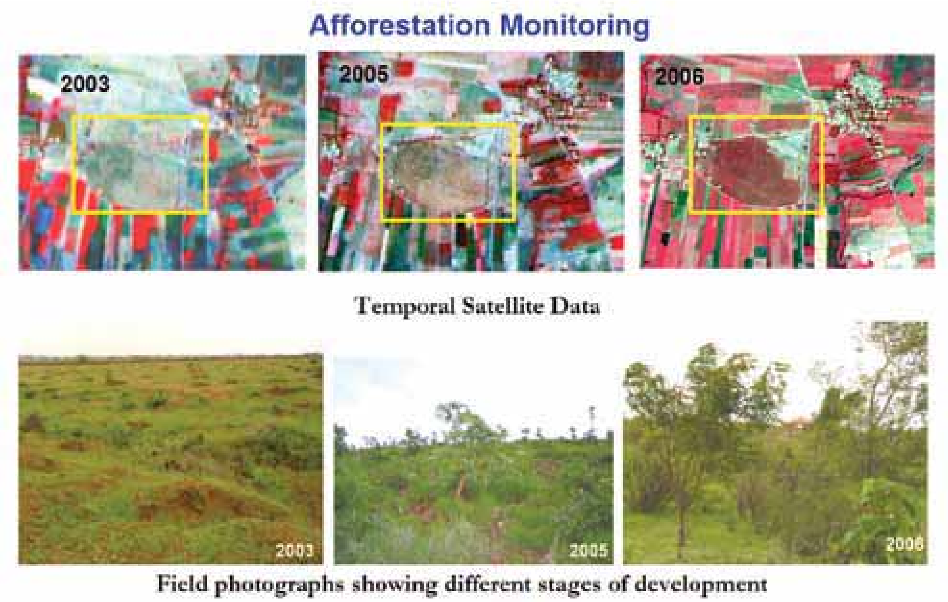

Figure 6. Use of Earth observation in measuring impacts.

Participatory observations, focus group discussions, transect walks are some of the other methods of data collection at community level. The data available from MIS/GIS system, thematic reviews and specific case studies are also utilised for the impact assessment. One of the most crucial points to be noted in effectively carrying out such impact studies is the establishment of a strong baseline database, both from satellite remote sensing, GIS and field based observations.

Impact

Some of the visible changes observed are: increase in average crop yields, crop diversity has increased from an average of 2-5 crops in the baseline to 4-9 crops; increase in annual household income due to employment, income-generating activities and agricultural productivity has increased by about 30%; the average water level has increased by 3 to 5 feet; shift to agro-forestry and horticulture and reduction in non-arable lands, increased employment and income has resulted in changed seasonal migration pattern and intensity. Greater transparency and capacity building has resulted improved awareness, participation,

Figure 7. Social Impacts due to transparency and participatory approach.

particularly amongst women, and social response (Figure – 7). Door delivery of livestock services has resulted in improved vet services and livestock health (Muniyappa et al. 2004)

Conclusion

A judicious mix of Earth observation inputs, geomatics, information technology and ground-based sample observations have successfully demonstrated the efficacy of micro level planning, concurrent project monitoring and impact assessment for a major watershed development project. The integrated approach for systematic planning of monitoring and evaluation with application of cutting edge technology including remote sensing has provided required transparency and results at grass roots. Proper adaptation of technologies with respect to natural resource regeneration and strengthening of local institutions has led the project towards greater sustainability. EO inputs have provided the much needed information for tracking and self-assessment of the project to achieve set goals against development indicators and milestones.

It has also enabled appropriate policy formulation, implementation of suitable strategies/action plans, assessing the impacts, resulting in mid course corrections and better impacts in the field. It has also significantly brought about transparency and accountability amongst all stakeholders.

Thus, the project has ushered a new era of hope and confidence into the hearts of the rural inhabitants of 1270 villages across five districts in Karnataka by rejuvenating natural resources and institutional strengthening through participatory developmental approach. This is an attempt to bring about a better balance amongst the basic prerequisites of sustainable development, social equity, environmental quality and economic efficiency. The transformation in the livelihoods and living standards of poor farming community is an interesting outcome indicating reduction in poverty. It has become a milestone on the path of sustainable development for the people, through external facilitators and sophisticated science and technology inputs for decision-making.

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A Mission to Enhance Productivity of Rain-fed Crops in Rain-fed Districts of Karnataka, India.

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Background

Water shortage is a major constraint for rain-fed crop production and a chief cause of poverty and hunger in the semi-arid tropics of the world. Over 95 per cent of the world's poor and malnourished people live in India, China, the Eastern and Sub-Saharan Africa and parts of Latin America. Rain-fed agriculture is practiced on 80% of the world's farm area, and generates almost 60% of the world's staple foods, providing the livelihoods of 80 per cent of the world's population. In India, 40% of the population depends on rain-fed agriculture, which is cultivated 85 million hectares, and produces 44% of food and fodder requirements for the country. Rain-fed areas in India covering 60% of agriculture produce 75% of pulses and more than 90% of sorghum, millet, and groundnut. These areas are the hot spots of poverty, suffer from water scarcity and droughts, land degradation and low rainwater use efficiency.

Rain-fed agriculture productivity is crucial for food security and economy of even Karnataka state as it has the second largest rain-fed area in India after the state of Rajasthan. Crop yields in the rain-fed areas are from 1 to 1.5 t ha^{-1}, which are two to five times less than those on research farms (Wani et al. 2009). Only 35% to 45% of rainwater is presently used to grow dryland crops in the state. Hence, there is huge scope for improving rainwater harvesting and efficient use of it for rain-fed crops. Scientific technologies including better cultivars could unlock the vast potential of rain-fed agriculture.

A study undertaken by (Singh et al. 2009) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) reveals that a large gap exists between current farmers' crop yields and potential yields. This is the case with all the major rain-fed crops (finger millet, groundnut, maize, sorghum and soybean) grown in Karnataka. The good news is that use of modern technologies has increased crop yields by two to three fold.

Science for Agriculture: ICRISAT and Sujala Watershed Project

Watershed Development Department of Karnataka had supported a community-driven watershed project across the six selected districts (Kolar, Tumkur, Madhugiri, Chitradurga, Haveri and Dharwad) in collaboration with ICRISAT. The project known as "Sujala-ICRISAT Productivity Enhancement initiative" covered over 3500 ha in 46 watersheds of the six selected districts during 2005-2008 crop seasons and adopted the consortium approach. Stakeholders, including state government departments, non-governmental organizations, farmers' organizations and women's self-help groups, were brought together to improve understanding on crop, water and soil management skills of farmers.

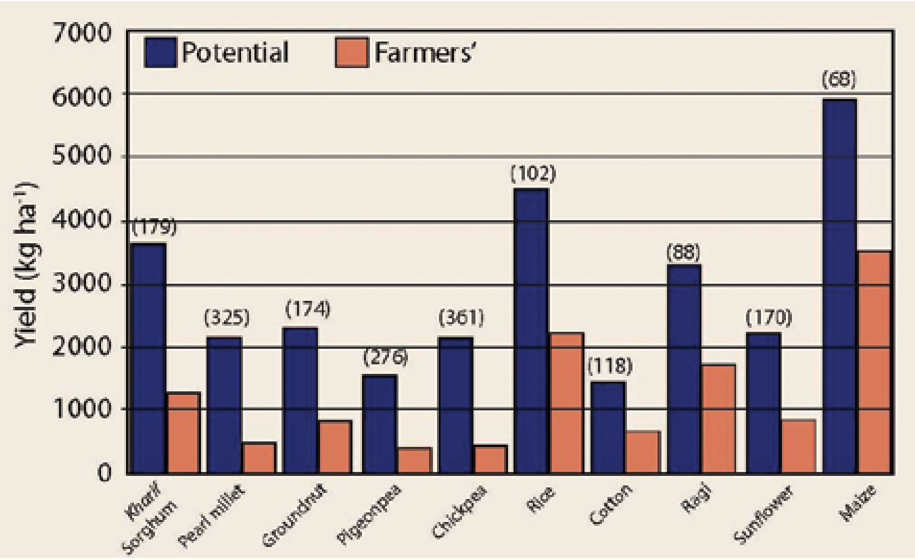


Figure 1. Yield gaps between farmers' field crop yield and potential yield of various dryland crops in Karnataka. (Source: Bhoochetana booklet (2009).

Soil Nutrient Diagnostic Studies

Soil sampling of over 11000 farmers' fields in the Sujala watersheds and their analyses for soil nutrient status revealed that soils in Karnataka desperately need not only water but also vital nutrients (Sahrawat et al. 2007). These soils were deficient in nitrogen, phosphorus, sulfur, zinc and boron, as well as low in organic carbon. Potassium deficiency was not a problem in the six districts. Spatial distribution of nutrients was also assessed using GIS techniques and prepared maps for the benefit of farmers and policy makers.

Bridging the Yield Gap

Through farmers' participatory field evaluation, the Sujala-ICRISAT initiative identified the best management options to increase crop productivity in watersheds of various districts in Karnataka. Better nutrition along with improved cultivars, integrated pest management and land and water management practices increased yields of various crops by 33-58% (Table 1) in spite of the poor rains during 2008 crop season (Progress Report 2008-09 Sujala-ICRISAT project, 2009).

Encouraged by the successes and lessons of the Sujala-ICRISAT initiative, Government of Karnataka (GoK) embarked on the path-breaking project 'Bhoochetana' in mission mode named as Bhoochetana for strengthening rain-fed farming and enhancing crop productivity in many more districts.

Table 1. Crop yield increase in farmers' fields of Karnataka with improved management compared to farmers' management during *kharif* crop season 2008. (Source: Progress report 2008-09, Sujala-ICRISAT project, 2009).

	Grain yield (kg ha^{-1})		
Crop	Farmers' management	Improved management	% yield increase in rain-fed crops
Ragi	1750	2770	58
Groundnut	1300	1940	49
Maize	4760	6490	36
Soybean	1225	1635	33

Goal and Objectives

The goal of Bhoochetana project is to make a difference in the lives of dryland farmers in 24 districts of Karnataka, including the six districts covered under the Sujala-ICRISAT initiative, by increasing average crop productivity by 20% in four years. The objectives of Bhoochetana are:

- to identify and scale-up best bet options (soil, crop and water management) including improved cultivars to enhance productivity by 20% for the selected crops in the selected 24 districts.
- training Department of Agriculture (DoA) staff to perform stratified soil sampling, analyze micronutrients, and prepare GIS-based soil maps. Also, provide guidance to DoA to establish a high-class soil analysis laboratory in Bangalore and Mandya.
- improving skills of farmers and other consortium partners in the sustainable use of natural resources. Stakeholders will also be trained to raise the productivity of dryland farms through best practices.

Strategies

To boost crop yields in rain-fed areas of Karnataka, DoA worked together with partners on a mission-mode, and decided to consolidate the gains of the Sujala-ICRISAT project in the six selected districts during the first year of Bhoochetana project. We adopted Integrated Genetic and Natural Resource Management approach that looks after the entire 'seed to food' chain with participation of Karnataka state Department of Agriculture, Watershed Development Department, Government of Karnataka, International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, University of Agricultural sciences, Bengaluru, Dharwad and Raichur, non-governmental organizations, community-based organizations, watershed committees, and farmers, in a consortium approach (Figure 2).

Government of Karnataka constituted a state level coordination committee (SCC) for Bhoochetana program which is headed by the Additional Chief Secretary & Development Commissioner to review the performance of the program at regular intervals. State level committee reviews the progress of project activities and interacts with district level

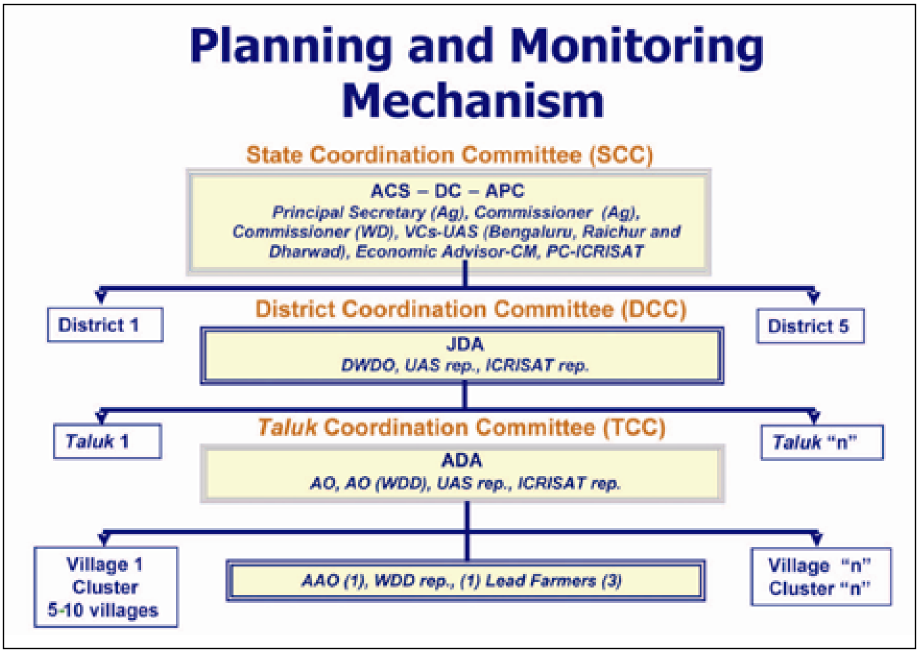


Figure 2. Organogram of project planning and monitoring mechanism set-up for Bhoochetana project, Karnataka.

officials instantaneously through video-conferencing and take stock of solutions to address problems arising in the field and issue directives to each district.

Timelines were defined clearly for encompassing activities of soil sampling and nutrient analysis mapping, capacity building of stakeholders, and productivity enhancements in 24 districts (Map 1) during the project period as shown in Table 2.

In addition to the strength of convergence through consortium, the mission has planning and monitoring mechanism at cluster, *taluk*, district and state levels. The mission has simple principle of accountability and delegation of authority at different levels without diluting the individual accountability in order to meet the mission goal collectively.

Besides, the mission intends to adopt rewarding mechanisms for the best performers i.e., the farmers at cluster, *taluk*, district and state levels with appropriate personal recognitions. Similarly, the mission staff who

Map 1. Selected rain-fed districts for crop productivity enhancement under Bhoochetana project in Karnataka.

Table 2. Timeline for execution of activities in Bhoochetana districts.

		% activity coverage in districts		
Activity	Year	1-6	7-15	16-24
Productivity enhancement	2009	25	-	-
	2010	50	33	-
	2011	75	66	50
	2012	100	100	100
Nutrient status mapping	2009	100	-	-
	2010	-	100	-
	2011	-	-	100
	2012	-	-	-
Capacity-building	2009	100	-	-
	2010	-	100	-
	2011	-	-	100

exhibit outstanding performance will also be recognized by the state government. To fetch complete information from cluster villages, *taluks* to district, weekly reports on progress of the activity were prepared by ICRISAT and ensured that the follow-up weekly reporting synchronized from JDA office and ICRISAT staff.

Rain-fed Agriculture Technologies for Implementation

ICRISAT with 35 years of experience in watershed research, especially after gathering farmers' evaluation locally on science-based methods in the Sujala project, is best suited to support Bhoochetana. Following rain-fed farming technologies have been implemented to increase productivity in the Bhoochetana project:

1. *In-situ* soil moisture conservation techniques

In-situ soil moisture conservation techniques like (a) contour cultivation across slope which is the most common practice for conserving soil moisture. In this method, all field activities including ploughing, planting and intercultivation are done across the slope; (b) contour furrows are a simple and efficient method to conserve moisture. They are laid with the help of country ploughs on a gradient of 0.2-0.4% at the time of sowing. (c) Broad-bed and furrow (BBF) system on Vertisol - a system of broad bed (1m) and furrow (0.5m) cultivation at 0.6% slope - is advocated for draining out excess water as controlled runoff, and furrows act as traffic zone. Raised beds facilitate good aeration for root growth and stores more soil moisture that supports good crop growth for longer period, which suits well for groundnut cultivation on Alfisols.

2 Integrated Nutrient Management

Stratified random soil sampling in farmers' fields and subsequently, results of soil analysis that tell macro and micronutrients status in soil samples of their fields were discussed. Farmers were given soil health cards, which show the nutrient status of their fields along with fertilizer recommendations for different crops. Basal application of micronutrients (sulphur, boron and zinc) on major crops was discussed with farmers in village meetings in the first year of Bhoochetana. Field facilitators, who were hired by the Department of Agriculture to raise awareness of best agricultural practices, initiated the meetings. Seeds, micronutrients and fertilizers (nitrogen, phosphorus and potash) were supplied to farmers at incentivized rates at the beginning of the season. Biofertilizers which are low-cost, eco-friendly organic agro-inputs, supplementary to the chemical fertilizers like *Rhizobium, Azospirillum*, Azotobacter, which add nitrogen to the soil, and phosphate-solubilizing bacteria were supplied to farmers. Phosphate Solubilizing Bacteria (PSB) and *Trichoderma viride* were applied to soil in Bhoochetana project. Seed treatment along with *Rhizobium* and fungicides were not suggested for groundnut and soybean. *Gliricidia* on field bunds were advised as the plant produces green leaf manure rich in nitrogen and thereby adds organic matter to the soil. It also helps prevent soil erosion. Preparation and application of vermicompost, a natural fertilizer was also advised to improve the health and fertility of soil.

3. Farmers’ preferred varieties

High-yielding short duration varieties of major dryland crops, which were evaluated by a large number of farmers in the Sujala-ICRISAT project and found advantageous for the six districts, were recommended for cultivation. Ragi varieties assessed by farmers were GPU 28, MR 1, HR 911 and L 5. Farmers of Kolar, Chikballapur, Tumkur and Chitradurga districts found L 5 and MR 1 suitable for their fields. Short duration varieties of groundnut ICGV 91114, GPBD 4, Kadiri 1375 and Kadiri 6 were evaluated by a large number of farmers. ICGV 91114 met the approval of the farmers in Kolar, Tumkur and Chitradurga while GPBD 4 was found suitable for Haveri and Dharwad districts where it rains better. Soybean cultivars JS 335 and JS 93-05 were evaluated by farmers. JS 93-05 showed good growth and was found to give high yields despite a drought. The variety has been introduced in three districts due to farmers’ preference.

4. Integrated pest management technologies

Farmers across districts were trained in pest control using pheromone traps, cultural practices, tolerant cultivars and biological methods. To check the spread of insect Helicoverpa, the primary pest on pigeonpea, farmers were advised to spray nuclear polyhedrosis virus (NPV) on early instars. This is a cost effective and eco-friendly biological method of controlling pests. Later at the flowering and pod-filling stages, farmers were advised to shake the larvae off the crops.

5. Custom hiring centers for agricultural machinery

Tropicultor is a bullock-drawn, multipurpose field machine, developed by ICRISAT. Cheaper than a tractor, a tropicultor can attach to itself various implements for ploughing, ridging, sowing, harrowing and application of fertilizers. Fast operation, reduction in labour charges and saving in seed and fertilizer costs are other advantages. The machine also ensures the placement of seeds and fertilizer in the fields at proper depth for better crop growth.

Tropicultors and Penugonda ferti-cum seed drill (kurgi) were placed in the control of each ADA to provide them for needy farmers on hiring. This approach helped farmers who can not afford to buy them in the season, but use them based on their operational efficiency and to reduce dependence on labor for timely operations like sowing cum fertilizer application.

6. Income-generating rural livelihoods

Village seed banks were put up in the Sujala-ICRISAT watersheds during the 2005-2008 sowing seasons. Bhoochetana is now setting up many more seed banks in several villages of the six selected districts. This will increase the availability of the preferred varieties of ragi, groundnut and soybean.

Project Activities

Capacity Building of Stakeholders

A team building workshop was conducted in Bengaluru which saw a participation of more than 75 staff of commissionarate of WDD and Department of agriculture along with senior agricultural officers from six districts on 2nd May 2009. As many as 19 district-level trainings with participation of 1128 officials; sixty eight *taluk* level trainings with participation of 930 field staff and facilitators, and 1806 village level trainings with participation of lead farmers and rural poor were organized in these six districts where government officials, field facilitators and lead farmers learnt about technological advancements in agriculture.

Awareness and Field Publicity Campaigns

The DoA staff ensured wall writings and exhibition of posters in all villages within short period before the on-set of monsoon, indicating the main objective of the program and areas to be covered by the program. Additionally, thousands of brochures and handouts were published in each district on improved management practices, information on nutrients status, nutrients recommended *taluk*-wise and widely distributed in all selected districts. Print media news coverage was extensive to introduce Bhoochetana program to farmers and also on activities during the season in all districts besides field facilitators and lead farmers contacts with individual farmers in selected village.

Awareness Building on Soil Nutrient Status

ICRISAT sampled soils of 25% of fields in each watershed. The method was scaled up by using Geographic Information System (GIS) to produce soil maps of the six districts. Soil sampling and mapping helped farmers diagnose nutrient deficiencies in their fields and turned them into eager partners in this mammoth development project.

Soils samples from around 11000 farmers' fields in several *taluks* of each district were collected in six districts during 2008, and were analyzed for diagnosing macro and micronutrients status of farmers' fields. Based on the established critical limits for each nutrient, fields were categorized as deficient or sufficient. Individual farmers were provided soil health cards in Kannada based on the mean nutrient status in the soils of the village as the soils analyzed were representative of the soils in the village. Soil nutrient status maps were provided for each district using GIS based extrapolation techniques for the benefit of policy makers. In 2009, more than 35460 soil samples were collected from 1773 villages in nine new districts were analyzed and soil nutrient status maps of the each district were provided by ICRISAT.

Assisted in Setting up Analytical Laboratory

Department of Agriculture, Government of Karnataka, showed interest to upgrade their Soil Testing Laboratories in order to meet the growing demand for soil analysis under Bhoochetana initiative. ICRISAT has commitment in this project, to assist DoA based on its own expertise to set up soil analytical laboratory that can meet the international standards and also to handle large number of samples analyses. ICRISAT scientists evaluated the facilities guided by senior staff of DoA and had discussions with Director of Agriculture. They submitted their assessment and recommendations for upgradation and integration of required facilities with these laboratories.

Scaling-Up Soil, Crop and Water Management Technologies for Boosting Productivity of Selected Crops

Kharif Season Rain-fed Crop Planning 2009

On thorough consultation, Department of Agriculture, University of Agricultural Science, Bengaluru, Dharwad, Raichur and ICRISAT arrived at a consensus on identified major crops in the selected 24 target districts of Karnataka considering the historical annual crop statistics published by Directorate of Economics and Statistics, Government of Karnataka, for enhancing productivity of major dryland crops in each selected district.

In each district, 25% of the cultivated area under two selected crops was identified in clusters of Sujala watershed villages (Table 3) and farmers were motivated about the project and possible benefits for participating in the technology uptake of the project. Technology input kits containing improved seeds, quality organic manure, bio-fertilizers (*Trichoderma, Azospirillum*), borax, gypsum, zinc sulfate, *neem* oil and endosulfan pesticide were made available by DoA at incentivized

Table 3. *Kharif* season cropping planned and actual area sown during 2009 in six districts.

District	Crop	Target area crop-wise (ha)	Total areas sown (ha)	% area sown
Kolar	Groundnut	3500	2800	80
	Ragi	15000	8635	57.6
Chikkballapur	Groundnut	12500	12203	97.6
	Ragi	10000	9350	93.5
Tumkur	Groundnut	35000	18200	52.7
	Contingent crops		13708	39
	Ragi	20000	19830	99
Chitradurga	Groundnut	33000	17308	52
	Ragi	10000	9850	99
	Maize	20000	19883	99
Haveri	Groundnut	6000	6000	100
	Maize	38000	38000	100
Dharwad	Groundnut	10000	10000	100
	Soybean	12000	12000	100
Total		188000	159546	

rates. Coordination with DoA staff for inputs mobilization, especially expediting the procurements or placing inputs at the disposal of field staff for easy distribution to farmers timely was harmonized. ICRISAT facilitated timely procurement of groundnut (ICGV 91114), pigeonpea cultivars, *bajra* hybrids and soybean cultivars by DoA.

Initial monsoon on-set rains and good follow-up rainfall helped farmers in Haveri and Dharwad to take up sowings of 100% target area under major crops in the districts. However, difficult conditions of low rainfall and long break in the months of June, July and August in Kolar, Chikkaballapur, Tumkur and Chitradurga were responsible for a suggestion of contingency crop planning to farmers by ICRISAT and DOA. Further staggered sowing opportunities in these districts were responsible for non-compliance of groundnut sowing in 100% target area. However, farmers turned the short fall in crop areas to good with contingency crops in these districts.

Rabi Cropping Targets 2009

Rain-fed *rabi* crops were successfully sown in Chitradurga, Haveri and Dharwad, covering 77-100% of target areas in the three districts (Table 4).

In Chitradurga, Haveri and Dharwad, vertisol areas provide opportunity for post rainy season rain-fed crops due to stored soil moisture in the profile. Predominant *rabi* season crops in the area are chickpea, *rabi* sorghum and sunflower with life supporting irrigation. The area planned with these crops for production enhancement is given in Table 4. Nutrient recommendations were prepared by ICRISAT based on the nutrient status of soils in each *taluk*. Nutrient recommendations of N, P, and K for different crops were based on DoA data and boron, zinc and sulfur recommendations were based on ICRISAT evaluations in the farmers' fields. DoA and ICRISAT staff coordinated efforts were rendered to support farmers by supplying inputs like seed, fertilizers and insecticides timely in the mission project and were successful in achieving target upto 78% in case of late sown sorghum. However, 90 to 100% targets of sowing was achieved with regard to soybean, chickpea and sunflower.

Table 4. *Rabi* cropping planned and area of sowing completed in different districts during *rabi* season 2009.

District	*Taluk(s)*	Crop(s)	Target area (ha)	Area covered (ha)
Chitradurga	Chitradurga, Hiriyur	Chickpea	5840	5302 (91.5%)
Dharwad	Dharwad, Hubli, Kundagol, Kalghataki, Navalgund	*Rabi* sorghum	18000	13990 (77.72%)
	Dharwad, Hubli, Kundagol, Navalgund	Chickpea	16500	16500 (100%)
Haveri	Haveri, Hirekerur, Savanur	Sunflower	3000	2654 (88.47%)
	Haveri, Hirekerur, Savanur, Shiggao, Ranebennur, Byadagi	*Rabi* sorghum	16000	14550 (90.93%)

(Source: Annual Progress Report 2009-10, 2010)

Field Days

Field days were conducted for groundnut farmers in Kurubaramalluru village on 17th September 2009 and for maize farmers in Kabur village on 12th September 2009 in Haveri district. DoA staff along with C M Udasi, the Hon. Minister of Public Works Department visited the fields of Haveri and observed a clear improvement in crop growth and yield, as a result of technology interventions in the Bhoochetana project.

Kharif Season Crop Planning 2010

During *kharif* 2010, the project was scaled out in nine new districts for production enhancement of rain-fed crops after soil diagnostic studies and awareness campaigns to farmers and other stakeholders about soil health in these additional districts. A target of 11 lakh hectares were almost covered with improved production enhancement technologies as a package in as many as 5038 villages in 16 districts of Karnataka.

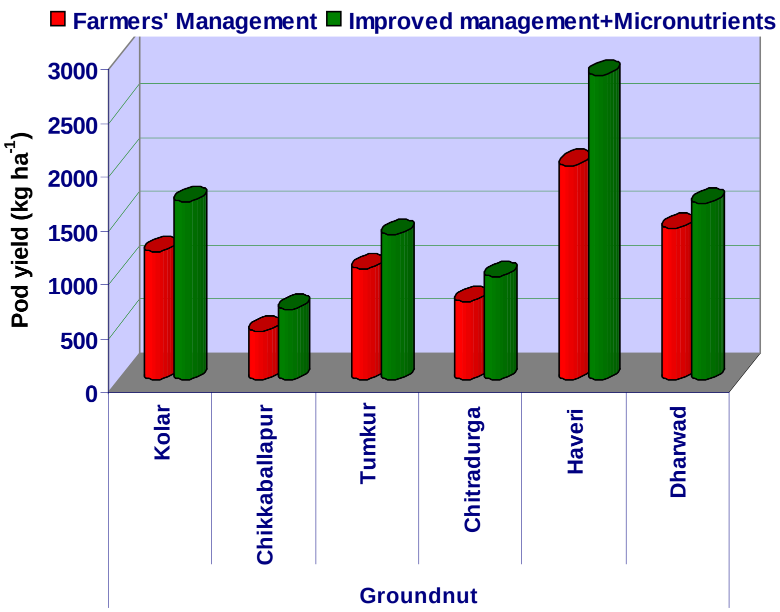
Results of Participatory Crop Yield Estimates

Crop Season 2009

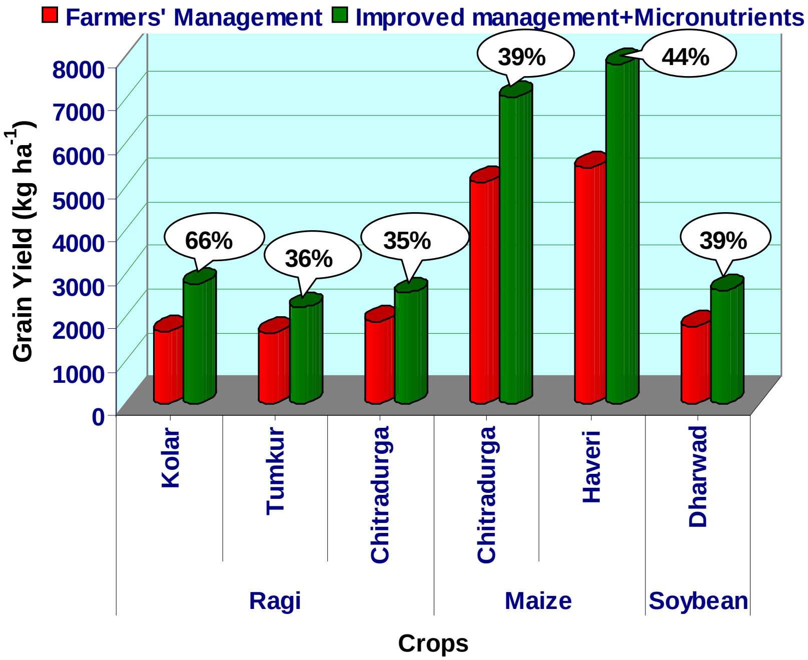
Rainfall in all the six districts was monitored, and it was erratic with early monsoon showers, followed by long dry spell extending up to 52 days in Kolar, Chikballapur, and Tumkur, affecting crop performance. In Haveri and Dharwad, rainfall distribution was normal during the season. However, heavy rainfall at the end of season when the crops were reaching maturity had affected crop harvesting. Participatory crop cutting experiments by a joint team of officials of DoA, UASs and ICRISAT undertook the crop cutting experiments along with participation of farm facilitators, individual farmers and stakeholders recorded observations in the farmers' practice as well as improved management in farmers' fields of five villages in each of all the six districts for yield estimation for selected crops.

With Bhoochetana initiative, groundnut pod yields increased across all *taluks* of six districts in the range of 32% to 41%, which varied from the lowest increase of 18% in Mulkalmur *taluk* of Chitradurga to the highest yield increase of 52% in Hubli *taluk* of Dharwad district. Ragi farmers harvested an additional one ton of grain yield and 1.5 t ha^{-1} of fodder by adopting improved management along with balanced nutrition in Kolar. Weighted mean grain yield increase across Kolar, Tumkur and Chitradurga districts varied from 35% to 66%.

Maize grain yield increase in farmers' fields with improved management was between 37-51% in different *taluks* of Haveri and 22% to 45% in different *taluks* of Chitradurga. On an average, farmers harvested grain yield of 1.5 tons and 3 t ha^{-1} of fodder additionally with improved management "balanced nutrition" compared to grain and fodder yields with farmers' management in Haveri. In Dharwad, farmers harvested grain yields in the range of 1480 to 2990 kg ha^{-1} with improved management and the seed yield increase across the district was 39% over farmers' management.



Groundnut pod yield increase (district-wise) with improved management compared to farmers' management in six districts of Karnataka during kharif 2009.(Source. Annual Progress Report 2009-10, 2010)



Grain yield increase in selected crops (district-wise) with improved management compared to farmers' management in five districts of Karnataka during kharif 2009. (Source. Annual Progress Report 2009-10, 2010)

Intense monitoring by state level high-power coordination committee at regular intervals, facilitated by ICRISAT to ensure good coordination of all stake holders to implement technologies in the project, resulted in successful implementation and crop yield increases between 35%-66% for farmers across six districts in the first year.

During *rabi* season 2009, chickpea seed yield increased by 23% in Chitradurga, sorghum grain yield increased by 43% in Haveri and 51% in Dharwad districts with improved management over farmers' management. Sunflower seed yield increased by 38% with improved management compared to farmers' management. Actual yield increase was about 300 kg ha^{-1} with sunflower or chickpea.

Table 5. District-wise crop yield increase in farmers' fields with improved management compared to farmers' management under Bhoochetana project, 2009.

Crop	District	Farmers' management	Improved management + Micronutrients	% yield increase
Groundnut	Kolar	1190	1660	41
	Chickballapur	460	660	43
	Tumkur	1030	1350	32
	Chitradurga	730	960	32
	Haveri	2000	2830	41
	Dharwad	1410	1640	35
Ragi	Kolar	1660	2750	66
	Tumkur	1630	2210	36
	Chitradurga	1890	2550	35
Maize	Chitradurga	5080	7040	39
	Haveri	5420	7800	44
Soybean	Dharwad	1580	2190	39

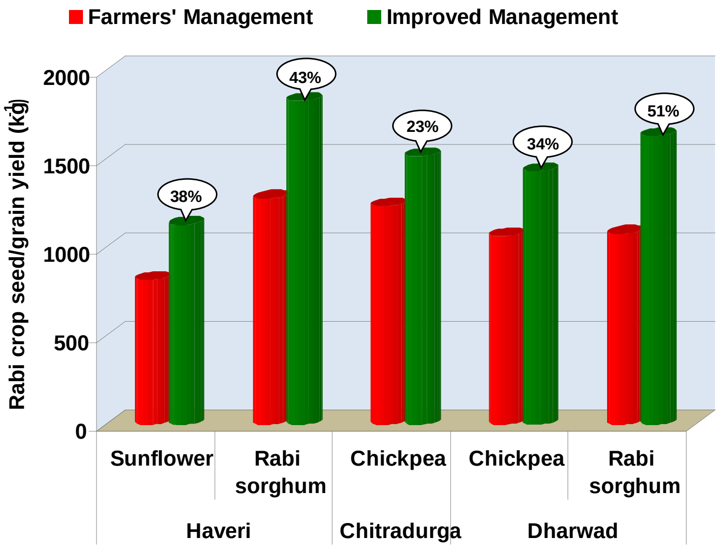
Increased Crop Yields and Economic Gains

We estimated additional economic grains to farmers by investing in application of micronutrients additionally as recommended based on nutrient deficiency diagnosis. Total additional investment made on application of boron, zinc and sulphur was Rs. 1435 per hectare. Total additional income obtained by multiplication of additional grain harvested per hectare with minimum support price per unit of grain (seed) for improved management. We calculated income per additional rupee invested by dividing total additional income with additional investment on micronutrient application. The additional income thus obtained by farmers in different districts was in the range of Rs 2.8 to 11.0 per additional rupee invested with selected rain-fed crops. Income gain to maize farmers on every additional rupee investment was higher in Chitradurga. Groundnut farmers economic gains on additional rupee investment was much lower at Rs.2.8 per rupee invested.

Table 6. Additional income to farmers on additional rupee invested for improved management during 2009 crop season

District	Crop	Crop yield in FM	Additional yield in IM	Additional income Rs.	Income per Rs. additional invested
Kolar	Ragi	1660	2750	9970	6.7
ChikkaBallapura	Groundnut	460	660	4200	2.8
Tumkur	Groundnut	1030	1350	6720	4.5
Chitradurga	Maize	5080	7040	16460	11.0
Dharwad	Soybean	1580	2190	8479	5.7
Haveri	Sunflower (*rabi*)	820	1130	6870	4.6

(Source: ICRISAT, 2010)

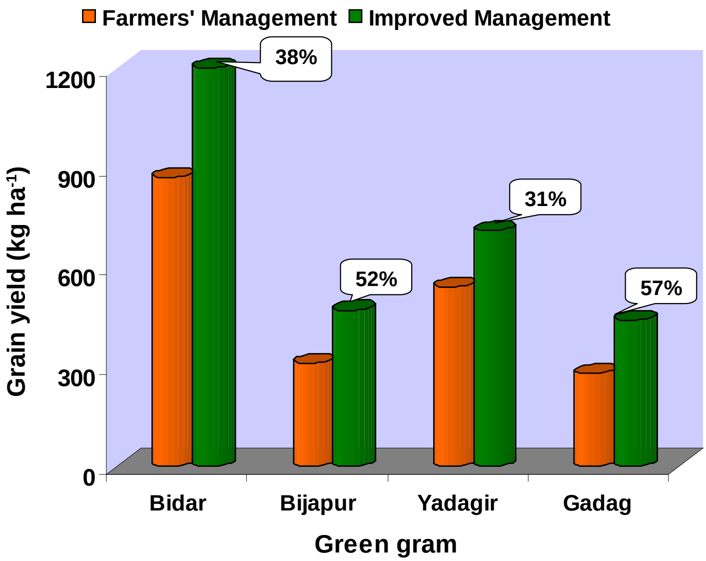


Grain yield increase in selected crops (district-wise) with improved management compared to farmers' management in three districts of Karnataka during kharif 2010. (Source. Annual Progress Report, 2010)

Crop Season 2010

During *kharif* season, rainfall has been above normal in all these districts, and in some districts. Short duration legumes and ragi are affected by incessant rains at harvesting and yield losses also mentioned by farmers. *kharif* crop harvesting and crop cutting experiment for yield estimations have beem completed in all sixteen districts. Early yield estimates for short duration crops like black gram, green gram, groundnut, soybean and ragi available hence presented in this paper to give a glimpse of rain-fed crops response to improved management during rainy season 2010.

According to early estimates available, groundnut pod yields increased by 33% and 35% respectively in Kolar and Haveri with improved management compared to farmers' management. Farmers in Haveri benefited by good crop harvest of nearly 3.5 t ha^{-1} of groundnut pod yield which was higher by 930 kg ha^{-1} in the improved management. Response of ragi crop to improved management in Kolar was very good with 46% grain yield increase and soybean seed yield increase was 25% over farmers' management in Haveri district.



Grain yield increase in green gram (district-wise) with improved management compared to farmers' management in four districts of Karnataka during kharif 2010. (Source. Annual Progress Report, 2010)

Green gram and black gram in North East or North West Karnataka districts were severely affected by terminal incessant rains, and farmers could not harvest the crop in time. Black gram mean grain yield in Bidar district was around 930 kg ha^{-1}under the farmers' management while it was 1230 kg ha-1 with improved management providing a yield advantage of 35% over farmers' management. Green gram crop yield in general this season was low with around 500 kg ha^{-1}. Grain yield difference between farmers' management and improved management ranged from 160 to 330 kg ha^{-1}. Crop response trends with improved management especially by the soil application of deficient micronutrients and introduction of new varieties, land and water management practices helped farmers to obtain significant higher yields and income from rain-fed crops in this project.

Conclusion

Bhoochetana is a unique project of Government of Karnataka in mission mode aimed at increasing crop productivity in 24 rain-fed districts of the state by 20 with the science-led consortium approach by converging all schemes of the government with capacity building and promoting cooperation. Expertise of international organizations like ICRISAT is harnessed for technical backstopping and forming the working consortium to harness the potential of rain-fed agriculture by taking science at the door step of the farmers. The mission mode project aims to increase productivity of selected rain-fed crops in 24 districts by 20 per cent in four years. It takes up the Integrated Genetic and Natural Resource Management approach to take care of the entire 'seed to food' chain by bringing improved agricultural technologies, seeds and other inputs to farmers' doorstep. Analysis of massive scale soil samples collected from farmers' fields in fifteen districts to map nutrient status of soils using GIS was big achievement in the right direction. Public-private partnerships (PPPs) to ensure backward and forward linkages to benefit farmers are envisaged in the mission mode project. A high level SSC to take quick decisions, plan, monitor and evaluate is ensuring that the program is implemented in a mission-mode. Farmer-friendly technologies besides improving soil quality helped farmers increase crop productivity in the range of 32 to 66% in rain-fed groundnut, finger millet, maize and soybean during *kharif* 2009. In *rabi* season of 2009, chickpea seed yield increased by 23% and sunflower seed yield increased by 38% in Chitradurga, sorghum grain yield increased by 43% in Haveri with improved management compared to farmers' management. During crop season 2010, Bhoochetana project targeted scaling up of productivity enhancement of rain-fed crops in sixteen districts as planned on 11 lakh hectares in 5038 villages. The project created awareness of technologies and facilitated farmers' uptake of improved management inputs. Rainfall was good during the season to obtain higher grain yields in the range of 31-57% with green gram, 46% increase with ragi, 35% pod yield increase with groundnut and 25% seed yield increase with soybean in different districts of Karnataka with early crop yield estimates during 2010. Producing more food with less water is the way forward. Better water management can indeed lead to more food security and help achieve the millennium development goal of halving the number of hungry people by 2015. We have to cross lot of humps to reach the goal and realize the challenge to establish well oiled supply chain and capacity building mechanisms for millions of small farmholder across geographically spread districts. These results clearly demonstrated the power and the success of the science-led approach for unlocking the potential of rain-fed areas in Karnataka to achieve increased food production and increased incomes for millions of small farm holders.

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Application of Meta-analysis to Identify Drivers for the Success of Watershed Programs

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Introduction

Nearly two-third (60 per cent) of total arable land in the country is rain-fed, characterized by loss of fertile soil through erosion, land degradation, loss of productivity, low income, low employment with high incidence of poverty and a bulk of fragile and marginal land. These areas witness acute moisture stress during critical stages of crop production, which make agriculture production vulnerable to pre and post production risks. Dryland agriculture contributes to 36 per cent of agricultural exports and 44 per cent of food production in the country. Thus, holistic development of the rain-fed areas is one of the prime challenges of the 21st century. Development of watersheds/catchment is one of the most trusted and eco-friendly approaches to manage rainwater and other natural resources, which has paid rich dividends in the rain-fed areas and is capable of addressing many natural, social and environmental intricacies (Samra 1998, Wani et al. 2002, 2003 a, b, 2009, Rockström et al. 2007). Management of natural resources at catchment/watershed scale produce multiple benefits in terms of increasing food production, improving livelihoods, protecting environment, addressing gender and equity issues along with biodiversity concerns (Sharma, 2002; Wani et al. 2003 a, b, 2009, Ahluwalia, 2005; Rockström et al. 2007). It is also recommended as the best option to upgrade rain-fed agriculture to meet the growing food demand globally (Rockström et al. 2007).

Watershed development program is, therefore, considered as an effective tool for addressing many of these problems and recognized as a potential engine for agricultural growth and development in fragile and marginal rain-fed areas (Joshi et al. 2005, 2008; Ahluwalia 2005;

Wani et al. 2006). The Government of India has accorded high priority to the holistic and sustainable development of rain-fed areas through the watershed development program since the VIIth Five Year Plan (1985-90).

A majority of watershed development projects in the country are sponsored and implemented by the Government of India, with the help of various state departments, non-governmental organizations (NGOs), self-help groups (SHGs), etc. Drought-Prone Area Program (DPAP), Desert Development Program (DDP), National Watershed Development Project for Rain-fed Area (NWDPRA), Watershed Development in Shifting Cultivation Areas (WDSCA), Integrated Wasteland Development Project (IWDP) are some of the important development programs that plan, fund and implement watershed development projects under the aegis of Ministries of Rural Development; Agriculture; and Environment & Forestry, Government of India. A total sum of Rs 286 billion has been invested on various watershed development projects since inception (mid 1980s) of watershed development programs in the country until 2006. Some international organizations also sponsor and implement watershed projects but a significant proportion (about 70%) of the investment in watershed development programs is being made by the Government of India under these five major programs.

During the last three decades, watershed programs have gone through a sea change. Numerous modifications are made in the watershed programs based on experiences and learnings from the implementation of different generation watershed programs. The first generation watershed programs were mainly designed for soil conservation whereas the second generation watershed programs aimed at conserving degraded land area or more specifically soils (Joshi et al. 2005; Ahluwalia 2005). The watershed development approach was adopted during mid 1980s and in early 1990s third generation watershed programs were introduced that emphasized on participatory approach. The new approach focuses on raising crop productivity and full livelihood improvement programs (Wani et al. 2006). The newly developed approaches like livelihood improvement and productivity enhancement are fairly superior to the earlier approaches but a large number of watershed programs are yet to graduate into a holistic/integrated programs. This paper intends to identify the drivers for the success of watershed programs using meta analysis.

Approach

The watershed development approach that evolved in India is based on the knowledge gained from various programs. Watershed development programs started with soil and water conservation programs and then laid emphasis on water harvesting and increasing crop productivity, and recently focused on livelihood improvement programs (Wani et al. 2006; Government of India, 2008). The new common guidelines emphasized on decentralization of powers to state/district level administration in order to ensure efficient implementation of the program. Although new approaches such as livelihood improvement and productivity enhancement have proven their supremacy, a large number of watershed programs have not graduated fully into holistic/ integrated programs. Wani and Ramakrishna (2005) noted that much of the watershed programs heavily emphasized on water augmentation interventions but did not accord much emphasis on efficient use of conserved soil and water resources.

In the beginning, watershed program went through the structure-driven approach for soil conservation and rainwater harvesting, aiming at only some productivity enhancements. Soil conservation program became synonymous with contour bunding and water conservation with check-dams. This was a compartmental and top-down approach. Along with the evolution of compartmental approach to the integrated and holistic approach, the process and institutional arrangements also evolved. The Government of India responded with revision of watershed guidelines, emphasizing more collective action and participation by the primary stakeholders (Government of India 1994; Hanumantha Rao 2000) and involvement of community based organizations (CBOs), NGOs and Panchayat Raj Institutions (PRIs) (DoLR, 2003). The Government encouraged 'Public Private Partnership (PPP)' in the area of integrated watershed development and evidence indicates that PPP is emerging in this area (Wani et al. 2007). Evidences show that watershed development programs have yielded considerable benefits in terms of equity, sustainability and efficiency (Kerr et al. 2000; Hanumantha Rao, 2000; Farrington and Lobo, 1997; Joshi et al. 2004, 2005; Sreedevi et al. 2006).

Even after almost over four decades of implementation of watershed programs in the country, there was still no strong evidence to show the actual performance of the programs. The results were scattered across different agro-ecoregions and few watersheds have proven their efficiency in terms of B:C ratio, internal rate of return (IRR) and net product value (NPV). In this context, Joshi et al (2005, 2008) assessed the aggregate impacts of watershed programs in India at the macro level, considering different socio-economic and agroecological indicators by adopting a meta-analysis approach. It was meticulously applied to evaluate the impact of watershed programs by Joshi et al., in 2005, with the help of 311 micro-level studies. In 2008, Joshi et al., re-emphasized and evaluated the impact of watershed programs with the help of 636 micro-level studies including the 311 studies included in the previous study to get more authentic and realistic results. These micro-level studies have been critically reviewed and analyzed for upscaling the conclusions to stipulate the macro-level picture of the watershed programs as well as impact of people's participation on the performance of watersheds[1]. This paper identifies drivers for the success of watershed programs in India using these results.

Benefits of Watershed Programs

The watershed programs produce multiple tangible and intangible benefits for individuals as well as for communities as a whole. It emanates that watershed programs have been successful in raising income levels, generating employment opportunities and augmenting natural resources, specifically soil and water in the rain-fed areas (Joshi et al. 2003; 2005; Wani et al. 2005). With the adoption of different soil and water conservation measures and trapping of surface run-off water, watersheds have emerged as the growth engines in the fragile rain-fed areas (Wani et al. 2008).

Summary of multiple benefits derived from watersheds, as indicated in numerous studies, is shown in Table 1. It is obvious that watershed

1 For detailed methodology, see Joshi et al. 2005 and 2008.

Table 1. Summary of benefits from the sample watersheds.

	Particulars	Unit	No. of studies	Mean	Mode	Median	Mini-mum	Maxi-mum	t-value
Efficiency	B:C ratio	Ratio	311	2.0	1.7	1.7	0.8	7.3	35.09
	IRR	Percent	162	27.40	25.9	25.0	2.0	102.7	21.75
Equity	Employment	Person days ha^{-1} yr^{-1}	99	154.50	286.7	56.5	5.00	900.0	8.13
Sustain-ability	Increase in irrigated area	Percent	93	51.5	34.0	32.4	1.23	204	10.94
	Increase in Cropping intensity	Percent	339	35.5	5.0	21.0	3.0	283.0	14.96
	Runoff reduced	Percent	83	45.7	43.3	42.5	0.34	96.0	9.36
	Soil loss saved	Tons ha^{-1} yr^{-1}	72	1.1	0.9	1.0	0.1	2.0	47.21

Source: Joshi et al., 2008

programs in India have yielded multiple exemplary benefits. On the part of efficiency, watershed programs performed well with a mean benefit-cost ratio of 2 that indicates that investment on watershed programs is economically viable and substantially beneficial. However, the performance of watershed in accordance with their BCR was quite varied. About 32 per cent watersheds generated a mean BCR above 2, which is quite modest (Fig. 1). Merely 0.6 per cent watersheds failed to commensurate with cost of the project. The mean internal rate

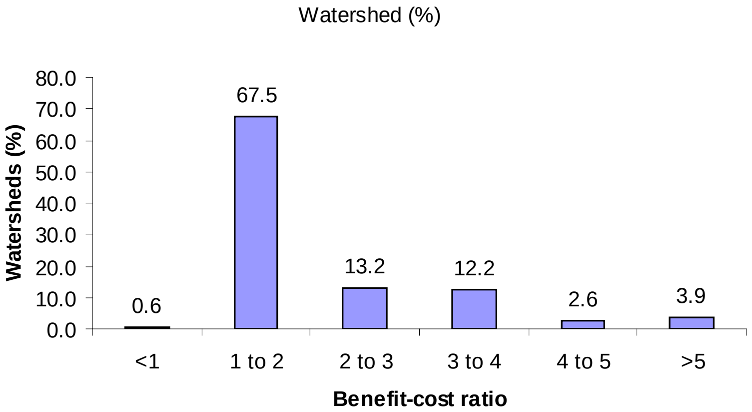

Figure 1. Distribution (%) of watersheds according to benefit-cost ratio (BCR).

of return of 27.4 per cent on watershed investment shows marginal efficiency of the projects. However, that seems to be significantly high and proves that investment in watershed programs is comparable with other successful government programs. It is interesting to note that about 27 per cent watersheds yielded an IRR above 30 per cent. The watersheds with IRR <10 per cent were only 1.9 per cent (Figure 2). These results reconfirm that watershed programs were able to meet their initial costs, generate substantial economic benefits and justify the investment in watershed programs as income levels were raised within the target domains.

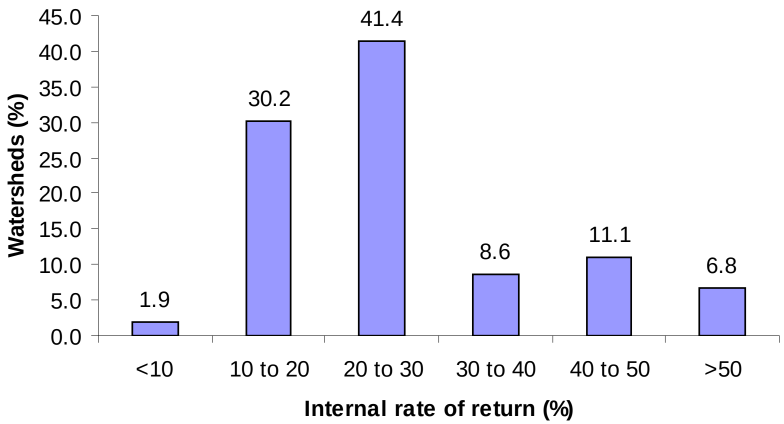

Figure 2. Distribution (%) of watersheds according to internal rate of return.

Another important purpose of the watershed programs was to generate employment opportunities and through that alleviate rural poverty and reduce disparities among rural households. The mean additional annual employment generation in the watershed area on various activities and operations was about 154 person days. It was as high as 900 person days per ha in those watersheds that included multiple activities. Based on these observations, the watershed investment may be characterized as a poverty alleviation program in the fragile areas.

Watershed programs have been specifically launched in the rain-fed areas with the sole objective to improve the livelihood of poor rural households that encounter disproportionate uncertainties in agriculture (Joshi et al. 2005). Their income levels are meager and uncertain. Their plight is further compounded by acute degradation of soil and water resources. The Government of India aggressively intensified watershed program in fragile and high-risk ecosystems, where the farm incomes had markedly descended due to excessive soil erosion and moisture stress. It was viewed that the watershed programs would augment farm incomes, raise agricultural production and conserve soil and water resources in rain-fed areas by providing appropriate technical and financial support.

The watershed programs are largely aimed at conserving soil and water to raise farm productivity. The available evidences revealed that both these objectives were accomplished in the watershed areas. Soil loss of about 1.1 ton ha^{-1} yr^{-1} was saved due to interventions in the watershed framework. Conserving soil means raising farm productivity and transferring good soils to the next generation. With regard to water conservation, it was noted that on an average about 38 ha m additional water storage capacity was created in a 500 ha watershed as a result of watershed program. Augmenting water storage capacity contributed in (i) reducing rate of runoff, and (ii) increasing groundwater recharge. These have direct impact in expanding the irrigated area and increasing cropping intensity. On an average, the irrigated area increased by about 52 per cent, while the cropping intensity increased by 35.5 per cent. Such an impressive increase in the cropping intensity was not realized in many surface irrigated areas in the country. These benefits confirm that the watershed programs performed as a viable strategy to overcome several externalities arising due to soil and water degradation. Therefore, it can be reiterated that watershed could be a safe and effective strategy for augmentation of water resources in the rain-fed areas.

Rain-fed areas are confronted with intrinsic problem of degradation of land and water. Soil erosion, which is often induced by high wind velocity and intense precipitation, not only degrades the land masses but also leads to the problem of sedimentation and siltation of water-bodies/ reservoirs and reduces their storage capacity and causes increased release of CO_2 from degraded silt carbon anaerobically. Consequently, a sizable volume of water that could be stored in these water-bodies/ reservoirs gets lost and leads to floods in low-lying rain-fed areas. Another water related problem that adds to the agony of rain-fed areas is loss of water due to heavy run-off of surface water. In general, rain-fed areas experience many contrasting agro-climatic conditions. A vast portion of rain-fed areas face arid and semi-arid type of situations and receive scanty rains for nearly 50-55 days during monsoons, which is grossly insufficient to meet the year-round water requirement. In contrary, there are regions (entire eastern region) that experience humid and perhumid climate with a long spell of intense and profuse rains. Technological interventions through soil and water conservation can greatly overcome these eventualities.

The above evidences suggest that the watershed programs successfully met initial three principal objectives of raising income, generating employment and conserving soil and water resources. These benefits have far reaching implications for rural masses in the rain-fed environment. The results of meta-analysis further showed that the benefits vary depending upon the location, size, type, rainfall, implementing agency, and people's participation, among others.

People's Participation and Benefits from Watersheds

People's participation in planning, developing and executing the watershed activities is indispensable (Wani et al. 2003a, b, Joshi et al. 2005). Active and voluntary participation of all stakeholders guarantees the successful implementation of watershed programs. Therefore, watershed programs always call for community participation and collective action. It is necessary because individual choices have collective consequences in the watershed framework as several externalities are involved. Action of one group of farmers in one location affects adversely (or favorably) to other group of farmers in different location (off-site impacts). Often the different groups and locations have conflicting objectives with respect to their investment priorities and enterprise choices. These need to be converted into opportunities. The action of all the farmers in the watershed should converge in such a way that the positive externalities are maximized, and negative ones are minimized. To achieve this, the community or stakeholders have to develop their own rules, which resolve their conflicting objectives. It is believed and observed that better organized and effective people's participation would yield higher benefits. Summary of results of people's

Table 2. Summary of benefits from the sample watersheds according to people's participation

			People's participation		
Indicator	Particulars	Unit	High	Medium	Low
Efficiency	B: C ratio	Ratio	2.63 (16.01)	1.60 (29.72)	1.42 (16.36)
	IRR	Per cent	38.28 (10.21)	22.26 (4.74)	17.30 (8.21)
Equity	Employment	Person days/ $ha^{-1}yr^{-1}$	165.17 (5.29)	118.73 (4.31)	105.42 (9.97)
Sustainability	Increase in irrigated area	Per cent	77.43 (8.23)	56.17 (8.07)	29.43 (10.32)
	Increase in cropping intensity	Per cent	44.60 (9.37)	24.96 (10.21)	32.03 (14.21)
	Runoff reduced	Per cent	43.24 (6.03)	40.41 (4.22)	69.00 (7.19)
	Soil loss reduced	T ha^{-1} y^{-1}	1.18 (43.21)	1.1 (18.21)	0.87 (22.33)

Notes: Figures in parentheses indicate t-values

Source: Joshi et al. 2008

participation and benefits from watersheds are given in Table 2. The available evidences confirm that there existed a positive relationship between people's participation and benefits from watershed program. The benefit-cost ratio was much more (2.63) in watersheds where people's participation was high in comparison to the watersheds with low participation (1.42). The other impact indicators were also far ahead in watersheds having greater people's participation.

It is interesting to note that benefits from watershed programs were conspicuously more in the low-income regions as compared to the high-income regions (Table 3). The benefit-cost ratio was 2.25 in low-income regions as compared to 1.75 in high-income regions. The corresponding figures for annual employment generation were 164 and 91 person-days ha^{-1}. The low-income regions call for such investments to enhance income levels of rural poor. This suggests that watershed program should receive higher priority by the government in medium and low-income

Table 3. Summary of benefits from the sample watersheds according to income status of the region.

			Per capita income of the region*		
Indicator	Particulars	Unit	High*	Medium**	Low**
Efficiency	B:C ratio	Ratio	1.75 (15.34)	1.96 (28.21)	2.25 (9.36)
	IRR	Per cent	24.55 (7.23)	27.9 (6.89)	30.64 (6.02)
Equity	Employment	Person days ha^{-1} yr^{-1}	91.05 (7.27)	159.7 (9.16)	164.3 (6.76)
Sustain-ability	Increase in irrigated area	Per cent	48.48 (12.50)	45.83 (8.09)	76.02 (6.71)
	Increase in cropping intensity	Per cent	31.4 (10.82)	34.09 (14.41)	43.75 (10.27)
	Runoff reduced	Per cent	43.21 (9.32)	43.27 (6.81)	49.32 (5.28)
	Soil loss reduced	T ha^{-1} yr^{-1}	1.18 (36.23)	1.1 (41.11)	0.87 (12.26)

Notes: Figures in parentheses indicate t-values. *, **, and *** include the states having per capita AgGDP greater than Rs. 4000, between Rs. 2000 and Rs. 4000, and below Rs. 2000 per annum, as in Joshi et al. 2005. (Source: Joshi et al. 2008)

regions. Such investments will not only raise income and employment opportunities in the backward regions but also contribute in conserving soil and water resources. Fan and Hazell (1997) demonstrated that the returns to investment in inputs as well as research at the margin were higher for dryland areas than for irrigated areas. Farmers in these regions could not invest due to low income and limited opportunities. Government intervention through watershed programs would benefit the rural poor in the low-income regions. Ironically, the participation of beneficiaries in planning and execution of the watershed in the low-income regions was observed to be less than the higher income regions. This implies that poor rural households were less involved in planning and decision-making processes in the watersheds. However, the rural poor in the low-income regions were offering their labour in various activities launched in the watershed. In fact, for the smaller farmers and the landless labourers in the watershed, there is often little prospect for development beyond the employment generated from the watershed works over the project period (Farrington et al. 1999). Perhaps greater involvement of the beneficiaries would yield higher dividends from the investment in watershed related activities.

Above evidences reveal that people's participation was the key determinant in the success of the watershed development programs. People's participation is not only critical during the implementation phase of watersheds but beyond the actual investment phase. In the absence of active involvement of the stakeholders, the watershed programs would not be sustained.

Drivers for the Success of Watershed Programs

The meta analysis identifies drivers for the success of watershed programs. The efficiency of watershed programs is determined by a number of factors. Joshi et al (2005) in their first meta analysis using 311 micro-level case studies found that geographical location, rainfall pattern, focus of watershed program, implementing agency, status of target population and people's participation are some of the critical factors that play a deterministic role in the performance and efficiency of watersheds. The study confirmed that performance of watersheds (Joshi et al. 2005, 2008) is largely influenced by the rainfall. Further, it concludes that the current approach 'one size fits all' does not benefit lower (<700 mm) and higher (>1000 mm) rainfall regions due to scanty and excessive water availability. Therefore, these regions need different soil and water management interventions.

Watershed development is a community approach. Active people's participation is, therefore, highly critical in the success of the watershed programs (Kerr et al. 2000; Sreedevi et al. 2004; Joshi et al. 2005). The results of Meta-analysis showed that the benefits were the highest from the watersheds where people's participation was high (Joshi et al. 2005, 2008). Therefore, the success of watershed programs is people centered and suitable technologies for different agroecoregions.

From Meta-analysis, the following issues have emerged as important drivers of success of watershed development programs in India.

People's Participation

As highlighted above active people's participation is a pre-requisite for the success of watershed development programs. Involvement of local stake-holders in planning, development and execution of the watershed activities is crucial. Watershed is a community development approach and hence, it calls for community participation and collective action (Sreedevi et al. 2007). It is believed that better organized and effective people's participation would yield higher benefits. Community participation does not happen simply; it needs to be nurtured through a process of trust building, by harnessing synergies between the project objectives and needs of communities and most importantly ensuring tangible economic benefits equitably for the community (Wani et al. 2003a, 2007).

The first generation watershed programs in the country were supply-driven. The government officials used to identify locations and decide various activities for implementation of watershed programs, which were funded by Central and state governments. This top-down approach did not match the needs of stakeholders in the watershed. In the absence of people's participation, the potential benefits of the watershed programs could not be realized. To overcome this problem, the concept of Participatory Integrated Development of Watershed was initiated in 1980s. However, only a partial success could be achieved and some radical steps were taken to involve the local stake-holders/people in planning, formulation and implementation of watershed programs in the country. Overtime, people's institutions, like *zilla parishad*, SHGs, and watershed implementing committees were gradually involved into the project management systems. With more funds allocated for watershed development, several non-government organizations (NGOs) aggressively participated in implementing this program, and demonstrated the importance of people's involvement in the success of the watersheds. Most of the arrangements were informal and vary across watersheds and implementing agencies. To make it formal, the 1994 watershed guidelines specifically included people's involvement as one of the conditions in the watershed development. It is more important to see how people's participation comes forward voluntarily. Only voluntary participation (not forced one) would sustain the watershed program. It is, therefore, important to identify conditions under which the watershed beneficiaries would involve themselves in implementation during the project tenure and maintenance of structures after the project is formally over.

Bottom-up Approach

The watershed that involves activities, which are able to cater to the specific needs of local people, certainly attracts higher people's participation. It is therefore, essential to ensure that once the watershed is identified, the needs of the stakeholders must be assessed together by the implementing agency and the stakeholders. Since a watershed has diverse groups of beneficiaries, all genuine and valid needs of each and every group should be appropriately addressed in the watershed. There are reports, which state that in many watersheds only influential and large farmers were involved, leaving out the involvement of small and marginal farmers. Besides, there were evidences that most of the watershed programs were not sensitive to the needs of women and landless laborers. Most often, the women and landless laborers were silently left out of watershed related decision-making processes (Meinzen-Dick et al. 2004, Sreedevi and Wani 2007). Efforts to integrate small and marginal farmers, women and landless laborers into the process require conscious efforts right from the beginning.

Tangible Economic Benefits to Individuals

In spite of bottom-up participatory approach for planning and implementation of watershed development, community participation was not forthcoming in most of the watershed programs. Main reason for low or contractual mode of participation was that a large number of small and marginal farmers were not getting tangible economic benefits as productivity enhancement initiatives were missing to a large extent (Wani et al. 2002). Improved groundwater availability benefited few well-to-do farmers who could invest and extract the groundwater. Such well-to-do farmers had no time to participate. On the other hand, a large number of small and marginal farmers who had time to participate were not getting any tangible benefit. One of the important drivers of success in a consortium approach was tangible economic benefits to a large number of farmers through increased crop productivity on individual farms through *in-situ* rainwater conservation and its efficient use with improved crops/cultivars, nutrient, water and pest management options (Wani et al. 2002, Sreedevi et al. 2004). Through this approach more number of farmers started participating in watershed development programs as they derived tangible economic benefits from the productivity enhancement activities from the first season itself.

Knowledge-Based Entry Point Activity

In most watershed programs, entry point activity (EPA) as identified by the community is undertaken under the project to build rapport with the community activities such as construction of meeting room, school, class room, bore well pump, drinking water tank, etc. However, it was observed that such cash-based EPA passed on a wrong signal to the community that all activities can be undertaken through project funds and they need not contribute their share. Such a subsidy dependency approach never got community ownership, resulting in neglect of the resources invested. ICRISAT-led consortium has developed knowledge-based EPA to build rapport with the community using soil analysis or introduction of disease-tolerant cultivars, etc., which provided free knowledge but for materials farmers had to pay (Wani et al. 2006; Dixit et al. 2007).

The knowledge-based EPA ensured that demand-driven technologies were evaluated by the farmers rather than supply-driven provided by the project staff, which resulted in cooperative and consultative mode of community participation as against the contractual mode in case of direct cash-based EPA. Knowledge-based EPA was one of the important drivers of collective action in the community watersheds developed through consortium approach for technical backstopping (Sreedevi et al. 2004; Shiferaw et al. 2006).

Agroecoregion Specific Technologies

Meta analysis of watershed case studies revealed that the current technologies and interventions showed better impact in terms of B:C ratio and IRR in the 700-1100 mm rainfall agroecoregion and not in

<700 mm and >1100 mm rainfall zones (Joshi et al. 2005). This study highlights the need to identify and adopt specific watershed development technologies for <700 and >1100 mm rainfall zones (Wani et al. 2007). Current practice of allocating greater proportion of resources for RWH structures that too of big size needs close scrutiny. Wani et al. (2003a) have demonstrated the benefits of low-cost water harvesting structures throughout the toposequence that benefited more number of farmers than construction of only masonary check dams at lower reaches in a watershed.

Targeted Activities for Women and Vulnerable Groups

In order to enlist active participation of women and vulnerable groups targeted activities benefiting these groups economically are suggested by Sreedevi and Wani (2007). Based on specific case studies these authors reported that more income-generating commercial scale activities for women resulted in better participation as well as improved decision-making power and social status for women in the family and society. Mere presence of women members on the watershed committee had no real impact on women as they were not effective in decision-making process in the committee (Seeley et al. 2000). Harnessing gender power by balancing activities for men and women, farmers and landless people was found effective to enhance the impact of community watershed programs (Sreedevi and Wani 2007, Sreedevi et al. 2007).

Watershed Institutions/Self-Help Groups

The next stage of people's participation is even more critical. It connotes the phase of implementation while various interventions are being made. This stage requires regular monitoring because success of the watershed depends upon how effectively the stakeholders are monitoring the progress. Evidences show that some successful watersheds constituted informal groups for regular monitoring of watershed activities. However, there was considerable difference between these groups. For instance, some watersheds constituted formal users' associations. The users' groups (UGs) were found active during the implementation phase only. They did not meet regularly once the construction activity was completed unlike the SHGs which met regularly for financial transactions. In a recent study of institutional arrangements in different watershed programs Sreedevi et al. (2007) observed that area groups (AGs) approach adopted in Sujala Watershed program in Karnataka was found far superior over UGs approach in terms of functional efficiency, sustainability and regularity as the membership was voluntary for undertaking project activities in their area and had a role in decision-making process in the watershed.

In the same study, membership criteria and actor linkages in the APRLP, Sujala, Indo-German Watershed development program (IGWDP) and Hariyali guidelines-based watershed program were studied. It was concluded that representation in watershed committee for women SHGs in Suajala and APRLP programs were effective for women's participation and decision-making where as community was not effective/functional in Hariyali program watersheds. The *gram panchayat* had a major role in Hariyali watersheds but it was not the same in other programs. Similarly, the apparent convergence of line department in Hariyali watersheds was evident only on paper. Effective and close working relationship between WDTs, WC and AGs were found in Sujala program (Sreedevi et al. 2007). The concepts like '*Mitra Kisan*' or '*Gopal Mitra*' have shown mixed results across different watersheds in different states (Deshpande and Thimmaiah 1999).

The success of watershed programs would not only rely on the watershed institutions, but depend more on how effective are the credit delivery system, input delivery system, output markets, and technology transfer mechanisms. It is, therefore, imperative to ensure that watershed programs/institutions should also have a strong linkage with various institutions like markets, banks, etc.

Decentralize Decision-Making Process

Decision-making is the key component of watershed programs. The success or failure of watershed programs very much depends on who and how decisions are made. Hence, decentralization of decision-making process is of great importance. A number of watershed evaluation reports show that watersheds performed reasonably well where decision-making process was decentralized. Decentralization of decision-making processes, however, requires flexibility. Often it is noted that the rigid norms did not allow decentralization of decision-making. To some extent, involvement of elected representatives of the people (MLAs and MPs) in the development process may ease the process (Joshi et al. 2004). There are reports that in Madhya Pradesh a conscious effort have been made since 1995 to involve elected representatives of people. Greater involvement of local MLA, MP and PRIs may assume significant role in project planning and execution. Since MLAs and MPs are the elected representatives, who like to take political mileage as a result of developmental programs like watershed, they become accountable to the watershed.

Commensurate Benefits and Costs

Watershed is a community-based approach but individual actions are also important. As stated earlier, the individual actions have collective consequences. There are many conflicting objectives among the stakeholders. Benefit-sharing is, perhaps the most complex challenge in management of watershed. In a watershed framework often benefits do not commensurate the cost incurred and the labour put on the watershed activities. Sharing of benefits in accordance with the cost and contributions of the participants will go a long way in sustaining the watershed program. For example, in the watershed framework, the farmers located at the upper reaches have to invest more but gains of their actions are enjoyed by farmers at middle or lower reaches (Joshi et al. 1996).

Capacity Building

Management of watershed is a complex process. Many of the watershed related activities that aim to conserve, restore and augment soil and water resources call for specialized skills. Most important and weak links in watershed programs are training and capacity building of all the stakeholders – from farmers to policy makers (Wani et al. 2008). Most stakeholders conceive watershed development programs as construction of rainwater harvesting (RWH) structures and never go beyond to include productivity enhancement, income-generating activities, livestock-based activities, institutions, monitoring and evaluation mechanisms, wasteland development, market linkages, etc. Most stakeholders emphasize the area of their expertise. For example NGOs emphasize social mobilization, and RWH and WDTs and technocrats emphasize technologies and overlook holistic integration. Technical backstopping through consortium approach provides on-ground opportunities for training and capacity development of all the actors involved. Thus, training of beneficiaries is another key element for the success of the watershed activities. Unawareness and ignorance of the stakeholders about the objectives, approach and activities is one of the reasons that affect the performance of watersheds. For example, in most watersheds not only the farmers but most stakeholders are not aware of the major constraints for increasing productivity or actual potential of the watershed (Wani et al. 2003 a,b). The stakeholders must be aware about the importance of various activities in the watersheds, and economic, social and environmental benefits. Many actions by the stakeholders in the watershed are being taken in ignorance, which adversely affect the income and environment of other stakeholders and locations. Educating all the stakeholders would minimize such actions, conflicts and maximize benefits from the watershed. Prof. Hanumantha Rao Committee and Sri Eshwaran Committee have strongly recommended the need for training of all stakeholders in the watershed. These recommendations must be adhered to make the program more participatory and successful.

Demand Driven Watershed Approach

Demand-driven watershed activities will attract higher people's participation. Once the watershed is identified, the needs of the stakeholders must be assessed together by the implementing agency and the stakeholders. Since there are diverse groups of beneficiaries in the watershed, their needs should not be overlooked. There are often reports that only the influencial and large farmers were involved, while invariably, the small and marginal farmers were left out. Besides, there were evidences that most of the watershed programs were not sensitive to the needs of women and landless labourers (Meinzen-Dick et al. 2004; Sreedevi and Wani, 2007). Most often, the women and landless labourers were silently left out of watershed related decision-making processes. Efforts to integrate small and marginal farmers, women and landless labourers into the process require conscious efforts right from the beginning. It is therefore necessary that need assessment of the stakeholders should be the precondition in designing and developing the watershed activities.

Target Poor Regions

Poorer regions should receive higher priority to get watershed programs. In poor regions the relatively backward villages should be given higher attention for the watershed program. Overall, the prioritization of stakeholders in poor regions was not sought effectively. It should be ensured that the stakeholders must be involved during planning and execution of the watershed. The observation from few watersheds in low-income regions was that the households generously participated in making the program successful to raise the farm productivity and augment income levels. The landless labourers would have incentives to get more jobs in the rural areas, and women folk for fetching water and fuel wood from the watershed area. There are reports that a well-knitted participatory approach checked migration of rural youth.

Conclusion

The paper has identified the drivers of success of watershed programs by collating information from micro-level studies to give a macro dimension. It was noted that the watershed programs were contributing in raising income, generating employment and conserving soil and water resources. The results of Meta analysis highlighted to undertake research to develop and identify suitable technological interventions for low (<700 mm) and high (> 1000 mm) rainfall regions. It suggested that the watershed program would be a vehicle of development to reduce poverty by raising farm productivity and generating employment opportunities in marginal and fragile environments.

The benefits of watershed programs were more where people's participation was higher. It was noted that people's participation is not only important during the phase of implementation of watershed development activities but beyond the actual investment phase. In the absence of users' involvement, the watershed programs would fail to sustain. The important drivers of success of watershed development programs are related to (i) people's participation, (ii) demand-driven watershed programs rather than supply-driven, (iii) involvement of all stakeholders (including women and landless labourers) in program implementation and monitoring, (iv) decentralization of decision-making process, (v) involvement of elected representatives and PRIs, (vi) tangible economic benefit to a large number of community members (vii) knowledge based entry point activity (viii) establishing effective linkages of watershed institutions with other institutions, like credit sector, input delivery system, and technology transfer mechanism, (ix) predisposition of the community for collective action, and (x) agroecoregion specific technologies.

Watershed program is one of the most important strategies to bring socio-economic change in the rain-fed system. In dryland regions, it has silently revolutionized the agriculture and allied sector through various technological interventions, particularly soil and water conservation, and land use diversification. There is an overwhelming policy and political support. Only problem is lack of appropriate institutional arrangement. This is a major obstacle in attaining the potential benefits of watershed program. Earnest efforts to enthuse stakeholders for their voluntary participation would sustain watershed development and bring prosperity in the rain-fed areas.

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Hydrological Modeling of a Micro Watershed using GIS-based Model SWAT: A Case Study of Kothapally Watershed in Southern India

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Abstract

Rain-fed agriculture in arid or semi arid tropics is complex, diverse, risk prone, and characterized by low levels of productivity and low input usages. Kothapally, a micro watershed of 450 ha area is located approximately 25 km upstream of Osman Sagar in Musi catchment of Southern India. Rainfall in this region is highly erratic both in terms of total amount and its distribution over time. ICRISAT consortium with national partners (Central Research Institute for Dryland Agriculture (CRIDA), National Remote Sensing Agency (NRSA) now NRSC, and District Water Management Agency (DWMA), in Hyderabad, Andhra Pradesh,); and non-governmental organizations (NGOs) started community based watershed development program in Kothapally village in 1999. Since the on-set of the program, water flows and crop parameters in the area have been monitored, creating database of hydrological data and crop yield information. This data was analyzed with the Soil and Water Assessment Tool (SWAT) to study the water balance for different water management options. In addition, flow reduction and soil loss from the fields was evaluated to assess the downstream impacts on the Osman Sagar reservoir. It was found that different water management approaches significantly changes the water balance of the system. Check-dams increase groundwater recharge which can be used for supplementary irrigation of the monsoon crop, and especially the second crop when rainfall is almost nil. Both check-dams and in-situ soil water management reduces the outflow from the system. In-situ soil water management increases evapotranspiration, which can be expected when more water is infiltrated into the soil. Monsoonal analysis shows that watershed management practices reduced surface runoff from 27% to 11%, improved groundwater availability from 9% to 22%, increased ET flow from 53% to 66% of total rainfall, and reduced soil loss from 1.5 t ha^{-1} to 2.5 t ha^{-1} compared to pre-development stage. This program has built resilience in the agricultural systems, and has improved the livelihoods of the farmers.

Keywords: *Hydrological modeling, SWAT, water balance, sediment transport, resilience, watershed management.*

Introduction

Degradation of agro-ecosystems and declining sustainability are major concerns for agricultural development in many poor regions of India where livelihoods depend on exploitation of natural resources (Reddy et al. 2007). In recent years, it has been realized that rain-fed agriculture, which were almost neglected during the green revolution in the 1970s, also has remarkable scope for agricultural development. The International Crop Research Institute for the Semi Arid Tropics (ICRISAT), a non-profit, non-political, international organization, consortium with national partners (Central Research Institute for Dryland Agriculture (CRIDA); National Remote Sensing Agency (NRSA) now NRSC; and District Water Management Agency (DWMA) in Hyderabad, Andhra Pradesh,); and non-government organizations (NGOs) started a community-based integrated watershed development program in Kothapally village as a benchmark study from 1999. This concept ties together the biophysical notion of a watershed as a hydrological unit with the social aspect of community and its institutions for building resilience in agriculture by sustainable management of land, water and other resources (Reddy et al. 2007).

We developed a modeling framework for the Kothapally watershed to represent its hydrology, soil and crop growth dynamics, using a hydrological modeling tool, the Soil and Water Assessment Tool (SWAT). The aim of the present study is to analyze the impact of agricultural water management on the local water balance and implications for downstream systems. More specifically, the objectives are to 1) parameterize, calibrate and validate a hydrological model (SWAT) on the Kothapally watershed, 2) compare the impact of four different agricultural water management scenarios (representing a degraded reference scenario and three watershed development program scenarios on the local water balance, soil loss and downstream impacts).

Study Area: Kothapally Watershed

The Kothapally watershed is located at 17°22’ N latitude, 78°07’ E longitude and about 550 meters AMSL altitude in Ranga Reddy district, Andhra Pradesh, India. This watershed is the part of the Musi sub-basin of the Krishna river basin, and situated approximately at 25 km upstream of the Osman Sagar reservoir (Fig. 1). Krishna is one of the largest rivers in Southern India and the basin lies within the states of Maharastra, Karnataka, and Andhra Pradesh (Immerzeel et al., 2008). Musi is one of the tributaries of the Krishna river and flows completely into state of Andhra Pradesh. There are three major reservoirs in the Musi catchment: Osman Sagar (OS), Himayat Sagar (HS), and Musi Medium (MM).

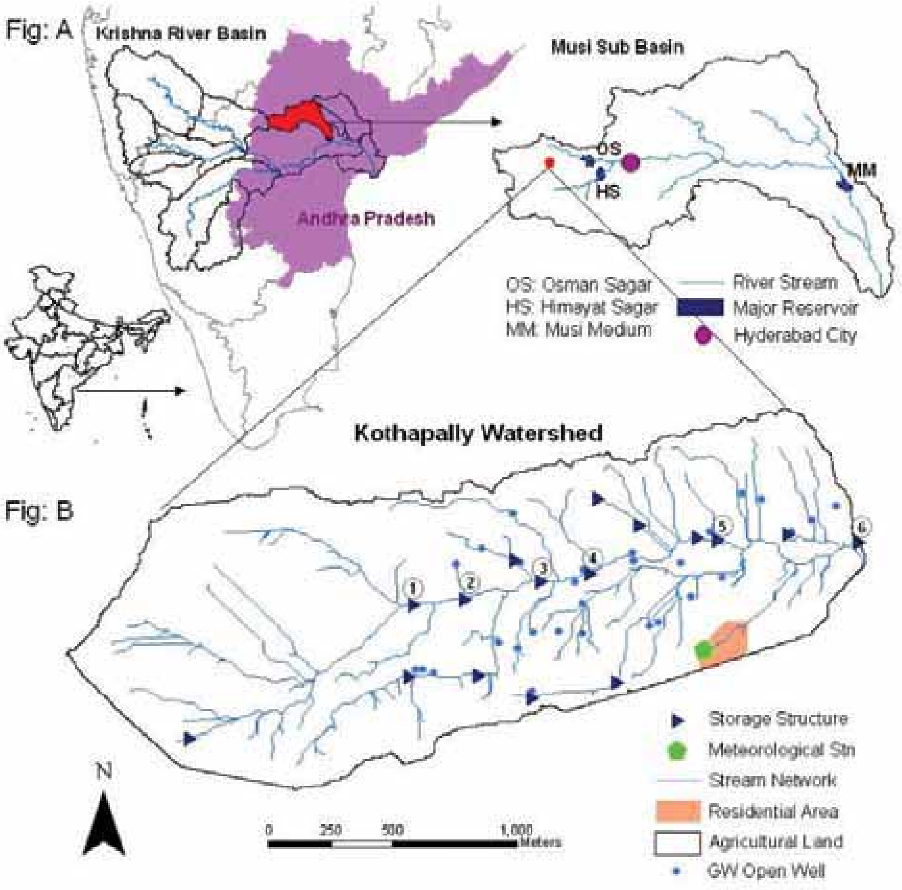

Figure 1. (A) Location of Kothapally watershed in Musi sub-basin of Krishna river basin, down stream reservoirs and Hyderabad city; (B) Stream network, location of storage structures, open wells, meteorological station, and residential area in Kothapally watershed.

The main criteria for selecting this watershed were: existence of a large proportion of cropland under rain-fed farming, low crop yields, non-existence of water harvesting structures and the potential for minimum interventions to conserve soil and water. The villagers have a positive attitude towards the watershed program and are willing to cooperate with the consortium partners to gain mutual benefit. The local leader (*Sarpanch*, Chief of *Panchayati Raj* Institution) has been actively involved in the watershed program. The consortium partners had several rounds of free and frank discussions before undertaking any activity. There is a visible mutual trust and a shared vision among partners. Easy access and timely advice to farmers are important drivers for the observed impressive impacts in this watershed. This has led to enhanced awareness of the farmers and facilitated their ability to consult with the right people when they faced problems (Sreedevi et al. 2004).

The watershed development program in Kothapally started from year 1999 onwards. Contour and graded bunds were built in the fields, and gully control structures, percolation tanks and check dams were constructed in the channels. Constructed bunds across the land slope reduce travel distance and minimize velocity of generated runoff and allow more water to percolate into the fields. This practice created opportunity to accumulate surface runoff along the contour line or disposes surface water safely outside the field and protects soil erosion. Check dams and other ex-situ practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge. Adoption of low-cost water storage and harvesting structures ensured water conservation benefits more equitably distributed in different parts of the watershed landscape.

Water availability and crop yield have substantially improved after the watershed development program was implemented (Sreedevi et al. 2004). For instance, many of the wells that were not functioning due to low groundwater levels have reverted into active well with good amounts of water yield. Moreover, the cropping pattern has changed in recent years. Farmers who used to be cultivating cotton of traditional varieties, sorghum, maize, paddy, onion, and chilly before the onset of the watershed development program, have started cultivating higher yielding cotton varieties (BT cotton) as irrigation water supply from the wells is now reliable. Those farmers who do not have wells for irrigation also started cultivating cotton as the soil moisture availability has improved after the in-situ conservation practices which allowed to crop to survive for another two to three months after monsoon without irrigation. Maize and paddy are now cultivated only in limited areas during monsoon and vegetables is being grown in irrigated area during summer.

An integrated nutrient and pest management approach was adopted along with the soil and water conservation measures. Detailed characterizations of soil chemical properties in agricultural fields suggested that Kothapally soils were deficient not only in major nutrients (N and P) but also had a poor status of zinc (Zn), boron (B) and sulphur (S) (Sreedevi et al. 2004). In addition to supplying chemical fertilizers, *Gliricidia* plantations along the field bunds started to generate N-rich organic matter in watershed. Vermi-composting was undertaken by self-help groups as a micro-enterprise to generate income and nutrient rich organic fertilizer.

The socio-economic status has improved after introducing IWM approach in the Kothapally village (Sreedevi et al., 2004). Most of the farmers were solely dependent on agriculture in 1999 and earlier. Farmers were motivated to do other job activities and services along with cultivating crops, which together with improved yields, led to a substantial change in their livelihood in recent years. Farmers started doing dairy farming, transport services, labor work for building roads and houses, nursery plantation and engaged with small scale business and local services (viz., running small café, saloon shop, stitching cloths in home, selling food and general materials in shops, selling coupons for recharging mobiles, etc.) locally. Approximately one fourth households in Kothapally watershed currently generate additional income other than agriculture. The average household income in the Kothapally watershed is about 50% higher compared to adjoining villages without watershed interventions (Sreedevi et al. 2004).

Methodology

Input Data and Model Setup

SWAT requires three basic files for delineating the watershed into sub-watersheds: Digital Elevation Model (DEM), Soil map and Land Use/Land Cover (LULC) map. A meteorological station (Figure 1) was installed in Kothapally watershed in 2000. Daily data of precipitation, wind speed, relative humidity, solar radiation and air temperature were monitored, and provided as input to the model. Check dam plays an important role in watershed hydrology; it captures excess surface runoff and prevents/reduces soil loss. We recorded exact location of storage structures using GPS and measured its surface area and storage volume. Structures that comprises storage capacity equal to or greater than 350 m^3 were exactly located as a reservoir into SWAT setup and smaller structures were all together lumped into single unit at every stream/channel. All together 14 reservoirs were created (Figure 1); their year of construction and other salient features (i.e., surface area and total storage capacity) were provided as inputs into model. Parameters concerned with management operation like tillage, plantation, fertilization, irrigation and harvesting were provided as input to the model. Cropping pattern in Kothapally is dominated by cotton as a major crop. Therefore, we assigned cotton plantation and its cultivation under the land management operation between June and December months.

Model Calibration

Calibration is required to characterize the system correctly before making any simulations for decision making. SWAT generates default values for each variable and allow user to modify parameter values during calibration process. In present study, model was calibrated based on (1) discharge at outlet, (2) reservoir stage-volume data, (3) sediment flow at outlet and (4) crop yield; and further model is validated using groundwater (water table) data.

Scenario Development

Impact of watershed management practices on water availability, sediment loss and crop yield was assessed. Four scenarios were developed with combination of (a) with or without In-situ land management practices and (b) with or without building storage structures in stream channel (called as ex-situ management). Thus scenarios are: 1) in-situ + ex-situ; 2) in-situ + no ex-situ; 3) no in-situ + ex-situ; 4) no in-situ + no ex-situ. ICRISAT meteorological data of 31 years from period 1978 to 2008 was used for scenario generation. Prior to this, Kothapally and ICRISAT rainfall data was compared for known period between year 2000 and 2008 and a good correlation (R^2=0.90) was found on monthly time scale.

Results

Water Balance of Different Water Intervention Scenarios

Different water interventions significantly change the water balance components in watershed (Figure 2). Before the introduction of the watershed development program (scenario four), approximately 60% of the rainfall became evaportranspirated (ET), while some 10% recharged the groundwater aquifer and 20% was lost from the watershed boundary as outflows, during the first cropping season. When the watershed development program was in place, the amount of water leaving the watershed as ET had increased to around 70%, groundwater recharge was also higher than previously, while outflows from the watershed was now less than 10% of the total water balance (scenario one). Constructing check-dams substantially increased groundwater recharge (scenario three), while in-situ practices resulted in a higher ET, since more water was available as soil moisture in the fields, and higher groundwater recharge (scenario two).

Sediment Transport and Soil loss

The average soil loss from the watershed has been less than 3.0 t ha in all years except in 2000, when Kothapally experienced a heavy downpour of 303 mm within 24 hours in August, which created enormous

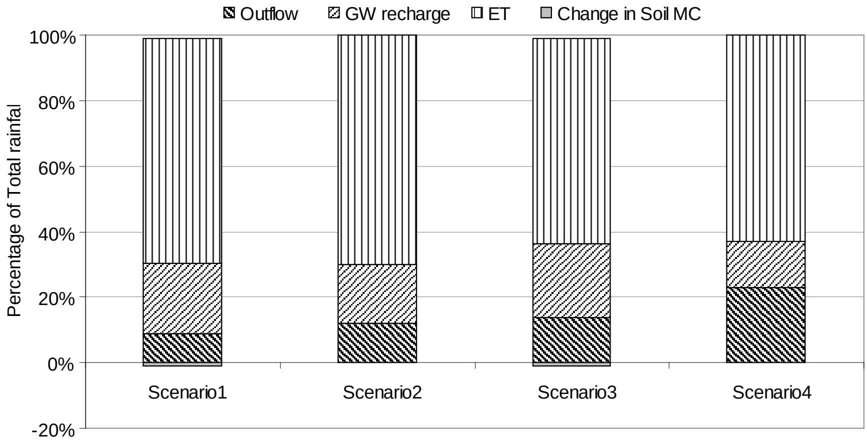

Figure 2. Water balance for the four different water management scenarios for the first cropping season (from June to Dec); scenario-1: in-situ + check-dams; scenario-2: in-situ + no check-dams; scenario-3: no in-situ + check-dams; scenario-4: no in-situ + no check-dams. GW recharge = groundwater recharge. ET = evapotranspiration.

amounts of runoff and soil loss from the watershed boundary. Simulations suggest that on average 7 mm of soil was lost from the entire watershed due to this extreme event. A soil loss map for 2000 shows that soil is lost from a large area of the watershed (Figure 3). Soils are deposited in those micro-watersheds where check dams were built, since the check

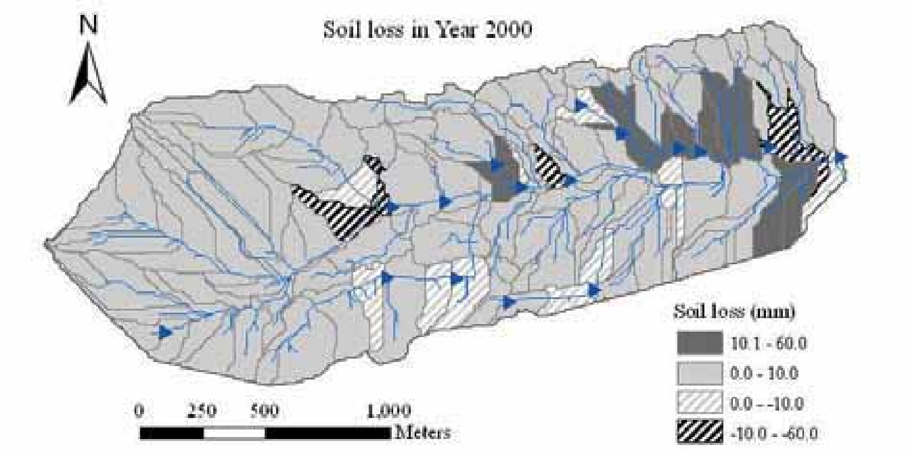

Figure 3. Soil loss in different micro-watersheds of Kothapally area in year 2000. Gray colour in map shows soil loss and crossed lines shows its deposition (also shown by negative numbers).

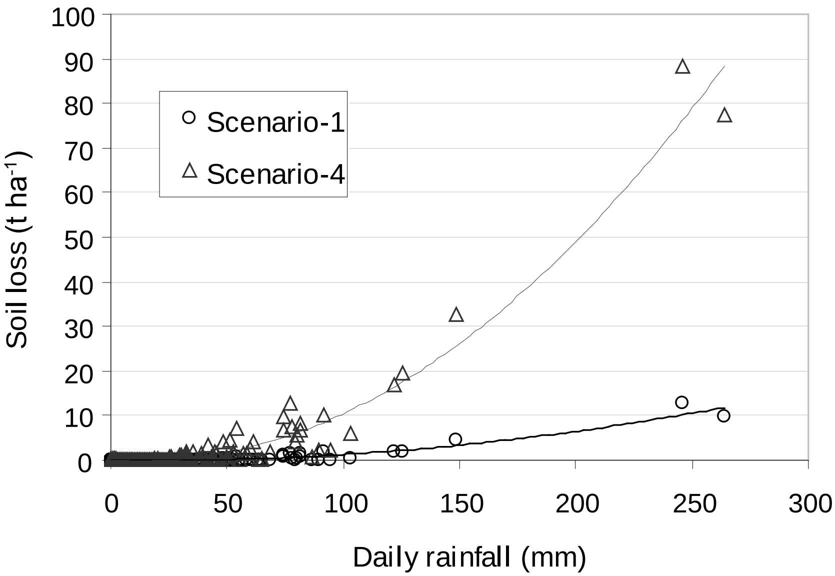

Figure 4. Rainfall vs. soil loss; scenario-1: in-situ + check-dams (post watershed development); scenario-4: no in-situ + no check-dams (no watershed development).

dams reduce the flow velocity of the water and allow silt particle to settle down.

Soil loss is strongly affected by rainfall intensity (Figure 4). Rainfall intensity below 50 mm/day did not generate much soil loss in any of the four management scenarios. However, a clear difference in soil loss can be seen between the situation before and after the implementation of the watershed development program at rainfall intensities above 50 mm/day, where more soil is lost from the system without water interventions. It is apparent that soil loss from the fields as rainfall intensities above 100 mm/day significantly impacts on downstream systems, in this case the sediment load to the Osman Sagar reservoir, without the watershed development programs. High rainfall intensities are expected to become more common with a changing climate, and soil loss from the fields can therefore be expected to increase in the future.

Discussion

Water Management Interventions Improve the Resilience of Small-scale Tropical Agricultural Systems

Because of the watershed development programs, the livelihoods of the farmers in the Kothapally village have improved. Agricultural yields are on the increase, and farmers are now able to save some of the incomes generated by the farm and to re-invest in the business. Because of diversification of sources of income due to more off-farm activities, their resilience to external shocks has been improved. More specifically, the water interventions have reduced the inherent risks in agriculture in the semi-arid zone posed by high rainfall variability and frequent dry-spells, thereby building resilience in tropical agriculture. With a more erratic precipitation under future climate change, water management interventions in tropical agriculture are likely to be of even greater importance.

The Choice of Water Management Intervention Depends on Hydro-ecological and Social Settings

Watershed management programs including in-situ water harvesting and check-dams, significantly change the water resources availability in watershed. Check-dams are helpful in storing water for groundwater recharge, which can be used for irrigation, as well for protecting soil loss. In-situ water management practices improve infiltration capacity and water holding capacity of the soil, which results in higher crop water availability.

The strategy of the watershed development program should be based on hydro-ecological zones and soil characteristics. In-situ management may be sufficient at higher rainfall amounts, while ex-situ water management for supplementary irrigation may be needed to complement the in-situ system at lower rainfall amounts (below 600 mm yr^{-1}) and to bridge dry-spells. However, practicing both in-situ and ex-situ management in low rainfall zones may not be economically viable because with in-situ management there may not be enough local run-off to collect in the ex-situ storage systems. At rainfall amounts above

600 mm yr^{-1}, both practices might be implemented without the risk of them competing with each other for water. In-situ practices in such areas would improve infiltration and at the same time check-dams can store surplus amounts of water and sediment. A common strategy cannot be implemented everywhere; it depends on topographic and soil characteristics, the location of the watershed and the objective of the development.

Ex-situ management is indeed helpful for storing water but it may create an unequal distribution if only some of the framers will be benefited but not entire community. In the Kothapally village, some farmers have wells on their properties which they use for irrigation of their own fields first, and, if there is water left after they have fulfilled their own irrigation requirements, they allow neighbouring farmers to use their water for a proportion of the income from that farm. Thus, in the case of Kothapally, the farmers with wells on their properties will benefit more by having the check-dams than the others.

Conclusions

Watershed interventions in agriculture in the form of in-situ and ex-situ water harvesting systems are important for building resilience in tropical agriculture, but may at the same time cause negative impacts to downstream systems because of reduced water flows. The watershed interventions in the Kothapally village resulted in higher infiltrability and waterholding capacity of the soil, as well as increased groundwater levels, which enabled supplementary irrigation of the monsoon crop to bridge dry-spells, and full irrigation of a second dry season crop on 30% of the fields. Soil loss has decreased by a factor ten because of the watershed development program, which is expected to have positive impacts on instream river ecology and the life-span of the reservoir downstream. Case study of Kothapally watershed has shown that integrated watershed management approach has built resilience in the agricultural systems, and has improved the livelihoods of the farmers.

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New Tools for Monitoring and Modeling Hydrological Processes in Small Agricultural Watersheds

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Introduction

Integrated watershed management is regarded as the most appropriate strategy to rehabilitate fragile ecosystems and improve the livelihoods of people living in rain-fed areas. The rural people living in such areas are under constant threat of low yields, unemployment and consequently poor living conditions. Effective watershed management can substantially reduce risks, make water for drinking and cultivation available in an equitable manner, increase farm productivity and raise income through a host of auxiliary activities. The comprehensive assessments of watershed programs in India by ICRISAT-led Consortium has shown that considerable improvement in the performance of watershed program can be achieved through scientific planning, management and evaluation of watershed projects. The new common guidelines for watershed development projects (GoI, 2008) also emphasizes using scientific data and new science tools to bring about paradigm shift in the different aspects of watershed programs.

The information on runoff volume, peak runoff rate, soil loss and other related parameters are essential for the proper planning and development of both in-situ and ex-situ soil and water management interventions. However, the adequate availability of the watershed scale hydrological data is scanty in most regions of India. This resulted in higher watershed development costs and often failure of the runoff harvesting and soil conservation structures. There are several reasons for unavailability of adequate hydrological data from the small agricultural watersheds. One such reason is unavailability of good standard equipments for monitoring soil loss from such small watersheds (50-5000 ha).

ICRISAT along with its partners have developed a range of new equipment for monitoring runoff and soil loss and hydrological models, which can be used on small agricultural watersheds. Some of these equipment and hydrological models are discussed in this paper. The salient features of these runoff and soil loss monitoring equipment in terms of accuracy, reliability, and cost effectiveness are also covered. The use of hydrological models in generating required information for proper planning and impact assessment of watershed programs and their key features in term of input data requirements, accuracy and output are also described.

Soil Loss Measurement from Agricultural Watersheds

The monitoring of soil loss and sediment flow from the small agricultural watersheds is a complex and difficult task. There are very few standard types of equipment available in the market, which can be used for measuring the soil loss from the small agricultural watersheds. Some of the serious problem with commonly used method and some new developments (Pathak and Sudi 2004), which has been made at ICRISAT Center for monitoring soil loss and sediment flow from the small agricultural watersheds are discussed below.

Manual Sampling

In India, manual sampling is still the most commonly used method for monitoring sediment flow from the small agricultural watersheds. However, there are some serious problems with this method. The extreme variation in sediment concentration during the runoff events makes this method totally inappropriate for monitoring sediment from small agricultural watersheds (Fig. 1).

Due to this extreme variations in sediment concentration the expected error in estimating the soil loss could be extremely high and are often found in the range of $\pm$ 30 to 420% that of actual soil loss. Also operationally it is very difficult to collect the runoff samples at the right time particularly during high rainfall events. This makes the data collected by manual method highly unreliable and often useless. Therefore the manual method of runoff sampling is not recommended for monitoring soil loss from the small agricultural watersheds.

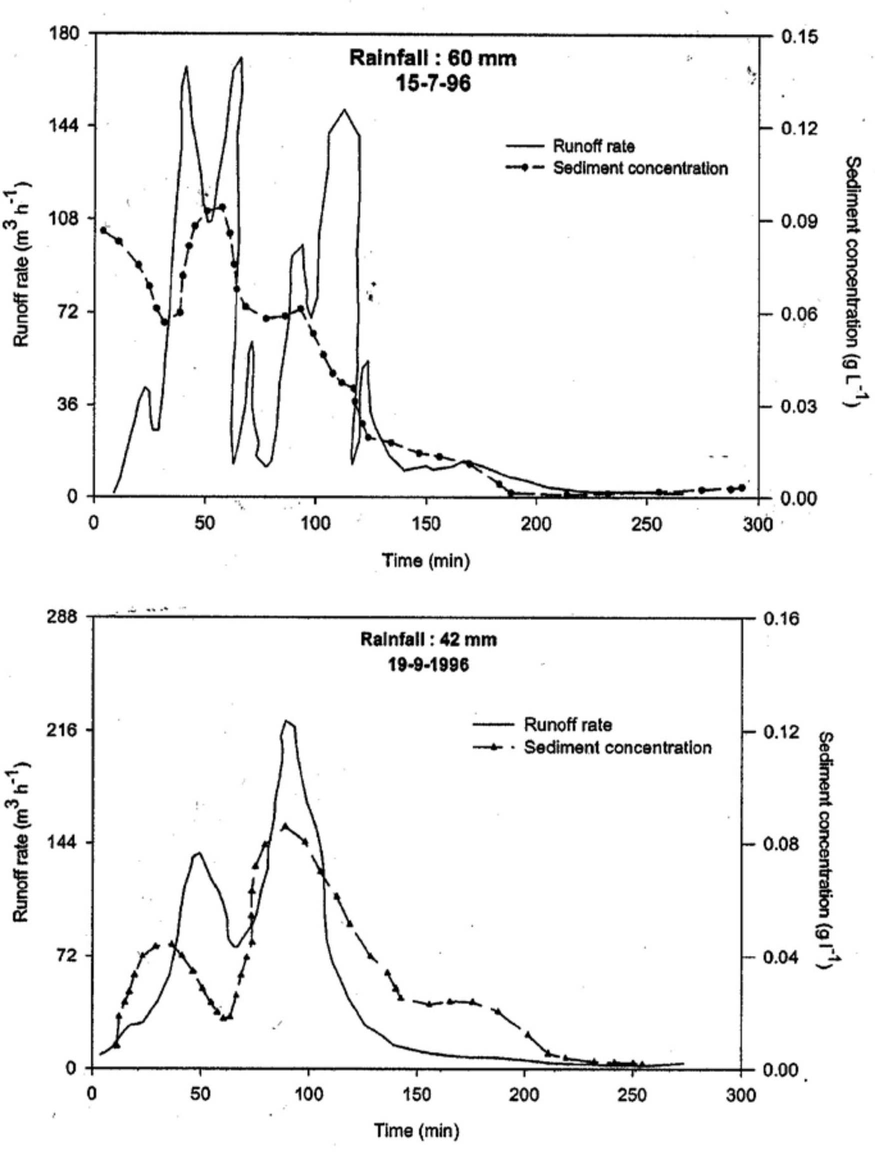


Figure 1. Sediment concentration variation with time during two runoff events at BW7 watershed, ICRISAT Center, Pantancheru, Andhra Pradesh, India (Pathak et al. 2004)

Sediment Samplers

Clock-based automatic sediment sampler

A clock-based automatic sediment sampler was developed at ICRISAT to monitor soil loss from small agricultural watersheds (Fig. 2). The sampler consists of a clock located at the center of a circular channel of 40 cm diameter. The channel is about 2.5 cm wide and 2.5 cm high with 50 small vertical independent partitions. An arm is fixed to the clock and this arm turns in a circle directly over the channel. Using a flexible plastic pipe, the runoff sample is led to the partitions in the circular channel. Each partition has a small pipe connected to the base of the chamber that carries the runoff sample to labeled bottle attached at a somewhat lower level. Once the samples are collected, they are related to the runoff hydrograph.

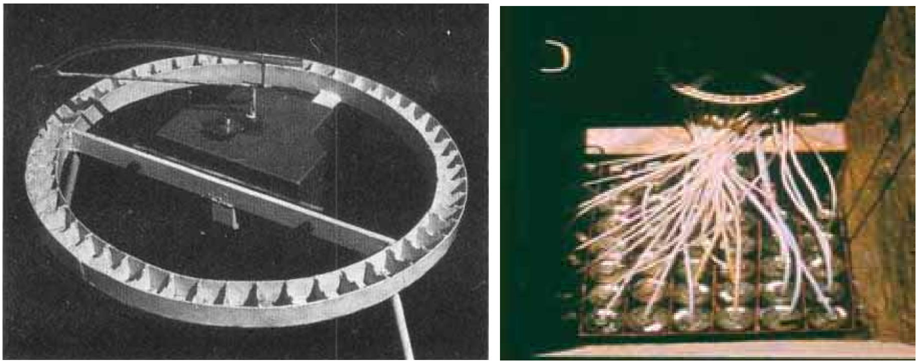


Figure 2. Clock-based automatic sediment sampler for small agricultural watersheds

Depth integrating sediment sampler

A simple depth integrating sediment sampler had been developed (Pathak et al. 1991) for monitoring sediment flow from the small agricultural watersheds (Fig. 3). This sampler has no moving parts and easy to fabricate and install. The working principle and details are given below.

Working principle and details: To simplify the design of the runoff sampler, momentary or instantaneous fluctuations in sediment

Figure 3. Depth integrating sediment sampler for small agricultural watersheds

concentration across a flow section are avoided. This is done by selecting the sampling site near the high-turbulence downstream point where the sediment variation across the flow section is minimized. The rapidly fluctuating nature of runoff flow from small watersheds, and its relation with time, is used in the sampler to account for the time variation in sediment loads (Pathak 1991). This is achieved by taking representative samples for different hydrograph segments and by collecting samples at different flow depths. The samples are taken through small-diameter pipes which are set at specified heights from the bed of the channel (Fig. 4), and are connected to separate containers by plastic pipes.

The working principle of the sampler is explained in Figure 5 in the form of a single-peak runoff hydrograph. The lowest pipe samples the sediment throughout the total runoff period, while the upper pipes, depending upon their relative positions, sample for shorter periods. The sample volume and sediment concentration for each container are determined individually and hydrograph data are recorded at each sampling point. The actual sediment concentrations for the different

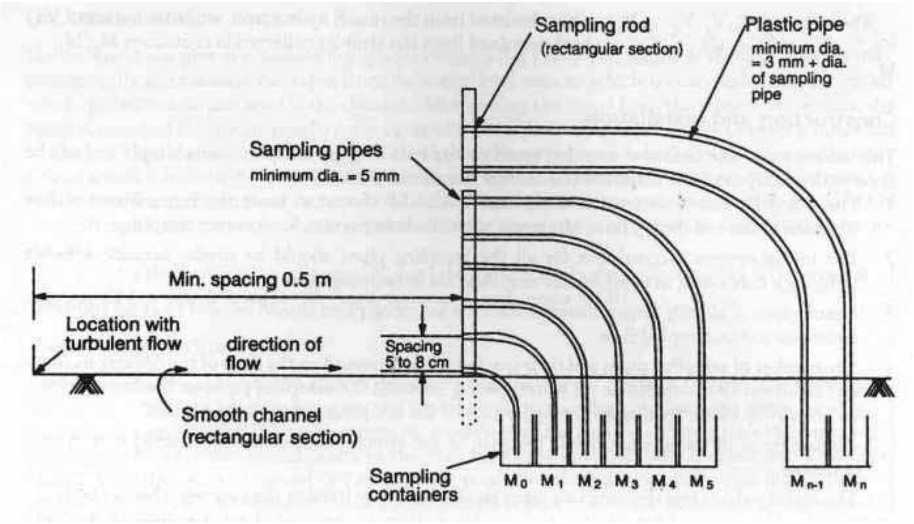


Figure 4. Schematic diagram of the depth integrating sediment sampler

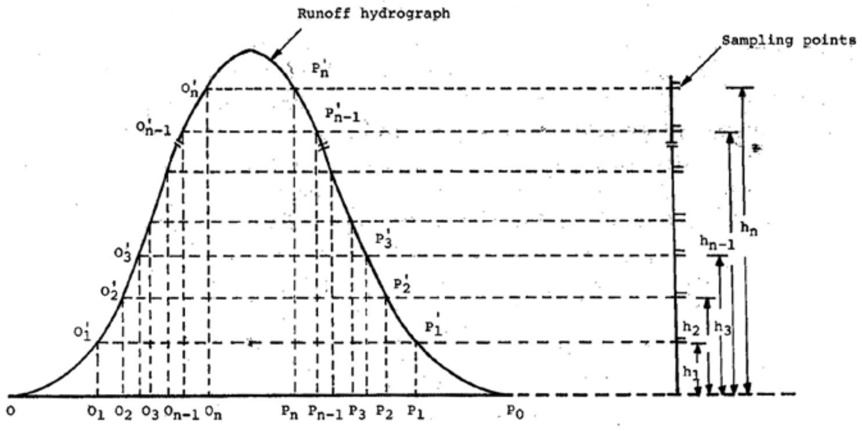


Figure 5. Working principle of the sediment sampler

hydrograph segments and total soil loss are calculated by using the following equation:

$$St = V_0 (Vs_0 Cs_0 - Vs_1 Cs_1) / (Vs_0 - Vs_1) + V_1 (Vs_1 Cs_1 - Vs_2 Cs_2) / (Vs_1 - Vs_2) + V_{n-1}(Vs_{n-1} Cs_{n-1} - Vs_n Cs_n) / (Vs_{n-1} - Vs_n) + V_n Cs_n$$

where $Vs_0, Vs_1, Vs_2, ..., Vs_n$ and $Cs_0, Cs_1, Cs_2, ..., Cs_n$ are the volumes and sediment concentrations of the runoff samples collected in the containers $M_0, M_1, M_2, ..., M_n$, respectively

The $V_0, V_1, V_2, ..., V_{n-1}, V_n$ are the runoff flow volumes for the hydrograph segments, $OO'_1O_1 + P_1P'_1P_0$, $O_1O'_1O'_2O_2 + P_2P'_2P'_1P_1$, $O_2O'_2O'_3O_3 + P_3P'_3P'_2P_2$, ..., $O_{n-1} O'_{n-1}O'_nO_n + P_nP'_nP'_{n-1}P_{n-1}$, $O_nO'_nP'_nP_n$.

The values of $V_0, V_1, V_2, ..., V_n$ can be calculated from the runoff hydrograph, while the values of $Vs_0, Vs_1, ..., Vs_n$ and $Cs_0, Cs_1, ..., Cs_n$ can be determined from the samples collected in containers $M_0, M_1, ..., M_n$.

However, the sediment sampler has few limitations and these include:

- it is not efficient where the eroded sediments contain a high proportion of coarse sands;
- for storms having multiple peaks (more than two) its accuracy to estimate soil loss is low;
- this sampler is useful only for small watersheds (upto 1000 ha).

Microprocessor-based Automatic Sediment Sampler

The Microprocessor-based Automatic Sediment Sampler can be used to measure soil loss as well as temporal changes in sediment movements during the runoff hydrographs from the agricultural watersheds/plots. At ICRISAT a micro-processor based automatic sediment sampler (Fig. 6) has been developed for small agricultural watersheds (Pathak and Sudi 2004).

This sediment sampler consists of circular sample collection unit fitted with DC shunt motor and bottles, microprocessor-based control unit, 12v 55 Amph battery, bilge submergible pump, water level sensors, and solar panel (optional for recharging 12v battery)

Figure 6. Microprocessor based automatic sediment sampler.

Theory of operation and other details of sediment sampler: Under idle conditions the entire system draws a minimum current of about 60 mA. The uninterrupt program enabled it to keep scanning for the runoff water in the channel. The microprocessor-based control unit, which when initialized by the water level sensors, operates the system, first by purging the pipe to clean off the old water sample, positions the nozzle on sample hole and then pumps the sample water into a bottle and positions the nozzle on to the next purge hole. The pump is kept in the channel, completely immersed in the flowing water. About 750 ml of runoff water is pumped into each bottle.

The microprocessor-based control unit: The microprocessor-based control unit controls the pump and motor of the sediment sampler automatically after sensing the input from the water level sensors that are energized when the runoff water reaches to a certain level in the channel/drain.

There are two types of control units viz. (1) single level sensor control unit, and (2) multiple level sensor control unit (Fig. 7). The multiple level

Single level sensor

Multiple level sensor

Figure 7. Single and multiple level sensors of control unit

sensor control unit having four or more level sensors also performs the operation in the similar fashion. In order to attain higher accuracy, during sampling the sampling periods are shortened in accordance with the new sensors. When the L1 and positive sensors come in contact with water the logic level is “0”. With the addition of a new sensor the sampler switches over to a new sampling period that is half of the previous sampling period. For example, if the initially selected interval (L1) is 40-min then the three different levels L2, L3, and L4 gives new sampling periods of 20-min, 10-min and 5-min, respectively.

Salient features of the sediment sampler

- Fully automatic runoff samples collection
- Samples can be collected at required time interval (15, 30, 60 and 120 minutes or any desired time intervals) as well as at required flow depths
- Can be used for soil loss estimation as well as temporal distribution of sediments during runoff hydrographs
- The 8748 microprocessor-based controller is used which can be reprogrammed easily
- Suitable even for the remotely located gauging station as well as small to medium size watersheds (1-5000 ha)
- Accurate and reliable data acquisition
- Simple and easy to operate
- Efficient and cost-effective

Runoff Measurement from Small Agricultural Watersheds

Accurate determination of runoff volume, peak runoff rate, and other related information from small and medium areas invariably requires the continuous recording of the water level. Stage-level recorders are commonly used for this purpose. Many types of stage-level recorders are commercially available. They can be broadly classified into two types: mechanical type and digital type stage-level recorders.

Mechanical Stage-level Recorder

In India, mechanical type runoff recorders are most commonly used for monitoring runoff. The mechanical stage-level recorder mechanically converts the vertical movement of a counter-weighted float resting on the surface of a liquid into a curvilinear, inked record of the height of the surface of the liquid relative to a datum plane with respect to time. The time element consists of a weekly winding spring-driven clock supported on a vertical shaft to which the chart drum is firmly secured vertically (Fig. 8). The gauge element consists of a float and counterweight-graduated float pulley. The movement of the float is transmitted to a cam and, with the help of a set of gears, it moves the pen on the chart in a vertical direction. Some recorders have a reversing mechanism and can therefore record an unlimited range of flow depth (Pathak 1999).

Figure 8. A drum-type mechanical runoff recorder.

There are several operational problems with the mechanical type runoff recorders. The most common problems are related to clock functioning, gear set functioning, pen and its marking on charts. The processing of data from chart is very time consuming and the recorder needs continuous monitoring.

Digital Automatic Stage-level Recorder (Thalimedes)

Thalimedes is a float operated shaft encoder with digital data logger which can be used to continuously monitor the runoff from the watershed/field (Fig. 9). It is easy to handle and its cost-effective ratio makes it an appropriate device for modernization of existing mechanical chart-operated stage-level recorder monitoring stations (Pathak 1999).

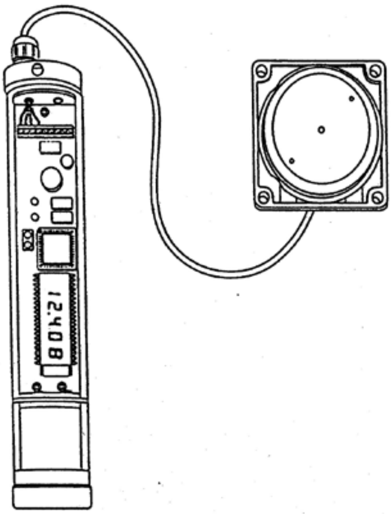


Figure 9. Digital runoff recorder

The in-situ data logging of the measured value results in the reduction of the expenditure of both cost and time as well as in elimination of errors that are brought in when data is readout or transferred manually. It eliminates all the problems associated with the mechanical chart type recorders such as the problems associated with the movement of chart, and drying/clogging/blotting of pen in the chart paper. The continuous recording of water levels ensures an uninterrupted measurement in changes of water level over a long period, which in turn yields a reliable database for competent decisions.

Salient features of digital automatic stage-level recorder (Thalimedes) compared to mechanical stage-level recorder are the following

- Thalimedes is a microprocessor-based electronic data logger. Being float operated, the shaft encoder is an ideal stage-level recorder.
- Digital LCD of measured water level (mm, m, or ft), date, time, and battery status (not possible with mechanical models).

- Thalimedes operates on a single 1.5 V DC C type battery, whichlasts up to 15 months at hourly measurement and not possible withmechanical models.
- Ring memory: EEProm stores up to thirty thousand (30000)measured values.
- Sampling and logging intervals can be set from 1 minute to 24 hours (flexibility not possible with mechanical models).
- Data transfer through non-contact IrDA interface (infrared technology) avoiding connectors and cable; 11000 measured values in 4 seconds for further processing.
- No moving parts; problem due to gear/clock and chart mechanism is avoided.
- No switches/connectors; so there are no contact problems.
- Compact, rugged, and light (only 0.32 kg); shaft encoder 0.14 kg.

Integrated Digital Runoff Recorder and Sediment Sampler Device

An Integrated digital runoff recorder and sediment sampler device has been developed by ICRISAT Scientists in collaboration with Farm and Engineering Services at ICRISAT (Fig. 10).

Figure 10. Integrated digital runoff recorder and sediment sampler device (new microprocessor is shown in inset).

The main feature of this new equipment is that all the operations (viz. runoff recording, sediment sampler operation and solar panel controller etc.) are controlled by one single micro-processor unit. The unit can store the data up to 130,000 records in 1 MB flash memory, which has a ring memory system. The complete unit works on a 12 v battery with solar panel to recharge it. Even during the emergency power operation or main battery failure, runoff recording is done with its backup battery. This integrated unit makes the calculation of runoff and soil loss very easy and accurate. It is also very cost effective.

Hydrological Models for Agricultural Watersheds

The hydrological data at the watershed scale are generally not available in most regions of India. The hydrological models can be effectively used to generate such data, which can be used for the planning and design of various watershed interventions. These models can also be used to assess the long-term impact of watershed program on soil and water resources. Some of the hydrological models developed at ICRISAT are discussed below.

Simple Runoff and Water Balance Models

Information on surface runoff is needed in the planning and design of watershed interventions particularly on soil and water management. For example, it is needed in the design of soil conservation structures, runoff harvesting and groundwater recharging structures, drains and other interventions. Runoff models can be used to generate this vital information. Some of the simple hydrological models, which have been developed at ICRISAT for small agricultural watersheds, are described below.

RUNMOD Runoff Model

A parametric simulation model was developed to predict runoff from small agricultural watersheds (Krishna 1979). The input data for it are the daily rainfall amount, storm duration or rainfall intensity, pan evaporation, and soil moisture. By means of a univariate optimization procedure, measured runoff data are used to determine the proportion of rainfall that infiltrates and the part that runs off. Once these parameters are determined for a particular soil and land management treatment, they can be applied directly to other watersheds of similar cover, topography, and moisture storage and transmission properties for predicting runoff and other water balance components. The model embodies upper zone and lower zone soil moisture reservoirs that are depleted by evapotranspiration and recharged by infiltration sequentially from the top. When both reach their capacities, further infiltration causes deep percolation. Daily evapotranspiration is computed from open-pan evaporation, vegetative cover, and the amount of water in the root zone. Hydrologic data from three ICRISAT Vertisol watersheds of similar size, shape, and topography but having different land management treatments were used for deriving and testing the model. Two years of data were used for calibration and the model was tested with data from the third year. In all cases, there was excellent agreement between computed and observed runoff events.

This model can be used on Vertisols for which it has been tested and cablibrated parameters are available. Its performance on other soils is not known. This model's biggest limitation is its parameters, which need to be determined for different soils, different land and water management system and rainfall conditions.

SCS Curve Runoff Model

A runoff model based on a modified SCS curve number technique and on soil moisture accounting procedure was developed for small watersheds in the semi-arid tropics (Pathak et al. 1989). In this model, certain soil characteristics that have strong influence on runoff such as cracking and land smoothing are included. The model uses one day time intervals and needs simple inputs, which are normally available such as: daily rainfall, pan evaporation, canopy cover coefficient, soil depth, initial soil moisture, moisture at wilting point and field capacity. The main outputs are daily runoff volume and soil moisture. The model has four input parameters which are estimated through calibration using measured runoff and soil moisture content data. Once the parameters are determined for a particular soil and land management system, they can be used to predict runoff and soil moisture from other ungauged

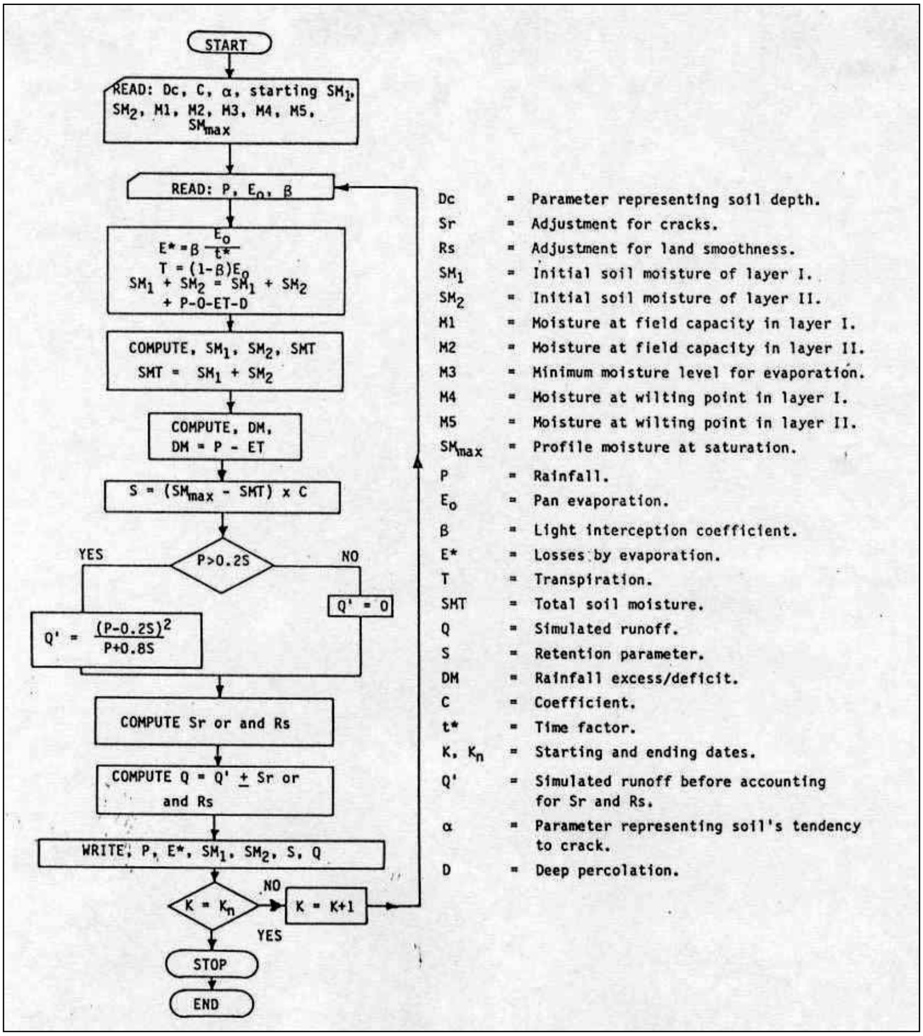
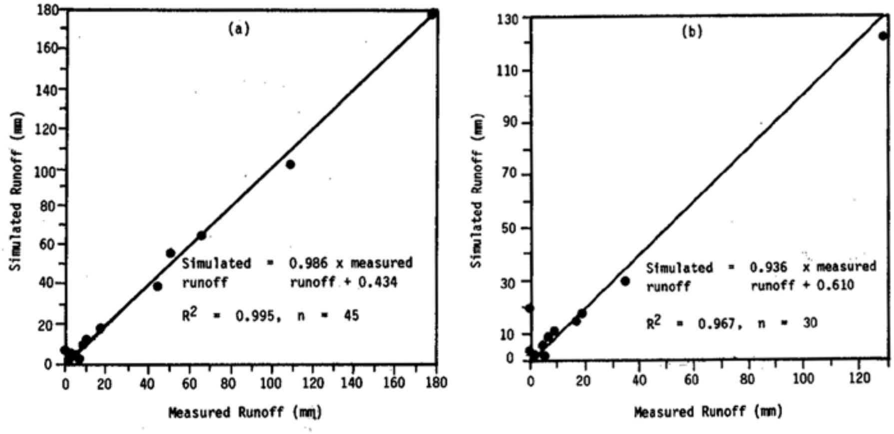


Figure 11. Flow chart of SCS curve runoff model (Pathak et al. 1989).

watersheds with similar soils and management systems. About 10-15 runoff events and daily soil moisture data are sufficient to estimate the parameters of the model. The flow chart of runoff model is shown in Fig. 11.

Tests with data from three small watersheds at ICRISAT Center in India show that the model is capable of simulating daily, monthly, and annual runoff quite accurately (Fig. 12). It is also able to simulate satisfactorily



BW2 watershed BW3A watershed

Figure 12. Runoff model comparison of measured and simulated daily runoff in two Vertisol watersheds at ICRISAT Center, Patancheru, Andhra Pradesh.

the daily moisture. The biggest advantage of this model appears to be its simplicity and accuracy. Also since this model is linked to SCS curve numbers, its use and applicability is quite wide.

Runoff Water Harvesting Models

A runoff cum water harvesting model was developed (Pathak et al. 1989, Ajay Kumar 1991) to simulate the daily runoff, soil moisture and water availability in the tank. The flow chart of the model is shown in Figure 13. This model has main components, the first component predicts the daily runoff and soil moisture and second component calculates the daily water balance in the tank. The basic principles of the water accounting in the tank is shown in Figure 14. This model has been extensively used in different regions of India for calculating various parameters for water harvesting. For example, this model was used to assess the runoff potential from three watersheds in Andhra Pradesh viz. Nandavaram, Sripuram and Kacharam. Hydrological data including daily rainfall and evaporation were used from three watersheds. Probability analysis applied to the results obtained from runoff model. Probabilities of getting 20, 40, 60 and 100 mm of simulated runoff were done based on the 26 years of climatic data (Fig. 15). Input data such as rainfall, evaporation,

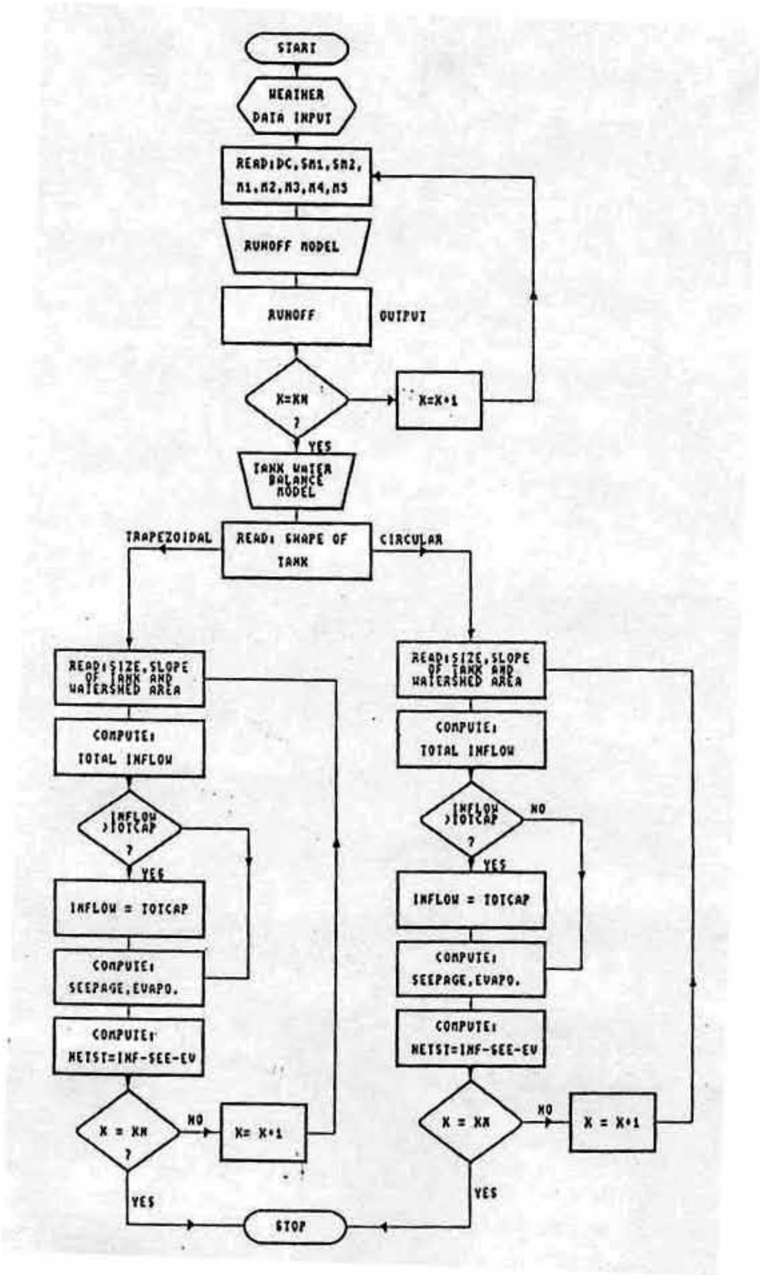


Figure: 13. Flow chart of water harvesting model.

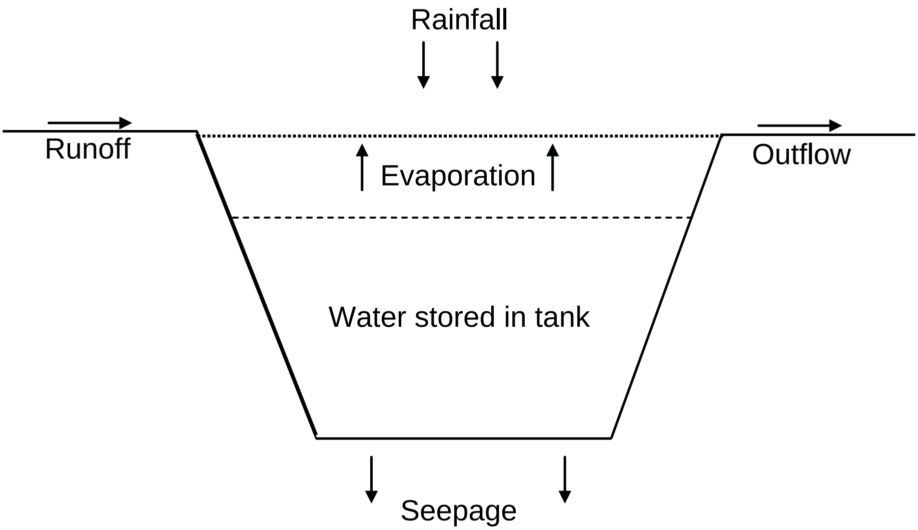


Figure 14. Basic water flow in water harvesting model.

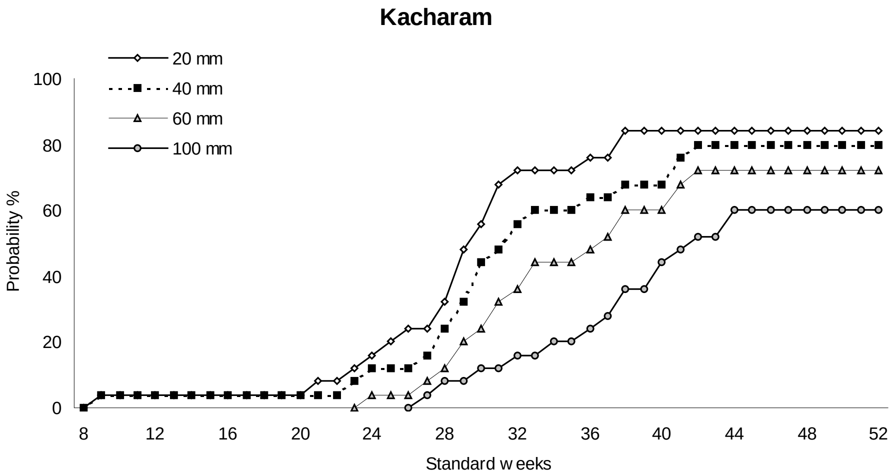


Figure 15. Probabilities of obtaining 20, 40, 60 and 100 mm cumulative runoff in Kacharam watershed (based on 26 years of simulated data).

soil parameters, seepage rate and catchment area were used to runoff water harvesting model (Sireesha 2003).

Considerable information on various aspects of runoff water harvesting could be obtained by using the runoff and water harvesting models.

These models can assess the prospects of runoff water harvesting. It can also be used to estimate the optimum tank size, which is very important for the success of the water harvesting system.

The runoff and water harvesting model can be used for following objectives:

- to assess the prospects of runoff water harvesting and groundwater recharging and its utilization for agriculture,
- to assess the probabilities of getting different amounts of irrigation water in the tank,
- to assess the conditional probabilities of getting different amounts of irrigation water in the tank,
- to find out optimum tank size and other design parameters,
- to develop strategies for scheduling supplemental irrigation.

Digital Terrain Model (DTM)

The automation of terrain analysis and use of digital elevation models (DEM) has made possible to easily quantify the topographic attributes of the landscape and to use topography as one of the major driving variables for many hydrological models. These topographic models, are commonly called as digital terrain models (DTMs). The DTM include the topographic effect on the soil water balance and coupled with a functional soil water balance to spatially simulate the soil water balance. ICRISAT in collaboration with Michigan State University, USA, developed a SALUS-TERRAE, a digital terrain model (Bruno Basso et al., 2000), which can be used at the landscape level. This digital terrain model gives how the terrain affects the vertical and lateral movement of water routing across the landscape. The output of the model is helpful in determining the appropriate management of water resources as well as for identifying the areas across the landscape that are more susceptible for erosion. Few of the outputs from the model are shown in Fig. 16 and 17. These digital terrain models are extremely useful for the watershed programs. However, their major bottleneck is on the accurate availability of topographic data.

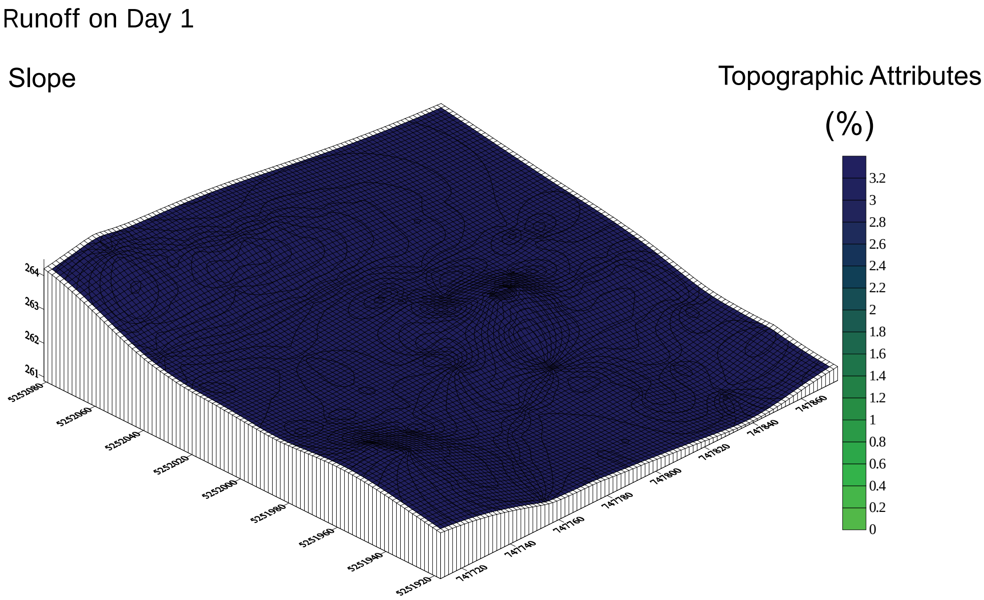


Figure 16. Slope levels in a landscape.

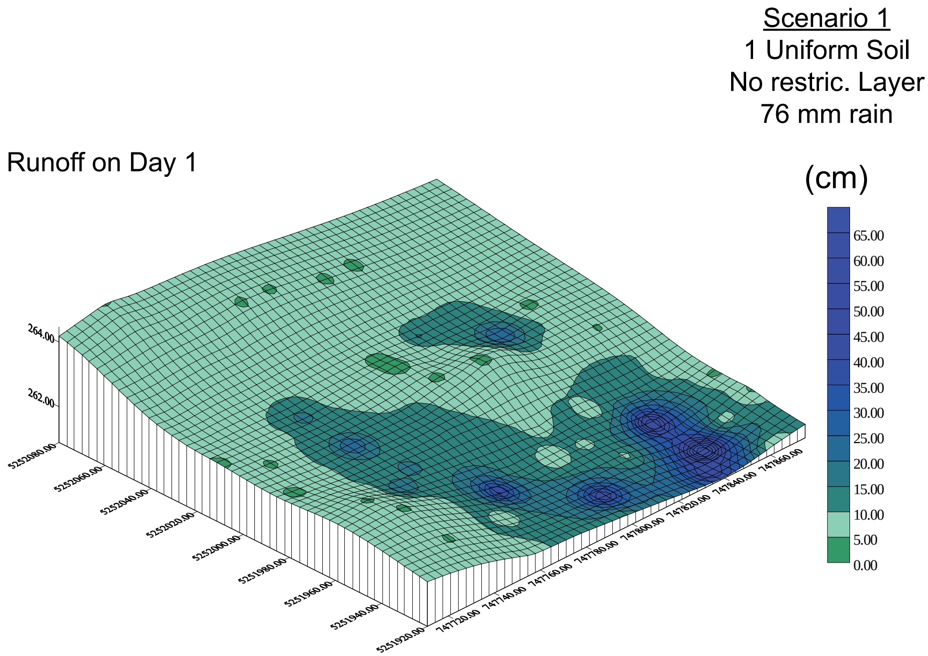


Figure 17. Runoff at day 1 and its ponding at landscape level.

Summary

Watershed development has emerged as a new paradigm for the management of land, water and biomass resources and for improving rural livelihoods. To achieve higher cost effectiveness and greater impact from the watershed programs, its proper planning, development and management based on sound understanding of hydrological processes and data is crucial. In most agro-ecoregions of India, availability of adequate hydrological data at the watersheds scale is lacking. This results in higher development costs, less impact and often failure of the structures and other soil and water management interventions. In this paper, some of the new equipment/tools, which can be used for monitoring runoff and soil loss viz. digital runoff recorder, depth integrating sediment sampler, clock-based automatic sediment sampler and microprocessor-based pumping type sediment sampler are discussed. Some of the key salient features of these equipment in terms of accuracy, reliability and cost effectiveness are also covered. It was found that the most commonly used method of manual sampling is not suitable for estimating soil loss from the small watersheds. This method is found to be highly unreliable and inaccurate. Among the various sediment samplers the microprocessor-based automatic sediment sampler is found to be highly reliable and accurate for monitoring soil loss from small agricultural watersheds. Recently ICRISAT has developed an integrated unit for monitoring runoff and soil loss from the small agricultural watersheds. This integrated unit combines the automatic digital runoff recorder, shaft encoder with microprocessor-based sediment sampler (which includes microprocessor-based control unit, bilge submergible pump, circular sample collection unit fitted with DC shunt motor, battery and solar panel).

Hydrological models are useful for assessing the long-term impact of watershed programs, understanding of complex hydrological processes within the watershed and generating long-term hydrological data for the new areas. In this paper some of the hydrological models developed at ICRISAT, which can be used for small agricultural watersheds are discussed. These include a parametric runoff model "RUNMOD", modified SCS curve number runoff and water balance model, and a runoff water harvesting model. The overall performance

of these models and their key features particularly in terms of input data requirements accuracy and outputs are described. Results have shown that considerable information on the various aspects of runoff water harvesting, groundwater recharging and field-based soil and water management interventions can be obtained by using these models. They can assess the prospects of runoff water harvesting and possible benefits from the irrigation. These models can also be useful to estimate the optimum size of structures and the probability of different amounts of irrigation water in the tank. The information generated from these models can greatly assist in the proper planning, development and management of land and water resources.

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Innovative Microfinance and Micro-enterprise Development in Integrated Watershed Development

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Abstract

The enterprise of rain-fed agriculture is perceived as highly risky due to vagaries of nature, i.e., wide variation in quantum and distribution of rainfall. Therefore, farmers have, over the time, evolved and adopted a 'low risk and low return' strategy. This high risk of rain-fed agriculture and low risk-bearing ability of rain-fed farmer is a major issue in rain-fed agriculture.

Moreover, bankers are not comfortable to lend to rain-fed agriculture because of the high percentage of bad loans, and they call this non-performing assets (NPAs). This is a risk cost to the bankers.

NABARD had initiated efforts to promote credit in rain-fed areas through measures like provision of cent per cent refinance, lower rate of interest on refinance, etc.

NABARD has been involved in implementation of watershed projects as a project holder under the Indo-German Watershed Development Programme (IGWDP) in Maharashtra since 1992. SHG-Bank Linkage Programme, which was launched by NABARD in 1992, is the predominant microfinance delivery model in the country catering to 86 million rural households through 6.1 million SHGs. The program has become a national movement and has the potential and promise of serving all the excluded people and places for providing financial services and promoting livelihoods. The rain-fed zones, tribal and forest areas, watershed areas, drylands, hilly tracks, etc., are the testing grounds for the bankers and development agencies for promoting microfinance and micro-enterprise development.

Introduction

Microfinance has made tremendous strides in India over the years in terms of outreach, socio-economic impact and need-based innovative services, particularly for the poor in rural areas. It has demonstrated its potential and efficacy in providing access to financial services and livelihood promotion in those areas where the formal banking system could not reach. SHG-Bank Linkage Program, which was launched by NABARD in 1992, is the predominant microfinance delivery model in the country catering to 86 million rural households through 6.1 million SHGs. The program has become a national movement and has the potential and promise of serving all the excluded people and places for providing financial services and promoting livelihoods. The rain-fed zones, tribal and forest areas, watershed areas, drylands, hilly tracks, etc., are the testing grounds for the bankers and development agencies for promoting microfinance and micro-enterprise development. The paper seeks to analyse the issues, initiatives and perspectives of microfinance and micro-enterprise development in such areas with special focus on watershed projects.

Significance of Land and Water Resources

The land serves as storage for water and nutrients required for plants and other living organisms. The demand for food, energy and other human requirements depends upon the preservation and improvement in the productivity of the land. But, our land resources are limited. India has about 18% of world's population and 15% of livestock population to be supported from only 2% of geographical area and 1.5% of forest and pasture lands and 4% of the total available fresh water. The increasing human and animal population has reduced the availability of land over the decades. The per capita availability of land has declined from 0.89 hectare in 1951 to 0.37 ha in 1991 and is projected to slide down to 0.20 ha in 2035. As far as agricultural land is concerned the per capita availability of land has declined from 0.48 ha in 1951 to 0.16 ha in 1991 and is likely to decline further to 0.08 ha by 2035. This decline in per capita land availability in the country is mostly on account of rising population. India has the largest irrigated area in the world, accounting for 22% of the global irrigated area. About 83% of the total fresh water accessed in the country is used for irrigation. Although water is renewable resource, its availability in appropriate quality and quantity is under severe stress due to increasing demand from various sectors. Agriculture is the largest user of water, which consumes more than 80%

of the country's exploitable water resources. The overall development of the agriculture sector and intended growth rate in GDP is largely dependent on the judicious use of the available water resources. The Standing Sub Committee Report estimated that the total demand for water by all sectors would surpass the total utilisable water resources by the year 2050, posing a big challenge to the country.

Importance of Rain-fed Agriculture

Out of 328.7 million ha of geographical area of India, 142 million ha are net cultivated area. Of this, about 57 million ha (40%) are irrigated and the remaining 85 million ha (60%) are rain-fed. This area is generally subject to wind and water erosion and is in different stages of degradation for subjecting to intensive agricultural production. Therefore, it needs improvement in terms of its productivity per unit of land and per unit of water for optimum production. Rain-fed agriculture is characterized by low levels of productivity and low input usage. Crop production is subjected to considerable instability from year to year due to its dependence on rainfall, which can be erratic and is variant in space and time. More than 400 million of the rural poor live in the rain-fed regions. 95% of jowar and bajra, 82% of ground nut, 77% of oil seeds, 87% of pulses, 66% of cotton, 80% of dryland agriculture, 67% of livestock comes from rain-fed areas. There is no denying of the fact that rain-fed areas have to contribute significantly to maintain our food security as the yields from the irrigated agriculture are plateauing off and the possibility of bringing more area under assured irrigation is reducing. It is now accepted that the best way to handle rain-fed farming is through watershed approach. In India, multiple ministries/agencies are involved in implementation of watershed projects. Upto X plan, 51 mha of degraded area were treated under various watershed programs. It is planned to complete the remaining 78.5 mha (20 mha, 25 mha and 28.5mha in XIth, XIIth and XIIIth Five Year plans, respectively) in the next three five year plans. The investment activities in watershed development are of two types, initial soil and water conservation measures and thereafter, investment in the fields of individual farmers to derive individual incremental benefits. The drought, poverty and land degradation nexus, low water use efficiency (30%), predominance of small holdings, poor infrastructure, low crop yields against vast potential, need for timely microfinance are the some of the difficulties which need to be addressed in these areas.

NABARD and Watershed Projects

NABARD has been involved in implementation of watershed projects as a project holder under the Indo-German Watershed Development Program (IGWDP) in Maharashtra since 1992. Subsequently, the program was extended to cover Andhra Pradesh, Gujarat and Rajasthan states. Realizing the benefits accrued to the communities under IGWDP, NABARD decided to replicate the watershed models in priority States, by setting up the Watershed Development Fund (WDF) during 1999-2000. The program is being implemented in 14 States.

Besides these two programs, NABARD was entrusted with the responsibility of implementation of watershed projects in eight districts of South Bihar by the Planning Commission out of the funds allocated under Rashtriya Sam Vikas Yojana to the Government of Bihar during 2004. During 2006, NABARD took the mandate of treating about 45000 hectares in each of the 31 distressed districts in of Maharashtra (6), Andhra Pradesh (16), Karnataka (6) and Kerala (3) supported out of its Watershed Development Fund.

All these watershed programs are being implemented with the whole-hearted participation of the village communities including the land-less and women. Taking into account all these programs, NABARD's involvement under participatory watershed development as on date covers an area of 1.7 million ha and the total funds handled are to the tune of Rs.1600 crore. Brief details about various watershed programs implemented by NABARD are given below.

Projects under Watershed Development Fund (WDF)

Successful implementation of IGWDP in Maharashtra resulted in creation of Watershed Development Fund in NABARD, with a corpus of Rs.200 crore (Rs. 100 crore each contributed by GOI and NABARD). The fund has grown to Rs.1125 crore as on 31 March 2009 by credit of interest on unutilized fund by NABARD as also on account of crediting RIDF interest differential.

Consequent to Government of India's (GoI) announcement of the Prime Minister's package for 31 distressed districts in four states, for developing an area of 15,000 ha annually over three years in each of the districts, 9.30 lakh ha. has been taken up for implementation during the year (2008-09) on cluster basis involving a commitment of Rs.1023 crore. The watersheds are implemented in a holistic manner, focusing on family-based livelihood activities and are expected to significantly mitigate farmers' distress. Several innovations and initiatives were taken by the bank to expedite implementation of the projects, viz. Use of satellite imageries for planning, software development for enhancing family-based livelihood opportunities, greater convergence with government implemented programs, engaging Resource Support Agencies for hand holding and capacity building among implementing agencies, opening of PMUs, etc.

Integrated Watershed Development Program-Bihar

The Planning Commission approved the captioned project with an outlay of Rs.60 crore, under Rashtriya Sam Vikas Yojana (RSVY), in 2004. The program envisaged development of 80,000 ha. of degraded land in eight districts viz. Jamui, Banka, Gaya, Nawada, Munger, Aurangabad, Bhabua and Rohtas districts in South Bihar with 'participatory approach' on IGWDP- Maharashtra / WDF pattern.

Indo German Watershed Development Program (IGWDP)

IGWDP - Maharashtra

KfW sanctioned IGWDP Maharashtra is under implementation in Maharashtra since 1992. Phase I, with an outlay of Rs.26.66 crore, was completed in April 1999 and Phase II, with an outlay of Rs.57.86 crore, was completed in December 2006. A total of 95 projects covering an area of 102386 ha were completed. Phase III of the program was started on 24 January 2005 with the outlay of Rs.110 crore. A total of 39 projects were under Full Implementation Phase (FIP) and 59 projects under Capacity Building Phase (CBP)/IP and eight completed.

IGWDP - Andhra Pradesh

KfW sanctioned IGWDP Andhra Pradesh is implementing of watershed development projects in the districts of Karimnagar, Medak, Warangal and Adilabad in Telangana region of Andhra Pradesh. The total outlay by way of grant is Rs.43.45 crore. The duration of the program is 10 years, commencing from 2002. A further commitment of Rs.11 crore has been made by the German Government towards Complementary Measures Program (CMP) for Capacity Building of stakeholders. The capacity building measures under CMP assigned to an international consultant are progressing. As on 30 March 2009, 37 watershed projects covering 42,535 ha were under implementation in the state, out of which eight projects were under FIP and the remaining projects were under CBP.

IGWDP - Gujarat

This program envisages rehabilitation of watersheds in four districts viz. Sabarkantha, Dahod, Panchmahal and Vadodara in the State of Gujarat. KfW has committed Rs.51.52 crore for the purpose. As on 31 March 2009, 35 projects have been identified under the program, out of which 28 projects were under CBP/IP, two projects in FIP and the remaining eight projects were under pre CBP stage. [A Program Management Unit (PMU) headed by a Senior Officer of NABARD has been set up at Dahod to oversee implementation of the program very closely. Three consultants have been engaged to help the PMU.]

IGWDP - Rajasthan

KfW, Germany, has committed to provide grant assistance of Rs.61.6 crore for the Watershed Development Program in Rajasthan to establish 30-40 watershed projects. The programs being implemented in five districts viz., Banswara, Chittorgarh, Dungarpur, Udaipur and Pratapgargh. A PMU has been set up at Udaipur. The PMU has identified 32 watershed projects (covering 35716 ha) and CBP has been sanctioned to all the 32 projects.

Issues Related to Credit Flow in Rain-fed Areas

***Risk to farmer*:** The enterprise of rain-fed agriculture is perceived highly risky due to vagaries of nature, i.e., wide variation in quantum and distribution of rainfall. Therefore, the farmers have, over the time, evolved and adopted a 'low risk and low return' strategy. This high risk of rain-fed agriculture and low risk-bearing ability of rain-fed farmer is a major issue in rain-fed agriculture. This low-risk bearing ability also prohibits farmers from greater investment and adoption of new and more productive varieties of crops and technology. Therefore, if the risk could be satisfactorily reduced, farmers could venture into adoption of better technology, thus breaking the vicious circle of poverty.

***Risk to banker*:** As the above mentioned risks of the rain-fed farmer could not be addressed properly and effectively, credit in this area has also not picked up. This is because the bankers are not comfortable to lend to rain-fed agriculture because of the high percentage of bad loan and, bankers call this Non-performing Assets (NPAs). This is a risk cost to the bankers.

***High transaction cost of banks*:** Existing set up of bank branches with limited staff is not in a position to cater to large number of farmers and located in dispersed manner require small amounts of loan. This leads to high transaction cost for the banks which is also a reason for the discomfort of banks to lend in these regions. Against the above scenario, NABARD had initiated efforts to evolve alternative and innovative approaches and incentive mechanism for enhancing credit flow to rain-fed areas.

NABARD's Efforts in Credit Flow in Rain-fed Areas

NABARD had initiated efforts to promote credit in rain-fed areas through measures like provision of cent per cent refinance, lower rate of interest on refinance, etc., but these met with limited success.

NABARD had also launched the concept of 'cyclical credit' for short term loans, on pilot basis. The rationale for introducing the concept was that there is a cycle of good and bad crop years. And even with the adoption of dryland farming technologies developed by ICAR and ICRISAT, the effect of weather aberrations on yields during bad years could not be totally eliminated but only moderated. But during normal/good rainfall years, the technology could give high yields. If the farmer had to improve the yields under dryland conditions and adopt the technology package during good as well as bad years, it was necessary to ensure that he did not face any resource constraints. Thus, the financing agency should stand by him by providing the required crop loan irrespective of the repayment difficulties induced by the weather cycle in bad year also. The farmer is expected to repay the entire loan taken during the 'cycle' in a good year. This approach was a search for a way to break the vicious circle of poverty (stated earlier).

The expectations from the farmer were that he would adopt the recommended technology and repay the amount assessed, based on the yields obtained each year. Ideally the banker should have an assessment of the production situation of each farmer so that this repayment capacity could be adjudged accordingly. Since, it was not possible to assess the production situation individually, the assessment of repayment capacity was to be made on the basis of adequate number of crop-cutting experiments conducted in the project area. The repayment capacity was determined with respect to the normative income to be obtained from different crops in each project area. The normative income was determined, *a priori*, based on the yield of crops (normative yield) that could be obtained in a normal year with the adoption of improved technology and a normative price that the farmer was expected to get for the produce. For judging the repayment capacity, it was provided that at least, 50% of the normative income should be left with the farmer for meeting his consumption requirements. This experiment was carried out in several states but the results were not satisfactory because of several reasons, e.g., farmers not following the technology, bankers not standing by, reluctance on the part of the farmers to increase their loan business, etc.

SHG – Formation and Linkage

Consequent to progress and success of SHG-Bank Linkage Program, SHGs have become the vehicle of development process, converging development processes. NABARD has been pursuing multi-pronged promotional interventions for formation of SHGs and their linking with banks across the country with involvement of Self-Help Promoting Institutions (SHPIs) comprising banks, NGOs and development agencies, etc. There has been spectacular growth and expansion of the program. The combined synergy–the flexibility, sensitiveness and responsiveness of SHGs with the financial resources and technical strength of banks had brought about win-win situation for banks and the poor, under the linkage approach. Under the approach, the financial services are made available in a cost-effective, hassle-free, participatory manner, on a sustainable basis. Notwithstanding the overall success of the program, the formation and linking of SHGs in the watershed areas of the resource-poor regions have had limited success in view of the attendant difficulties of terrain, social mobilization processes and bank branch network, etc.

Joint Liability Groups (JLGs) – Bank Linkage

The small farmers, marginal farmers, oral lessees and landless farmers have been encouraged to form JLGs and avail bank finance on the strength of mutual guarantee as a collateral substitute, to pursue farm and non-farm activities under the JLG-Bank Linkage Program launched by NABARD.

Broad Approaches & Focus of NABARD

NABARD has been promoting watershed development with the following tenets:

i. participatory approach encouraging community in the planning, implementation, monitoring and sustaining of the project,

ii. intensive capacity building efforts and interventions of the stakeholders,

iii. promoting Village Watershed Committee, SHGs, User Associations, etc., to take up larger responsibility,

iv. transparency in funds management,

v. social discipline and natural resource management by banning on tree falling/cultivation of water-intensive crops and encouraging low water intensive crops,

vi. focus on holistic livelihood promotion, empowerment, sustainability and social inclusion (equity and gender),

vii. propagating credit + approach and watershed + interventions,

viii. value addition to existing practices taking recourse to the services of NGOs, extension agencies, universities, KVKs, farmers clubs, development agencies.

Suggestions/Recommendations for Rain-fed Agriculture

For reducing risk to the rain-fed farmers the following measures are suggested.

Dryland Agriculture Technology

- It is now widely accepted that watershed approach is the best approach for development of rain-fed areas as it creates favourable conditions for risk reduction and improving productivity. Further, watershed should be developed using participatory approach for ensuring sustainability.
- There is a need for location-specific research for developing crop varieties and also agronomic practices suiting various rain-fed areas.
- Agricultural extension is the key to improve the fate of rain-fed forming.
- Inputs like timely sowing, appropriate crop density, fertilizer application and pest management, etc., need to be propagated to farmers through extension systems. Similarly, the existing location-specific technologies, which have been evolved by research institutions, agricultural universities, etc., should also be transferred to farmers effectively.
- Efficient utilization of the scarce water resources using the drip and sprinkler system would go a long way. Available limited water should be utilized efficiently by use of efficient water-dispense mechanism like drip and sprinkler irrigation system.
- Encourage farmers to undertake agro-forestry silvipasture, agro-horticulture, animal husbandry and non-farm sector activities which are resilient to vagaries of monsoon.

- Rain-fed farming must eschew water intensive crops and the farmers must be taught the fine art of making water budgets.
- Capacity building and utilization of appropriate technology are the key approaches for rain-fed farming.
- Rain-fed farming is both an art and science. There is need for complete and mandatory understanding of the ecosystem. It may be a better idea to document the indigenous knowledge and refine it wherever required and reintroduce the same. The scientific establishments need to recognize this approach.
- Most of the successful indigenous systems have multiple crops but the scientific system usually talks about mono crops. How can the villagers cope with the demand of seeds? Can we think of training rain fed communities in the art of managing seed banks? NABARD has a few successful interventions in Orissa and Madhya Pradesh in the rain fed regions.
- If there is a demand pull for the products of the rain fed region like millets, farmers would take interest themselves. At present the PDS never gives the millets. Most of the urbanites do not know millets. Can the scientific establishment promote products which will create a demand? Britannia's five grain biscuit is an example.
- The scientific establishments need to strive to develop farm machinery to cater to the rain fed region crops. Do we have a thresher for ragi or foxtail millet? These crops are very nutritious and farmers use very antiquated systems to separate the grain from the chaff.
- The hall mark of rain fed cropping systems is a fine integration of crops, animals and small timber. Do we have any integrated model?
- What is required to fertilise the rain-fed region? Chemical fertilizers or the farm yard manure? Chemical fertilizers in a low moisture regime are harmful to the plants. How can the rain fed farmers utilize the fertilizer subsidy the Government provides? Have we thought about this?
- Technology, be it indigenous, refined indigenous or modern will only crack the rain fed farming productivity puzzle. But the current paradigm is application of the green revolution technology framework which apparently has not yet worked. We, thus, need to define the

problem correctly to find a workable solution. Bankers will be too willing to partner the scientific establishments as their business will certainly improve with a winning technology.

- Once the technology issue is figured out, capacity building and appropriate agricultural extension will get the required importance.

Risk Mitigation

- The existing NAIS requires a relook and improvement, specially in the rain-fed areas.
- Farmers have several activities in rain-fed areas to mitigate risks and for improving income, bankers could thus follow 'portfolio approach' to lending where instead of financing a single activity, a basket of activities could be financed. This will allow flexibility to the farmer for shuffling the resources depending upon the opportunity.
- The quantum of assistance required for each farmer will naturally vary, depending upon the activities constituting the portfolio' for that farmer. Thus, ideally, the banker should work it out for each farmer and decide the amount of credit required. However, in practice, this may be difficult in view of large number of farmers to be serviced by each branch. Therefore, some parameters may have to be evolved for deciding this amount. For example, a farmer with 2 ha. of field crops, ¼ ha. vegetables and a couple of cows may require approximately. Rs.32,500/- (Rs.10,000/- + Rs.2,500/- + Rs.2,000/-, respectively) for these activities. This quantum will vary from farmer to farmer. For deciding farmer-wise requirement, banks may seek support of village-level peoples' organizations like SHG/VWC, etc., in lending as well as recovery. Banks will have to provide suitable delegation to rural branch managers for the sanction of loans and exercising flexibility.
- The conversion of crop loan to term loan and reschedulement of term loan should be done at the level of the bank itself (not depending upon the system of 'annewari' declaration by state government.). If banks find it difficult to delegate the powers of conversion to branch managers, then, at least, the same could be delegated to one level higher (or regional manager, etc.)

Micro Enterprises & Marketing

- Micro enterprises like value addition, food processing and other non-farm sector activities may be encouraged for additional income generation.
- Producer companies/SHG federations may be encouraged for value addition and marketing of the rain-fed agriculture produce.
- The producer companies can purchase inputs in bulk and supply to the producers and market the produce in bulk for increasing the margin to rain-fed farmers.

For Micro Enterprise Promotion – 3M approach (Micro Planning, Micro Finance and Micro Market) pilot tested by NABARD for matured SHGs may be tired/ replicated.

Micro Financial Services & Delivery Mechanism

- Bankers need to be sensitive about various aspects of processes and impact of watershed development.
- To reduce transaction cost and risk cost, bankers should explore the possibilities of lending through groups viz., village watershed Committees(VWC) / Self Help Groups(SHG) / Agents & Joint Liability Groups (JLGs).
- Promotion of SHGs is an integral part watershed projects. The livelihood activities for asset-less people and women are routed through these SHGs for implementing various production, income-generating and entrepreneurial activities in a phased and gradual manner, depending on maturity of SHGs, which are a part of the Integrated watershed Development.
- Credit institutions may be involved in watershed activities right from the initial phase.
- Separate credit plans may be prepared for watershed plus activities in watershed projects by bankers and watershed committees.
- Community-Based Organizations (CBOs) like SHGs, VWCs may be leveraged for credit facilitation, disbursement and monitoring.
- Suitable incentive package may be considered for SHPIs, by keeping in view the intensive efforts required in social mobilization in such areas.

- Maintenance and Development Fund should be created out of the voluntary contributions and/or, by way of project support or such combination as may be deemed appropriate. Besides utilizing a part of the Maintenance Development Fund for financing income-generating & production oriented activities, the same may be credit linked with banks.
- The VWCs be clustered to form associations/federations /farmers' cooperatives. This will facilitate easy access of credit from financial institutions, inputs, value addition/processing & marketing, etc. In the completed watershed projects, the NGO/professional agency may be given long term assurance and need-based support to enable them to provide professional support in the area as required for sustenance of the activities.
- A comprehensive insurance cover for crop/livestock/assets may be evolved and introduced as risk mitigation measure to reap full benefits of watershed practices preferably through SHGs.
- The SHGs promoted in the watersheds may be equipped to act as a business correspondents for banks and insurance companies. SHG network could be utilized for delivering micro finance services like micro-savings, micro-credit, micro-insurance, micro-remittance, micro-pension, etc.
- Transparency in fund management, social audit and adherence to social performance standards are very crucial and need to be maintained.

Road Map for upscaling and deepening Microfinance and micro-enterprises

Massive sensitization efforts may be embarked upon for banks to enable them to appreciate the potential and problems of dryland farmers, watershed community and SHGs in the resource poor regions. Appropriate modules of training programs may be internalized by the training institutions and development agencies with inclusion of case studies, success stories, innovative approaches, study findings, scientific tools and methods, etc., in the course materials. Exposure visits to the good projects may be encouraged.

The SLBC, DLCC and BLBC may regularly review the progress, trends, issues and perspectives of the microfinance and micro-enterprise development in such areas. The potential Linked Credit Plan (PLP) prepared by NABARD may suitably capture the potential and perspectives of microfinance and micro-enterprise promotion for bankers' guidance and support.

Suitable incentives may be evolved and implemented for farmers prompt repayment and best practices, for the bankers/MFIs for providing timely, need-based and family-centric credit products and services, in flexible, hassle-free and adequate manner and for the promoting agencies for pro-active and progressive steps in these areas.

Stimulus to JLG/SHG members for micro-enterprise promotion, supportive intervention by facilitating market access and forward/ backward linkages, sustenance of the activities through institutional mechanism and livelihood promotion opportunities are deemed necessary.

More of Business Facilitators and Business Correspondents may be taken recourse to by banks for facilitating financial inclusion in these areas, considering the difficulties of connectivity and infrastructure. The authorized leaders of SHGs have already been recognized by RBI as business correspondents. There is need for increased sensitization efforts for the newly inducted BCs and BFs in the watershed areas.

There is need for convergence of efforts, mutual cooperation in information-sharing and consortium approach for systematic upscaling and graduation of microcredit to microfinance development and to micro-enterprise promotion.

Perspectives

People's participation is the hallmark of watershed development. Every watershed projects should aim at establishment of user groups and SHGs. A self-supporting system will ensure sustainability. The participatory approach will open up opportunities to the stakeholders to jointly negotiate their interests, set priorities, evaluation opportunities, implementation and monitor the outcomes. The increase in overall productivity in dryland and watershed areas may lead to food security, development of markets and other off-farm livelihood opportunities. The watershed plus activities covering degraded forests, pastures and crop land will increase soil/ moisture level, control soil erosion, checking rural migration, enhance crop productivity and increase ground water recharge, etc.

The paradigms in microfinance viz., feminist empowerment, poverty reduction, livelihood promotion, skilling mission, social and financial inclusion, financial sustainability, institutional convergence could be fully operationalised and resultant impacts experienced in the dryland/ watershed areas. There are huge opportunities and challenges in the Microfinance and Micro Enterprise Sector, in these regions which can be tapped and addressed in holistic, collaborative and convergence approach. NABARD has been directing its efforts in these directions in a holistic and integrated approach.

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Impact of Climate Change on Dryland Sorghum in India

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Abstract

This paper presents results of climate change impacts on sorghum in semi arid tropics (SAT) regions of India and adaptation strategies to overcome the impact. The main objective of the paper is how to use crop simulation model to assess the climate change impact and how best we can reduce the impact through integrated watershed approach. InfoCrop, a generic dynamic crop model, provides integrated assessment of the effect of weather, variety, pests, and soil management practices on crop growth and yield, on soil nitrogen and organic carbon dynamics in aerobic, anaerobic conditions, and also greenhouse gas emissions. The model has reasonably predicted phenology, crop growth yield. Sorghum crop was found to be sensitive to changes in carbon dioxide (CO_2) and temperature. Future climate change scenario analysis showed that sorghum yields (CSH 16 and CSV 15) are likely to reduce at Akola, Anantpur, Coimbatore and Bijapur. But yield of CSH 16 will increase little in Gwalior (0.1%) at 2020 and there after it will reduce. At Kota, the sorghum yield is likely to increase at 2020 (3.3 & 1.7 % in CSH 16 and CSV 15, respectively) and no change at 2050 and yield will reduce at 2080 in both varieties. The increase in yield at Gwalior and Kota at 2020 will be due to reduction in maximum temperature and increase in rainfall from the current. Adoption of adaptation measures like one irrigation (50mm) at 40-45 days after sowing would be better for rain-fed kharif sorghum in the selected location of the SAT regions. The yield gap between district average and simulated rain-fed potential is so wide at Akola, Anantpur, Bijapur and Kota compared with Coimbatore and Gwalior. If we bridge the yield gap, we can overcome the climate change impact. Integrated Genetic and Natural Resource Management (IGNRM) through watershed management would be an appropriate method to bridge the yield gap to sustain the sorghum yield and food security.

Key words: *InfoCrop, Simulation, Watershed, Adaptation, Dry matter, Leaf area index, Maturity, India, SAT.*

Introduction

Sorghum is the fifth most important cereal crop grown on 47 million ha in 99 countries of Africa, Asia, Oceania, and the Americas. Major producers are the USA, India, Nigeria, China, Mexico, Sudan and Argentina. The crop occupies 25% or more of arable land in Mauritania, Gambia, Mali, Burkina Faso, Ghana, Niger, Somalia and Yemen, and >10% of this area in Nigeria, Chad, Sudan, Tanzania and Mozambique. For direct human use (>55%), grain is mostly consumed in the form of flat breads and porridges (thick or thin); stover is an important source of dry season maintenance rations for livestock, especially in Asia; also an important feed grain (33%), especially in the Americas. India is the second largest sorghum grower in the world after 2005 (area of 8.45 m ha during 2007-08), followed by Nigeria. Sudan is the world largest sorghum grower (area of 8.95 m ha during 2007-08). China topped in productivity (4584 kg ha^{-1}) among the nine countries where sorghum is grown in more than 1 m ha. India ranks seventh and Sudan ranks eighth in productivity (Table 1).

Table 1. Area, production and productivity of sorghum in India compared with rest of the world.

	Area (m ha)		Production (M t)		Productivity (kg ha^{-1})	
Countries	1981	2007	1981	2007	1981	2007
World	44.89	46.92	65.52	63.38	1458	1350
USA	5.27	2.32	19.16	12.64	3618	4300
Nigeria	2.68	7.80	3.28	9.06	1461	1159
India	16.36	8.45	11.38	7.15	695	846
Mexico	1.49	1.78	4.99	6.20	3343	3495
Sudan	3.05	8.95	2.27	5.84	725	652
China	2.83	0.53	7.03	2.43	2493	4584
B. Faso	1.05	1.61	0.62	1.62	589	1007
Ethiopia	NA	1.46	NA	2.17	NA	1484
Niger	NA	2.84	NA	0.98	NA	344

In India sorghum is mainly grown in the Deccan Plateau, Central and Western India apart from a few patches in Northern India as a dryland cereal crop. It is nutritionally superior to other fine cereals such as rice and wheat with high fiber content, minerals and slow digestibility. As sorghum is generally cultivated in nutrient-poor soils in frequently drought-prone areas, it offers food and fodder security through risk aversion on sustainable basis. Traditionally, sorghum is grown for food and fodder purposes. In view of decreasing demand for sorghum (rainy season, (*kharif*) sorghum grain in particular) as a food crop, it is increasingly diverted for various alternative uses such as animal feed, poultry feed, potable alcohol from grain (Dayakar Rao 2008). Water stress is one the major constrain in sorghum production in rain-fed area. In India the yield gap analysis of sorghum results showed that the total yield gap for all production zone was 2410 kg ha^{-1}. The primary production zone had the lowest gap of 2130 kg ha^{-1}, followed by secondary production zone with the gap of 2530 kg ha^{-1} and tertiary zone with a gap of 2560 kg ha^{-1}. Yield gap I (simulated minus FLD yield) was 60-65 % and Yield gap II (FLD minus average farmer yield) was 35-40%. The mid season drought was identified as the most important constraint across the state in India. They concluded that the integrated watershed management approaches, encompassing harvesting and storing of excess run off for supplemental irrigation, improved cultivars, integrated nutrient. Pest management practices are required to abridge the yield gaps of *kharif* sorghum. Rise in temperature and rainfall variation due to climate change will further aggravate the problem in SAT regions. The IPCC has already projected a temperature increase of 0.5 to 1.2^{o}C by 2020, 0.88 to 3.16^{o}C by 2050 and 1.56 to 5.44^{o}C by 2080 for the Indian region, depending on the scenario of future development (IPCC, 2007). It is very likely that hot extremes, heat waves, and heavy precipitation events will become more frequent.

These changes in the global climate may affect the crop yields, incidence of weeds, pests and plant diseases, and the economic costs of agricultural production. Easterling *et al*. (2007) analyzed modeling results to show that in low-latitude regions, a temperature increase of 1-2°C is likely to have negative yield impacts for major cereals. There is a probability of 10-40% loss in crop production in India with increase in temperature by 2080-2100 (IPCC 2007). There are a few Indian studies (Saseendran *et al*. 2000; Aggarwal 2008) that also confirm decline in the agricultural production with climate change. The CERES-sorghum simulated results indicated a decrease in yield and biomass of rainy season sorghum at Hyderabad and Akola under all climate change scenarios. The positive effect of increased CO_2 if any, were masked by the adverse effects of predicted increase in temperature, resulting in shortened crop growing seasons (Gangadhar Rao *et al*. 1995).

Crop simulation analysis for *kharif* sorghum at Parbhani showed that a temperature increase of 3.3°C, which is expected to increase by the end of this century, will on average reduce the crop yield under good management by 27%. However, the effect of 11% increase in rainfall will be marginal. Despite variable response across seasons to increase in temperature, an average yield reduction of groundnut crop at Anantpur will be about 38% and an increase in rainfall will benefit the crop marginally. Considering the impacts of increase in temperature and CO_2 concentration, the yield reduction of rain-fed crops across a few selected locations in India are simulated to be 22 to 50% for *kharif* sorghum, 33 to 51% for pearl millet, 23 to 29% for groundnut, 8-11% for pigeonpea and 7% for chickpea (at Nandyal and Akola). However, the climate change impacts at current low levels of management of crops would be marginal (Piara Singh *et al.* 2009 unpublished data). This means that as we improve the management of crops to achieve higher crop yields to achieve food security the impacts of climate change will become significant. On the other hand, global warming impact was likely offset to some extent by increased CO_2 levels in atmosphere, although the magnitude of these effects are uncertain and this needs more debate and research (Long *et al*. 2005, 2006).

There are limited studies to assess the probable impact of climate change on sorghum productivity in SAT regions of India. The objective of this study was therefore using crop simulation model to quantify the impact of future climate change on sorghum crop with an additional objective of the study was to assess the benefits of adaptation strategy like supplemental irrigation.

Materials and Methods

Model

Info Crop considers following processes of growth and development, soil, water, nitrogen and carbon, and crop-pest interactions. Each process is described by a set of equations, the parameters of which vary depending upon the crop/cultivar.

- Crop growth and development: phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source: sink balance, transpiration, uptake, allocation and redistribution of nitrogen.
- Effects of water, nitrogen, temperature, flooding and frost stresses on crop growth and development.
- Crop-pest interactions: damage mechanisms of insects and diseases.
- Soil water balance: root water uptake, inter-layer movement, drainage, evaporation, run off, ponding.
- Soil nitrogen balance: mineralization, uptake, nitrification, volatilization, inter-layer movement, denitrification, leaching.
- Soil organic carbon dynamics; mineralization and immobilization.
- Emissions of green house gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O).

The basic model is written in Fortran Simulation Translator programing language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands), a language also adopted by the International Consortium for Agriculture Systems Application (ICSA) as one of the languages for systems simulation (Van Kraalingen, 1995). Another version of the model has been developed to facilitate its greater applications in agricultural research and development by the stakeholders not familiar with programing. The user-interface of this software has been written using Microsoft. Net framework while the back-end has FSE models and databases in MS-Access. More details of the model are provided by Aggarwal *et al*. (2006a and b).

Climate Change Impact Assessment

Climate change scenarios: Impact of projected climate change scenarios was assessed by running the regional validated model for 2020, 2050 and 2080. The functions were from the output of the $HadCM_3$ A2a scenario, which has continuous population rise along with regionally oriented economic development. Projected temperature rise during the sorghum growing season is given in Table 2 for different locations. Projected rainfall also varied in all six regions during *kharif* season (Table 2). Impact of changing climate on sorghum crop yield in A2 scenario was assessed.

Table 2. Projected mean temperature rise (°C) and rainfall changes during sorghum growing season in A2a scenarios.

	Max. temp. (^{0}C)			Min. temp. (^{0}C)			Rainfall (%)		
Location	2020	2050	2080	2020	2050	2080	2020	2050	2080
Akola	0.9	1.9	2.7	0.9	1.9	3.2	-1.9	-10.5	-1.5
Gwalior	-0.2	0.6	1.7	0.8	1.9	3.2	20.9	28.3	15.1
Anantpur	0.7	1.6	2.5	0.8	1.6	2.4	-3.0	-13.3	-6.6
Coimbatore	0.8	1.7	2.7	0.8	1.6	2.6	1.3	3.7	9.3
Bijapur	1.0	2.3	3.5	1.0	1.9	3.5	20.9	28.3	15.1
Kota	-0.2	0.6	1.7	0.8	1.9	3.3	18.9	27.2	17.8

Adaptation Strategies

One adaptation strategy (50 mm supplemental irrigation at 40-45 DAS) was selected and crop model was run for future climate change scenarios. Yield loss of rain-fed sorghum was compared with district average, current rain-fed potential as well as with adaptation measures.

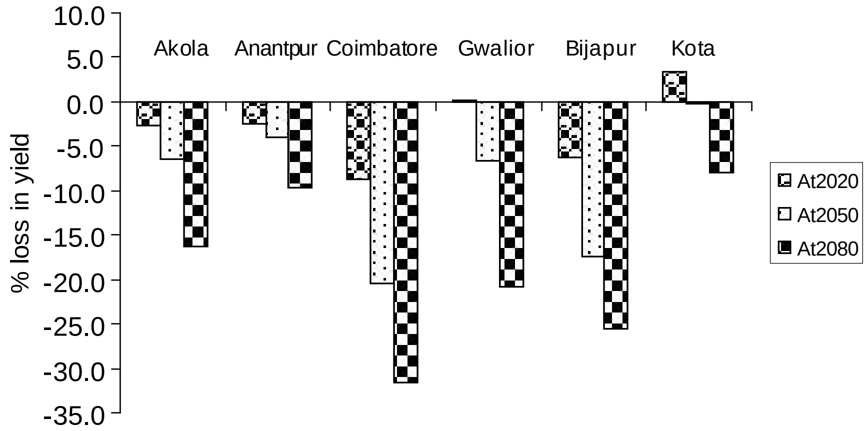
Results and Discussion

Impact Assessment

CSH 16 –Sorghum hybrid

In future climate change A2a scenarios projected sorghum yield to show a spatial as well as varietal variation among all six regions (Fig 1). The

Without adaptation CSH - 16



With Adaptation CSH - 1

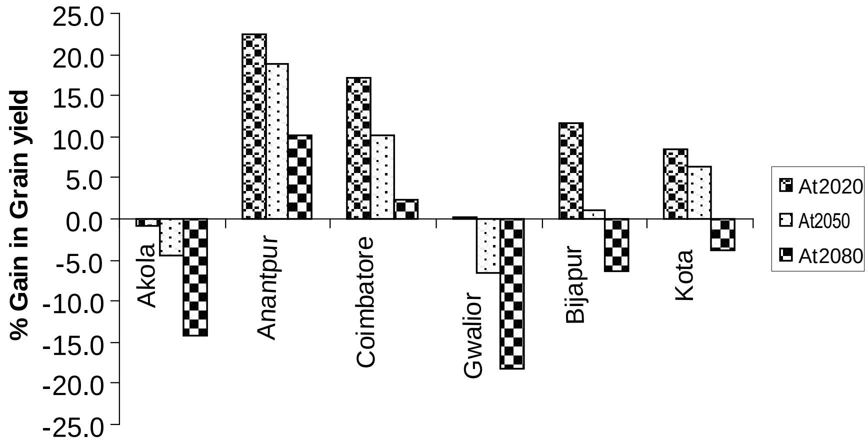


Figure 1. Simulated per cent change in yields (CSH 16) in HadCM3 – A2a scenarios of climate change without and with adaptation.

yield of CSH 16 is likely to reduce in four regions (8.6% in Coimbatore, 6.3% in Bijapur, 2.6% Akola and 2.5% in Anantpur) and increase in Kota (3.3%) and Gwalior (0.1%) at 2020. But from 2050 the reduction of yield would occur in all six regions. A2050, the more yield reduction would occur at Coimbatore (20.6%) and Bijapur (17.5%). The least reduction is projected in Kota (0.1%), followed by Anantpur (3.9%), Akola (6.4%) and Gwalior (6.5%). The highest reduction is going to occur in Coimbatore region (31.7%), followed by Bijapur (25.6%), Gwalior (20.9%), Akola (16.3%), Anantpur (9.1%) and Kota (8.0%) by the end of the century.

CSV 15 Sorghum variety: The yield reduction of CSV 15 (Fig. 2) would also have spatial variation. In 2020 the yield reduction will occur in all regions except Kota, where there will be 1.7% increase in yield. After 2020, the same trend has been observed like CSH 16, such as the highest yield reduction would occur in Coimbatore (31.3%) and Bijapur (24.8%), followed by Gwalior (16.5%), Anantpur (14.6%) and Akola (11.3%). The less reduction is observed in Kota (8.4%) by 2080.

Yield reduction of sorghum with future climate change scenarios in different locations of India was primarily attributed to reduction in crop growth period (days to anthesis and days to physiological maturity) with rise in temperature. This highest reduction in Coimbatore will be because of its low rainfall during *kharif* season as well as temperature rise (2.6°C) in 2080. The yield increase at Gwalior and Kota during 2020 will be, due to reduction in maximum temperature (0.2°C) from current temperature and little increase in rainfall (Table 2).

Increasing temperature lowered days to flowering and days to maturity, which in turn lowered total crop duration. In plants warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set, resulting in poor yield (Rawson, 1992; Morison, 1996). Simulated results also confirmed reduction in leaf area index with climate change which in turn lowered the

Table 2. Projected mean temperature rise (°C) and rainfall changes during sorghum growing season in A2a scenarios

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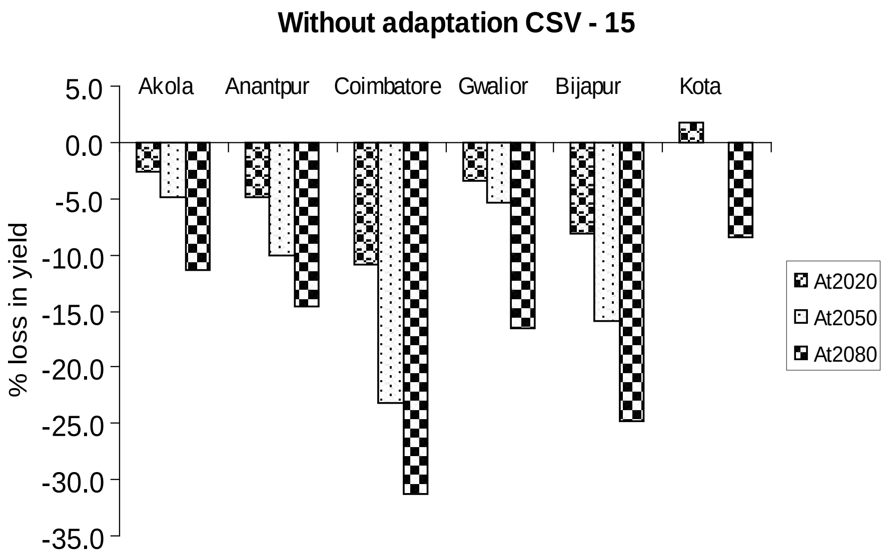

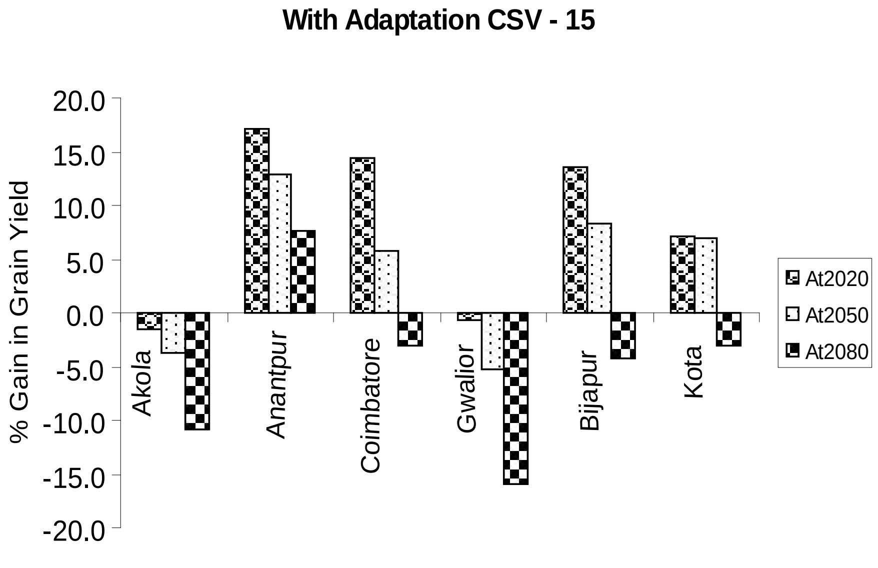

Figure 2. Simulated per cent change in yields (CSV 15) in HadCM3- A2a scenarios of climate change without and with adaptation.

radiation use efficiency (RUE) of the crop. Less leaf area together with low RUE has lowered net photosynthesis and finally reducing total dry matter production of sorghum crop. Pidgeon et al., (2001) also reported that changes in climate affect crop radiation use efficiency (RUE). Spatial variation in temperature as well as rainfall and its distribution led to spatial variation in yield reduction. This study supports the recent report of the IPCC and a few other global studies that indicate a probability of 10-40% loss in crop production in India with increase in temperature by 2080-2100 (IPCC, 2007). Simulation study conducted by Singh *et al*., (2008) also revealed that with rise in temperature, rain becomes deciding factor in regulating crop production. It is envisaged that the increase in temperature, if any, may be compensated by increase in rainfall.

Adaptation Strategies

There are many adaptation strategies highlighted in fourth assessment report of IPCC such as alteration of sowing date, replacement of variety, supplemental irrigation, etc. The change of sowing date and changing variety are applicable for assured irrigation condition or irrigated crops; we have taken supplemental as one of the adaptation method in rain-fed areas. Also Government of India is promoting micro-watersheds in rain-fed areas, which can store the excess water collected during peak rainfall and can be utilized for supplemental irrigation. A supplemental irrigation at 40-45 DAS is found to prevent yield loss to certain extent irrespective of the different SAT regions of India. The supplemental irrigation could improve the yield (CSH 16) up to 33.7%, 19.9%, 19%, and 4.2% (Fig. 1) in Coimbatore, Anantpur, Bijapur and Kota, respectively. At Gwalior and Akola, the simulated yields show that there will be little improvement (2%) due to a supplemental irrigation.The same way the simulated results showed that there could be better improvement in yield of sorghum variety CSV 15 (Fig. 2) in Coimbatore (28%), Bijapur (20%), Anantpur (17%), and Kota (5%). There is not much improvement at Gwalior (0.5%) and Akola (0.9%) because at Akola and Gwalior the average rain fall during the crop growth period (600 mm and 720 mm respectively) is higher than that of other selected SAT regions which receive low average rainfall (480 mm at Kota, 372 mm at Bijapur, 368 mm at Anantpur and 196 mm at Coimbatore) during crop growth period. So in these two regions, the variety of longer duration than present variety might be a better adaptation strategy.

Yield Gap

But on the other hand the comparison of district average yield with water stress potential yield, shows wide gap at Akola (3.45 Mg ha^{-1}), Kota (2.78 Mg ha^{-1}), Bijapur (1.56 Mg ha^{-1}) and Anantpur (1.48 Mg ha^{-1}). At Coimbatore, the yield is also low due to less average rainfall (196 mm), thus causing fewer gaps between water stress potential and district average yield in both hybrid and variety. On the other hand, the average rainfall (720 mm) is sufficient for growth and development of sorghum at Gwalior, which shows very narrow yield gap between water stress potential and district average. Bridging the gap by using IGNRM techniques through watershed development program (Wani *et al*., 2009), will be a better adaptation strategies against climate change as well as for sustainable production of sorghum to ensure food security.

Summary and Conclusion

Results from this simulation study revealed that the yield of sorghum (C_4 crop) increased with elevated CO_2 concentration in some extent, while the positive effect of increased CO_2 was nullified by temperature rise. The above result supports the adverse impacts of future anticipated climate change on sorghum growth and yield. Spatial variation was noticed in terms of its yield loss with all selected SAT regions in India due to soil type and weather parameters such as temperature and rainfall. Adaptation strategies like a supplemental irrigation would be helpful in preventing yield loss of rain-fed sorghum crop in all locations except Gwalior and Akola. But on the other hand, the comparison of district average yield with water stress potential yield, shows wide gap. Bridging the gap by using IGNRM techniques through watershed development program will be a better adaptation strategy against climate change as well as for sustainable production of sorghum to ensure food security in India.

Acknowledgement

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Glimpses of the Workshop

Participants of National Symposium on
Use of High Science Tools in Integrated Watershed Management

Program

Monday 1 February 2010

0900–0930 Registration

Session 1 Inaugural Session

0930–0935	Welcome	Prabhat Kumar
0935–0940	Background and Objectives	Suhas P Wani
0940–0945	Address by DDG, ICAR	AK Singh
0945–0950	Address by Special Secretary, DoA	NK Das
0950–1005	Address by Secretary, DoLR	Rita Sinha
1005–1015	Inaugural Address	William D Dar
1015–1020	Release of Books	WD Dar/ AK Singh NK Das/ Rita Sinha
1020–1050	Group Photograph and High Tea	

Session 2 Technical Session I

***Chair* : PK Agarwal**

***Rapporteur* : P Pathak**

1050–1120	Harnessing New Science Tools through IWMP to Unlock Potential of Rain-fed Agriculture	Suhas P Wani
1120–1150	Application of Geomatics in Watershed Prioritization, Monitoring and Evaluation – CRIDA's Experiences	B Venkateswarlu et al.
1150–1220	Use of GIS for IWMP Planning in Gujarat: A Case Study	Rita Teotia & Ram Kumar
1220–1250	Use of Modeling for Integrated Watershed Planning	Alok K Sikka et al.
1250–1300	Chairs Remarks	
1300–1400	Lunch	

Session 3 Technical Session II

	***Chair* : VN Sharda**	
	***Rapporteur* : Kaushal K Garg**	
1400–1430	Application of Econometic Methods for Assessing the Impact of Watershed Programs.	K Palanisami et al
1430–1500	Harnessing Agrometerology for Increasing Rain-fed Agricultural Productivity through Watershed Management	N.Chattopadhyay & L.S.Rathore
1500–1530	Recent Developments in Vadose Zone Hydrology: Opportunities and Challenges for Sustainable Utilization of Water and Nutrients for Enhancing Productivity	BS Das
1530–1545	Health Break	
1545–1615	Use of Agroclimatic Datasets for Improved Planning of Watersheds	AVR Kesava Rao et al
1615–1630	Discussion	
1630–1645	Chairs Remarks	

Tuesday 2 February 2010

Session 4 Technical Session III

	***Chair* : K Palanisami**	
	***Rapporteur* : AVR Kesava Rao**	
0930–1000	Advances in Geospatial Techniques for Integrated Watershed Management	PS Roy
1000–1030	GIS-based Monitoring Systems for Integrated Watershed Management	PG Diwakar
1030–1100	Bhoochetana – A Mission Mode Initiative of Govt.of Karnataka for Enhancing Agricultural Productivity in Dryland Agriculture.	NC Muniyappa & KV Raju
1100–1120	*Health Break*	

1120–1150	Application of Meta-analysis to Identify Drivers for the Success of Watershed Programs	PK Joshi
1150–1210	Discussion	
1210–1230	Chairs Remarks	
1230–1315	*Lunch*	

Session 5 Technical Session IV

***Chair*: Basu Chinmay**

***Rapporteur*: K Boomiraj**

1315–1345	Hydrological Modeling of a Micro-watershed Using GIS-based Model SWAT: A Case Study of Kothapally Watershed in Southern India	Kaushal K Garg & Suhas P Wani
1345–1415	New Tools for Monitoring and Modeling Hydrological Processes in Agricultural Watersheds	P Pathak
1415–1445	Innovative Micro-finance for Enterpreneurship Development for Farmers in Integrated Watershed Areas	Biswabandhu Mohanty
1445–1545	Group Discussion	
	Group I – Recommendations for Use of High Science Tools in IWMP Planning	Facilitator–PS Roy
	Group II - Recommendations for Use of High Science Tools in IWMP Execution, Monitoring & Impact Assessment	Facilitator–PK Joshi
1545–1600	Health Break	

Session 6 Plenary Session

***Chair*: Rita Sinha**

***Rapporteur*: P Pathak**

1600–1700	Rapporteurs' Reports
1600–1610	Technical Session - I
1610–1620	Technical Session - II
1620–1630	Technical Session - III
1630–1640	Technical Session - IV

1640–1650	Recommendations from Working Group-I	
1650–1700	Recommendations from Working Group-II	
1700–1720	Chair Persons Concluding Remarks	Rita Sinha
1720–1730	Vote of Thanks	P Pathak

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About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger, malnutrition and a degraded environment through better and more resilient agriculture.

ICRISAT is headquartered in Hyderabad, Andhra Pradesh, India, with two regional hubs and four country offices in sub-Saharan Africa. It belongs to the Consortium of Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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