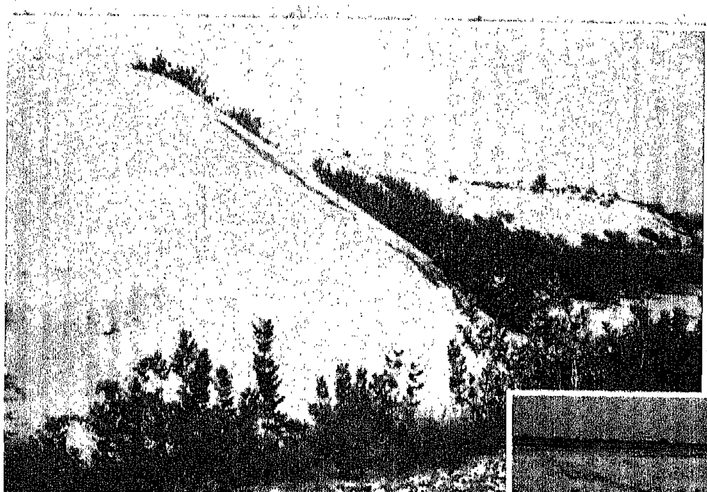
NATURAL RESOURCES APPRAISAL FOR LAND USE PLANNING IN ARID AGRO ECO-SYSTEM



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PREFACE

In recent past Indian continent has witnessed fast growing human and livestock populations, ever-growing demands of society for land based products, unabated over exploitation of natural resources leading to land degradation, desertification, droughts, floods and consequently plateuing or sometimes decline in land productivity. This emerging scenario calls for sustainable management of natural resources through efficient land use planning. A reliable assessment of natural resources, needs of society, prioritization and development commitment are genuinely required for efficient land use planning.

Macro and micro level zonification and planning has been attempted by several organizations in past. The All India Soil and Land Use Survey, Govt. of India carried out soil survey and land use planning for conservation of natural resources on catchment basis and for flood prone areas. Rapid reconnaissance soil survey in catchment and detailed survey in priority areas was carried out and information used for control of soil erosion.

Based on physiography, biophysical and climatic parameters, country was classified to land resource regions, agro-climatic regions and sub-regions and subsequently to widely accepted agro-ecological regions proposed by NBSS&LUP, Nagpur. Specific to arid region, CAZRI, Jodhpur has been carrying out semi-detailed survey and integrated appraisal of natural resources and developed concept of composite mapping as "Major Land Resources Units" by modifying land system and "Unique Mapping Area" approach of CSIRO, Australia for arid region of India. The approach has been satisfactorily utilized for classification, assessment and mapping of natural resources at 1: 250,000 scale for hot arid region of NW India and the information has been utilized for development purposes including some policy decisions.

It has been increasingly realized that development of implementable land use plan in cognizance of land capability is a massive task. The Department of Space, Govt. of India, utilized remote sensing and GIS approach contemplating action plans of large part of country under Integrated Mission for Sustainable Development at 1:50,000 scale. The State Remote Sensing Application Centre, Govt. of Rajasthan generated watershed maps and their development plans using remote sensing and GIS. Watershed has been recognized as a unit of development unequivocally.

Realizing gravity of situation, a mission mode project was launched under the auspices of NATP for land use planning on watershed basis. The mission is led by NBSS&LUP, Nagpur with five lead centres, one each under rainfed, irrigated, arid, coastal and hill and mountain agro-ecosystems and 52 cooperating centres. Deliberations of workshop included an overview by the lead Institute highlighting mission objectives, methodology, work plan and major achievements. This was followed by presentations of five lead centres and their cooperators. Under the Rainfed Agro-ecosystem, 16 cooperating centers conducted detailed soil and socio-economic survey of 1763 farm families and 78 field experiments using improved package of practices. Hill and Mountain Agro-ecosystem presented results of field experiments, socio-economic impacts and farmer's training on 11 watersheds. Under the Irrigated Agro-ecosystem, 28 soil series were identified and soil site suitability criteria developed at 11 centers. Coastal Agro-ecosystem identified production constraints in 10 watersheds, potential land use options and soil site suitability criteria for as many as 63 crops. Arid Agro-ecosystem analysed weekly weather data, digitized khasra wise maps, detailed soil mapping and developed soil site suitability criteria of 28 crops based on 230 field experiments.

Although the results of mission have been encouraging, however strong awareness about natural resource conservation, conflicts by societal demands, encroachment of marginal and degraded lands and environmental concerns, optimum land use planning has received a focused attention of planners and policy makers. The natural resource managers are often asked to provide site specific reliable developmental plan at larger scale (1:50,000 and preferably 1:10,000) ready for execution and arid zone is not an exception to this issue. Desert scenario is also fast changing due to human activities, intensive cultivation on marginal lands, over exploitation of ground water and excessive irrigation in IGNP command area resulting in waterlogging/salinisation, accelerated wind erosion and degraded mine spoil areas. Above all, oil has been struck in the desert and human activities will further intensify rapidly. Besides, this region is drought prone and desertification is an on going process. Therefore, *Environmental Conservation* will be a major issue in times to come. Without being complacent on achievements, CAZRI will have to take lead and concentrate on monitoring health of natural resources and impact assessment of human activities by adopting a well defined Road Map for Arid Region.

1. ***Assessment and monitoring of natural resources***: Utilizing remote sensing and intensive ground truthing, dynamic natural resource and socio-economics are to be assessed and mapped at 1:50,000 or 1:10,000 scale for need based land use planning. Besides, climatic data is to be analysed exhaustively on a time scale.

2. ***Creation of database in GIS environment***: Natural resource data may be digitized and spatial **database** be created under GIS environment and updated regularly. The facilities of remote sensing and GIS need further strengthening.

3. ***Interpretation of data and generation of thematic maps***: Through GIS, generation of thematic maps as per needs and integration of natural resource information is required to develop action plan at desired scale for sustainable land management. The concept of MLRU is to be made more flexible in the light of new concepts of agro-ecounits and soil site suitability using RS & GIS and Decision Support System for multipurpose diversified agriculture.

4. ***Develop sustainable land use plan by integrating technological interventions for stakeholders***: Linking market forces with the biophysical resources and socio-economics, micro level action plan should be developed on area basis encompassing livestock, silvi-pasture, agro-forestry, agri-horticulture, herbal farms, rehabilitation of mine spoil and reclamation of industrial effluents. Besides, revival of water resources like streams, tanks, nadis and khadins and ground water recharge, greening of oran and gochars are to be given highest priority.

5. ***Combating Drought and Desertification:*** Development of bench mark and indicators and early warning systems for monitoring land degradation/desertification are essential. In addition, long term and short term strategies are also required for effective management of drought and desertification.

We are grateful to Dr. S.L. Mehta, National Director and Dr. K. P. Agarwal, National Coordinator (Mission Mode), NATP, New Delhi for their kind permission and financial support for organizing this workshop. Thanks are due to Dr. K.S. Gajbhiye, Director, NBSS & LUP and Mission Leader of NATP project on "Land Use Planning for Management of Agricultural Resources". Our thanks are also due to Dr. S.N. Das, AISLUS, New Delhi, Dr. R. P. Dhir, (ex. Director), and Dr. Surendra Singh (ex. Head, Division of Natural Resources and Environment) CAZRI, Dr. J. R. Sharma and Dr. N. K. Kalra from RRSSC and SRSAC for their valuable suggestions in preparing this manuscript.

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I

Land use planning for Management of Agricultural Resources

An Over View

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Background

In the 21st Century Indian Agriculture is being challenged as never before, on one hand the burgeoning population and on the other, a need to provide food to the teeming millions. India has, at present, about 18% of world's human and 15% of livestock population to be supported from only 2% of geographical area and 1.5% of forest and pasture lands. Over millennia, people have become progressively more involved in exploiting land resources for their own ends. The limits of these resources are finite while human demands are infinite. Since net cropped area is limited, additional food has to be produced through higher yield per unit of land.

Various national and state research institutes including SAUs are involved in the development of agriculture in the five different agro-ecological systems of our country, namely, the rainfed, irrigated, arid, hill & mountain and coastal. Inspite of all these efforts there still exist a number of limitations for sustainable land management, important ones being non-involvement of farmers in the land use planning process as well as lack of coordinated multidisciplinary approach towards proper land use planning and its adoption. Any corrective measure/improvement would, therefore, need multidisciplinary, area specific and participatory mode of research in land use planning that would be related to issues specific to each agro-ecosystem. Land use planning would, therefore, ensure improved, optimal and sustainable use and management of agricultural resources.

The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, under Indian Council of Agricultural Research has the role of, a) survey and mapping the soils of the country to promote scientific and optimal land use programme; b) conducting and promoting research in the National Agricultural Research System in the areas of Pedology, Soil Survey, Land Evaluation and Land Use Planning; and c) impart training and promote awareness, education and monitoring on the soil resources and its state of health. The Bureau has developed research programme which will help in developing cutting-edge technologies for resource mapping at watershed level, characterization of the extrapolation domains of the agricultural technologies, resource information management in GIS framework and application of remote sensing technology in monitoring land use, land cover changes, degradation of resource base and in data processing and analytical techniques relevant to land evaluation and land use planning.

Rationale

Most developing countries in the world are faced with a dilemma of limited essential physical resources, such as land, water, nutrients and energy and the lack of appropriate technologies necessary for increasing food production. Proper planning and management of the available resources is necessary to ensure maintenance of their production potential, quality and diversity.

Any programme on Land Use Planning is related to issues specific to a particular agro-ecosystem. In India there are five agro-ecosystem viz. Rainfed, Irrigated, Arid, Hill & Mountain and Coastal. Each of them needs to be studied in detail vis-a-vis the present land use, the available resources, technological needs and their efficiency. The proposed research programme under NATP will develop strategies and options for sustainable land use planning for different agro-ecological systems in close association with ICAR/SAU networks, using multi-disciplinary approach. To accomplish the same, a number of activities will have to be undertaken which mainly include preparation of resource inventory of available information on soil, water and land, identification of constraints in each agro-eco system, integration of research findings/technologies (developed in isolation) through the multidisciplinary approach for assessing the efficiency of each agro-eco system, develop soil-site suitability criteria and land evaluation for different crops/cropping systems in the target (watershed) area, identification of research and development priorities for alternate land use planning and impact analysis of the suggested land use/land use plan models in the target areas.

The NBSS&LUP, Nagpur, as mentioned earlier, has recently completed the task of preparing soil resource inventory of different states and has generated huge information on the soil resources of the country. It is therefore, well equipped with necessary infrastructure, soil and climatic database of the country and necessary expertise to associate with each of the lead institute, identified for each agro-ecosystem. The project will also involve participation of the cooperating centres under each system and other stakeholders and adopt a coordinated multi-disciplinary approach towards handling the land use planning issues.

Project Mission

The mission of the project on land use planning is aimed at developing strategies and options for rational and scientific land use plans at watershed level integrating geo-referenced bio-physical information on land and socio-economic attributes for maximum and sustained production in different agro-eco systems. To achieve this mission, following objectives are set.

Objectives

To prepare resource inventories (data base) of what is known (present reference status) about present land use, production level, soil, water, climate, cropping systems, animal husbandry and socio-economic parameters for each agro-eco system.

- To identify constraints and demand (bio-physical, social and ecological) which determine the success/failure of land use efficiency and resource sustainability.
- To delineate micro level variations in each of the identified watersheds under each agro-ecosystem with respect to soil, climate, available water resource and socio-economic factors.
- To review the present cropping pattern/system, risk and economic viability of land use in each production system of a given agro-ecosystem.
- To develop eco-region specific land use options (models) based on land evaluation and socio economic factors and issues
- To monitor the state of health of natural resources - land and water at chosen bench mark sites at farmer's fields
- To validate land use models, in the identified watersheds, disseminate them and analyze impact of the suggested land use plans.

The Overall Approach

The project involves the NBSS&LUP, Nagpur as the "Main Lead Institute" and five other lead institutes identified for the five agro-ecosystems. PDCSR, Modipuram is the lead institute identified for the irrigated agro-ecosystem; CRIDA, Hyderabad for rainfed, CAZRI, Jodhpur for Arid, CSWCR&TI, Dehradun for Hill & Mountain and TNAU, Coimbatore for the Coastal agro-ecosystem. The lead institute in each agro-ecosystem will carry out its programme on land use planning with the help of different SAU's/ICAR institutes/ICAR Regional Research stations which will act as the cooperating institutes. These cooperating institutes have been selected in such a way that they represent all the sixty agro-ecological sub-regions (AESR) of the country.

Irrigated Agro-Ecosystem

There has been a considerable improvement in irrigation potential of the country during successive five-year plan periods. Development of surface water resources has taken precedence over the development of ground water resources. Out of the total cultivated area, about 51.4 m ha of land is under irrigation. Of the total irrigated land in the country, about 54% is irrigated by wells, another 33% by canals, 6% by tanks and the rest (7%) by other sources. A relatively very low (below 15%) and low (15-25%) percentage of irrigated land is confined to the western and central parts of India as well as Orissa, West Bengal and Assam from Eastern India. Moderate percentage (25%-45%) of irrigated land is in Andhra, Bihar, Uttar Pradesh and Jammu and Kashmir whereas relatively high percentage (above 45%) of irrigated land is only in the states of Punjab (78.8%), Haryana (51.4%) and Tamil Nadu.

The irrigated areas that have contributed significantly in increasing food grain production during green revolution are now facing serious problems of rise in ground water table and soil salinization. Various studies indicated that adoption of appropriate water management method could lead to increase water use efficiency. The impact of soil degradation in irrigated areas due to soil salinization and waterlogging has not been evaluated adequately. Soils having swell-shrink potential and poor drainability, show little sign of resilience once alkalinity is developed. Despite huge investment and scientific effort on creation of irrigation potential, the productivity potential remained low. The average productivity of irrigated land is low as compared to the international standards. This could be due low efficiency of irrigation system and/or lack of resource based sustainable land use planning. Land and water management problems must be viewed as a whole and cannot be considered in isolation from each other. One of the major defects in the existing data on irrigation is lack of uniformity in definition and classification of irrigation resources. Again there are a number of problems of measurement of irrigation potential and areas actually irrigated.

In any irrigation project, there are certain soil and land characteristics significant to design and operation of irrigation system. Soil Survey data shall be of much use in designing land development work, irrigation scheduling, on-farm water management, designing surface and sub-surface drainage, land reclamation measures for salt problems and deciding suitable crops and cropping pattern. Under this system 10 co-operating centres covering different regions are considered.

Arid Agro-Ecosystem

The arid zone of India consists of arid hot and arid cold regions and covers about 12 per cent of India's total geographical area and occupies over 38.7 mha out of which 31.8 mha is under hot and 7 mha under cold arid region. The hot arid is spread in the states of Rajasthan (61%), Gujarat (20%), Punjab (5%) and Haryana (4%) and Andhra Pradesh (7%).

The hot arid eco-system is characterized by low and erratic rainfall, extreme temperatures, very high wind velocities, low humidity and frequent droughts. Low productivity is associated with inadequate length of growing period. It also experiences hot summer and cold winter, annual precipitation ranging between 200 to 500 mm and PET exceeding 1800 mm, as most of the year is dry with severe drought. The area represents aridic soil moisture regime and hyperthermic soil temperature regime. The eco-system is blessed with an abundance of solar radiation, land and soils capable of responding to management, well adapted grasses and trees, annual crops, excellent breeds of sheep and goat as well as cattle. The underground water is deep and saline.

The cold arid ecosystem occupies Ladakh region of Jammu and Kashmir and is characterized by meso-thermal regime, mild mid summers and severe winters with mean annual temperature less than 8°C and mean annual rainfall of less than 150 mm. The precipitation covers less than 15 per cent of annual PET. The area qualifies for aridic soil moisture regime and cryic soil temperature regime. The annual growing period is less than 90 days. Low temperatures in most part of the year restricts in the choice of crops.

Arid ecosystem is stress agro-ecosystem. The constraints associated with the characteristics of ecosystem and the climatic parameters restrict sustainable productivity, unfavorable growth environment, limited choice of crop and cultivars, particularly in water deficit environs and aberrant weather conditions, low cropping intensity and low and unstable productivity. The constraints in arid ecosystem are limitations imposed by weather, high biotic pressure and soil and water loss due to erosion. Hence Land degradation is frequently a serious problem.

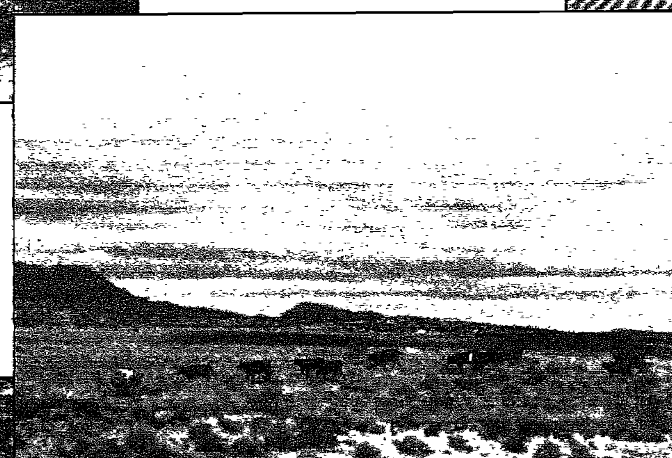
In this system, 8 watersheds/villages representing hot arid agro eco-sub regions were selected to elucidate the researchable issues.

Rainfed Agro-eco system

Dryland agriculture is the backbone of Indian agriculture as nearly 70 per cent of our cultivated area is rainfed and the fortunes of majority of farmers are linked with the success of dryland agriculture. Though the irrigated area is on the rise, more than 45 per cent of the cultivated area in the year 2000 AD was rainfed. Out of 225 million tones of food grain production targeted for 2000 AD, at least 100 million tones produced by drylands only. About 90 per cent of the pulses and oilseeds are grown in these areas. The low productivity of these dry lands is due to poor fertility, aberrant weather and short growing season. In dry farming regions, rainfall is the main source of water for raising various crops and its erratic behavior coupled with the reduced amount keeps the farmer guessing about the state of his crop. Drought detection, monitoring and early warning systems that provide timely and reliable information about the onset, spatial extent and termination of drought conditions are critical inputs for effective drought management in rainfed areas. The best available knowledge on the time and spatial variability of deficit rainfall must be translated in terms of soil moisture availability; possible effects on agricultural production, food shortages etc. Lot of research effort in dry lands in India has gone into quantifying the length of growing period available for each zone.

A single cropping system involving a long fallow period (Oct.-June) is the rule in these regions rather than exception. The deep vertisol in semi-arid region of India (about 12 m ha) are left fallow during the rainy season. A post rainy season crop like sorghum, safflower and chickpea are commonly grown either as sole or intercrop combinations. This is an under utilization of cropping period, more so in assured and medium to high rainfall areas. In some Vertisol regions, cotton intercropping with pigeon pea is common. In Alfisols, cropping in rainy season is common. The practice of intercropping is more productive

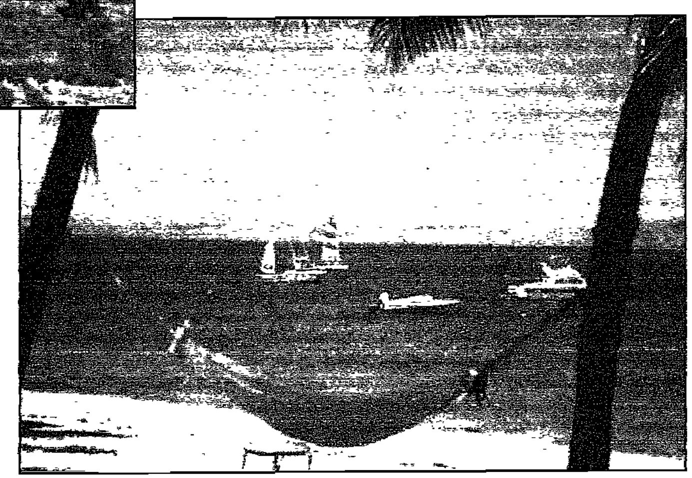
PDCSR, MODIPURAM
(IRRIGATED)



CRIDA, HYDERABAD
(RAINFED)

CAZRI, JODHPUR
(ARID)

CSWCR&TI, DEHRADUN
(HILL & MOUNTAIN)



TNAU, COIMBATORE
(COASTAL)

than growing them separately. Double cropping systems in dry lands could be possible in areas receiving more than 750 mm of rainfall with a soil moisture storage capacity more than 20 cm of available water. A number of implements have already been developed for use in dry land farming, whose use may ensure a substantial rise in productivity. In areas where arable cropping enterprise is not feasible, land use systems such as alley cropping, lay farming, agri-horticulture, silvi-pasture and tree farming would be appropriate.

The watershed development has become an important strategy for development of rainfed agriculture. The Government has already taken up many watershed projects and some of the experiences of these watersheds have been found highly encouraging in the context of drought mitigation. To achieve the research goals under the ecosystem sixteen watersheds have been considered under different agro eco-sub regions.

Hill & Mountain Agro-Ecosystem

Hill & mountain agro-eco system is very fragile and covers a large area (54 mha) encompassing mainly northern and north-eastern frontier states as well as some parts of central and southern states. The ecosystem is highly fragile due to geological, topographical, climatic and demographic reasons. Inaccessible rugged terrain, high risk, low pay off, fragmented small farm holdings and multiple ethnicity compounds the complexity of the ecosystems. Degradation of natural resources due to demographic pressure, diminishing forest covers, increasing pollution, extinction of biodiversity and global warming are serious environmental issues. Soils of this eco-system are less fertile with problems associated with soil acidity, low exchange capacity and aluminium toxicity. The ecosystem has tremendous off-site effects since it regulate floods, droughts, ground water recharge and sediment deposition in reservoirs and flood plains. Hill and mountain ecosystem has been gifted with tremendous opportunities to meet these challenges. The ecosystems have rich biodiversity and high potential productivity and regulate hydrology of river basins. A judicious land use is therefore a key to translate these challenges into opportunities. In spite of availability of adequate funds for watershed management, developmental works have suffered a great deal for the want of appropriate land use plans. Towards this goal, ten watersheds representing different agro eco-sub regions under the ecosystem have been considered.

Coastal Agro-Ecosystem

Coastal agro-ecosystem covers an extensive area stretching in nearly 7000 km along the east coast, encompassing parts of West Bengal, Orissa, Andhra Pradesh, Pondicherry and Tamil Nadu states and along west coast representing Gujarat, Maharashstra, Karnataka and Kerala states. The areas are endowed with a variety of contrasting conditions related to soil, rainfall, water resources, agricultural, horticultural and forest crops including fisheries. The ecosystem is associated with problematic soils such as saline, alkaline, acid sulphate, marshy and water logged soils. These soils are low in organic matter and have deficiency and toxicity of some elements.

The benefits of 'green revolution' have not reached to many areas in India, especially the coastal areas. There are large imbalances in the growth of agricultural production among different states under different bio-physical and socio-economic environment. The chief problems in the coastal areas are of both low productivity and lack of sustainability.

Coastal agriculture supports (i) agricultural subsistence food and cash crops (ii) perennial crops, consisting of forestry, horticulture and plantation crops and (iii) fish culture. Rice-based cropping system is most common but the yield of rice is much low. There has been research focus on a single crop i.e. rice for a very long time and has not been directed to meet the requirement of a mixed system in which the farmers are interested.

The ecosystem suffers, both in monsoon and post-monsoon seasons due to excess rain and high salinity of ground water respectively. Nevertheless, the coastal areas are endowed with bountiful resources including a variety of soils, and climatic conditions suited to different farming systems. The coastal areas offer ample scope for plantation crops and low cost brackish water fish culture. Expansion of inland fish culture in many states has resulted in augmenting fish production. Coastal region is the highest recipient of pollutants through discharge of untreated sewage, harbour wastes, urban garbage, agro-chemicals, etc. which degrade the water quality and affect marine life. Considering the increasing environmental threat, exploitation of coastal ecosystem needs appropriate remedial strategies.

In view of the problems faced by coastal agriculture, the complexity of biotic system must be considered along with socio-economic factors for future planning. The cross-cutting research project is, therefore, aimed at achieving the overall development of coastal ecosystem through proper land use planning by addressing multi-disciplinary and location specific approach with special emphasis on sustainability and environmental protection. Towards this goal, ten watersheds representing different agro eco-sub regions in the ecosystem have been considered.

Methodology and Work Plan

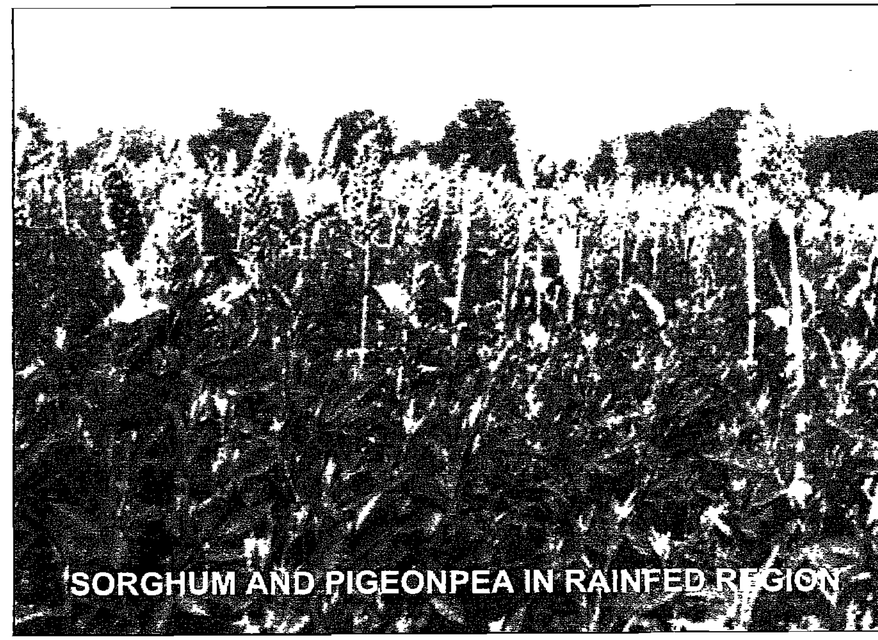
Lead centres identified for five major Agro-eco systems will work on land evaluation and land use planning in identified watersheds in close association with their respective co-operating centres and the implementing agencies of the watersheds spread all over the country. The proposed study is expected to generate precise data at parcel level (a few hectares), which in turn can be used as point data to reflect large area aggregate. Ground survey (1:10,000 scale) at village/watershed level will be carried out to generate large scale resource data. For the study and/or prediction of large area (i.e. small scale representation) remote sensing and GIS techniques are proposed to be employed in conjunction with Survey of India toposheet of comparable scale.

1. Each of the identified co-operating research centres in a given agro-ecosystem will delineate/demarcate and select a watershed to study micro-level variation (if any) with respect to soil, climate and socio-economic status in the context of existing land use. Within each watershed, different themes will be studied in detail and at different levels of classification, namely, present land use and climate at the level of watershed; soils at the level of soil series and phases (wherever required); farming system and socio-economic parameters at the level of village and/or individual farmer and hydrology at watershed/village level. The scale of operation will be 1:10,000. However, it may vary slightly depending on the physiography and drainage as well as the availability of appropriate base map. Relatively homogeneous units thus can be grouped together for land evaluation.

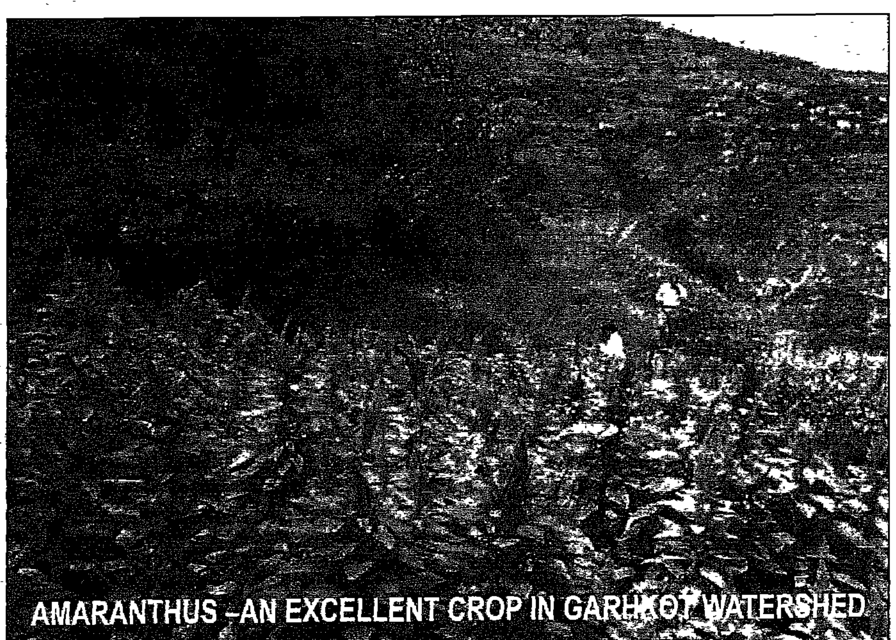
2. It is proposed to prepare resource inventories (data base) for each watershed encompassing present land use, soil and climatic conditions, socio-economic conditions and local policy issues. These datasets and lab analyses at watershed level of each agro-eco system will be utilized in evaluation and selection of options for proper land use suited to specific bio-physical and socio-economic conditions. These studies would be conducted partly in research farm and partly in the fields of small, marginal and large farmers.

3. Each of the co-operating research centres under each ecosystem lead Institute will identify constraints/threats responsible for poor productivity or decline in productivity and mis-match in land use practices.

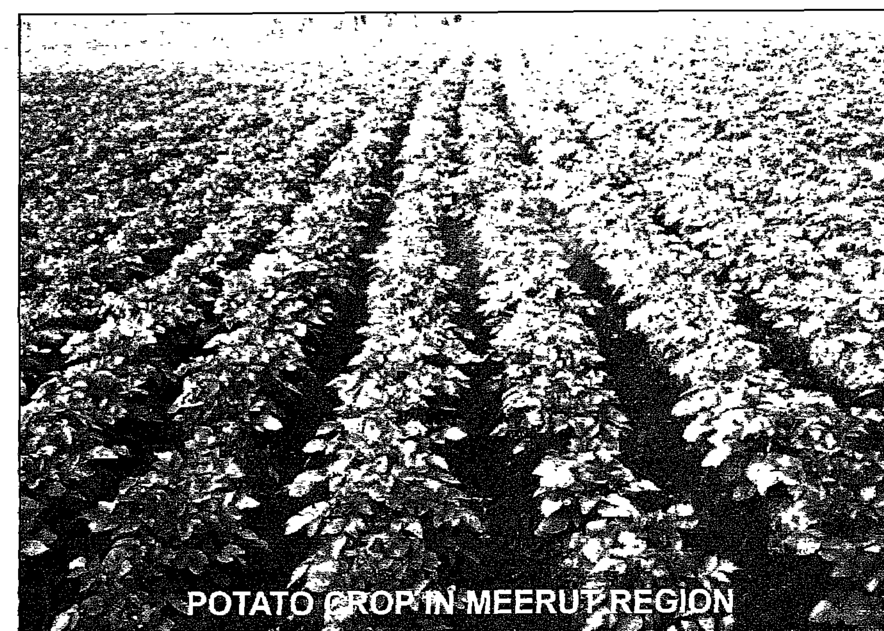
RICE CULTIVATION IN COASTAL REGION



SORGHUM AND PIGEONPEA IN RAINFED REGION



AMARANTHUS - AN EXCELLENT CROP IN GARHKOT WATERSHED



POTATO CROP IN MEERUT REGION

4. Cooperating centres will also identify the local social criteria related to land tenure, land ownership etc., which largely determine the land use form and management.

5. Research personnel (or extension staff) of each co-operating centre will have direct contact with the stakeholders to assess and incorporate their views in the impact analysis. They will also take a stock of the animal husbandry, and allied avocations related to land use planning.

6. Based on these information (Detailed data sets) generated by the co-operating centres in a given Agro-eco system, the sub-programme lead institute in consultation with main lead institute will be able to assess the situation and research needs.

7. Integration of bio-physical and socio-economic data base will be done at main lead institute in close association with sub-programme lead institutes using the latest GIS software. Based on these large data sets it will be possible to identify options for optimal land use through multiple linear programming and GIS software on land use planning such as ALES etc. This GIS framework will help in continuous review of changes in the land use scenario leading to identification of research and development priorities for alternate land use planning through land evaluation. Development of soil-site suitability criteria for crops/ cropping pattern depending on soils and associated attributes for each production system will be carried out. Issues like introduction of non-conventional crops in areas where traditional crop (or a specific genotype) showed decline in productivity and/or demand is less; prediction of crop diversification, phasing out of certain crops, and alternate land use plans will be considered.

8. Land use models based on land evaluation, potentials, limitations and socio-economic parameters will be generated for implementation at different watersheds. These models will be used for alternate cropping systems and will also be linked up with planning system.

9. Impact analysis (validation and assessment) of the suggested land use models will be assessed for improvement and/or modification.

10. Successfully validated models will be disseminated.

Periodic monitoring of resources (Soil and Water) will be carried out as per agreed programme of agenda.

Achievements

Major achievements in general and under each of the agro ecosystem are presented as under :

- Study area watershed / villages / command area has been selected by all the co-operating centres in the five agro-ecosystem
- Socioeconomic Survey of each household using pre-structured proforma has been completed in the respective watersheds by all the cooperating centres.
- Major socio-economic constraints have been identified by all the cooperating centres though constraint analysis and PRA techniques
- All the cooperating centres have completed detailed soil resources survey of the respective watersheds.
- Analysis of about 5,000 soil samples (surface & sub-surface) for different physical and chemical parameters has been completed by all the centres.
- Major soils and their constraints have been identified in the watershed of each cooperating centre.

- Soil site suitability criteria were developed for each ecosystem and land evaluation completed for the major crops prevalent in each watershed.
- Suitable alternate crops including those crops having special demand in local markets were identified by all the cooperating centres (based on soil suitability and need of the stake-holders).
- Periodic monitoring of soil properties viz. pH, EC, organic carbon, and available nutrients and of water quality parameters viz., pH, EC, SAR, and RSC of the soil and water samples was completed as per schedule.
- Based on the resource survey and subsequent identification of major constraints, suitable interventions have been suggested.
- Since the initiation of the project a good deal of rapport could be built up with the farmers (of the watershed/village) through organization of farmer's days, field demonstrations, night meetings, etc. A total number of 34 farmer's days/field days were organized to educate more than 3000 farmers on the efficient use of fertilizers/pesticides, post harvest technology, selection of crops based on suitability criteria and also to solve their problems mainly related to crop production.
- Sixty five co-operating scientists have been trained on various aspects of land use planning.

Rainfed Agro-Ecosystem

K. P. R. Vittal

Central Research Institute for Dry land Agriculture (CRIDA), Hyderabad

Introduction

The land use planning under Rainfed Agro-ecosystem consists of Central Research Institute for Dry land Agriculture (CRIDA) as Lead Centre with 16 co-operating centres (11from SAUs, 4 from ICAR and 1 from BHU) covering 16 Agro eco- sub regions (AESR) ranging from 2.3 to 10.3 spreading in 10 states of the country. The multidisciplinary research team has 112 scientists (comprising of agronomy, soil science, soil and water conservation engineering, agro-forestry, entomology, agricultural extension, agro-meteorology, agricultural economics, agricultural statistics, GIS specialists, home science, animal sciences). The total operational area is 5250 ha in 16 watersheds. The spatial distribution of the centres over laid on Agro-eco sub region map is given in Fig. 1.

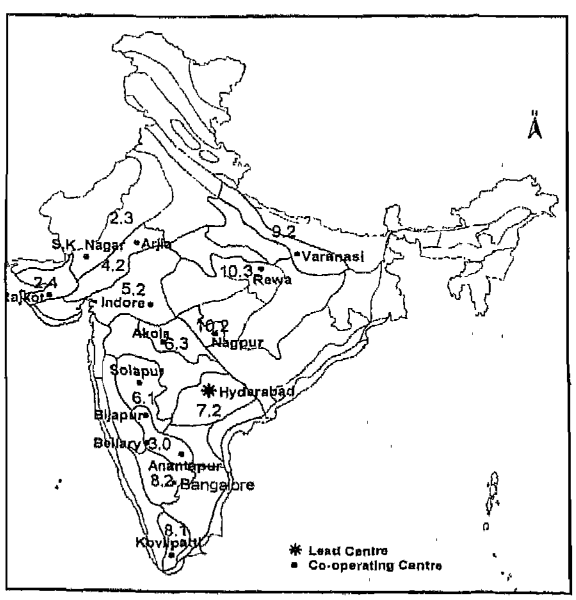


Fig. 1. Network of Cooperating Centres.

Achievements (January 2001 to November, 2003)

a. ***Climate***: All the 16 centres completed climatic data collection and analysis. Climate is semiarid in Akola, Bangalore, Hyderabad, Indore, Kovilpatti, and Solapur; subhumid in Varanasi, Rewa and Nagpur and arid in Anantapur, Arjia, Bellary, S.K. Nagar, Rajkot and Bijapur. During 2002 *kharif* a severe drought was experienced at all the centres with a rainfall deficit ranging from 30-50%.

b. ***Soil resource inventory***: All the 16 centres completed soil resource inventory in 5258 ha area. 4 major soil orders viz., Entisols, Alfisols, Inceptisols, Vertisols and 120 soil sub groups were identified. Detailed soil survey reports of the cooperating centers were brought out.

c. ***Socio-economic inventory***: Socioeconomic data were collected for 1763 households from 16 adopted watersheds and preliminary analyses were done vis-à-vis land use dynamics, constraints analyses and other parameters.

Monitoring of Soil and Water Quality:

All the 16 centres collected surface soil samples and water samples from bench marked sites and analyzed the data. In general, the water quality data indicated safe for irrigation with few exceptions.

Interventions

For sustainable, economic and viable land use planning, both conservation and utilization of land resources and crop management needs a complementary consideration. The land parcels are highly spatially variable. To encompass this high variability watershed is taken as a basic experimental unit for land use planning in rainfed agriculture. During 2002-03, 78 interventions were undertaken across 16 centres in 38 varying soil units.

Achievements

Technical programme for the year *kharif* 2002-2003 was implemented at all the centres. The salient findings are given below.

- At Varkhed watershed (Akola), farmers accepted cultivation of cucurbits (Ankur, Himangi) followed by sesame (AKT-64) being short duration crops
- At Anantapur, soils having more than 25 cm depth are suitable for successful raising of groundnut under scarce rainfall conditions
- At Arjia (Dist. Bhilwara) introduction of short duration, early maturing and drought resistant varieties of maize, black gram, green gram and sesame improved the yields by 74, 42, 40 and 40 per cent respectively over farmers practice in Typic Huplustepts.
- The mean increase in groundnut + sesame intercropping system was 17 per cent over farmer's practice, while for maize + black gram intercropping, there was 65 per cent over farmers practice.
- Fodder sorghum (M.P.Chari) yielded 25 per cent more over local
- At Amanishivpurkere watershed (Bangalore), amongst finger millet, cowpea, fiedbean and *Mucuna* performed better despite drought in Kandic Paleustalfs, Ultic Haplustalfs and Typic Dystrustepts. Finger millet recorded high yield in Typic Dystrustepts.
- At Gadehothur watershed (Bellary), the chickpea and coriander sown in October performed better. In wasteland area *Styllosnathus hamata* seeds were broadcasted which are coming up well. Sunflower and sorghum performed poorly.
- At Kaulagi micro watershed (Bijapur), sunflower paired row planting performed better on Typic Haplusterts compared to traditional sunflower cropping. Groundnut + pigeon pea (4 :2) and pearl millet + pigeon pea (2 :1) performed better in Typic Haplustalfs over traditonal groundnut + pigeon pea intercropping (5 :1) and pearl millet + pigeon pea (5:1) respectively.
- At Nallavelli watershed (Hyderabad) despite severe moisture stress castor (Kranti) could performed to some extent and performed better in Typic Rhodustalfs.
- At Panubali micro watershed (Nagpur), sorghum performed better. Sorghum and soybean performed better in Typic Haplustepts. Cotton hybrid NHH-44 found suitable for Typic Haplusterts.
- At Salempura micro watershed (S.K.Nagar), castor (GSH-4), pearl millet (GHB-235) + green gram (GM-4) and cluster bean (GC-1) performed better in Typic Ustorthents, Typic Ustochrepts and Typic Ustorthents respectively.
- At Sarole watershed (Solapur), pearl millet (RHRPH-8609) and pigeon pea (ICPL-87), sunflower (SS-56), fodder maize (African tall), black gram (TAU-1), green gram (Kopergaon) in Typic Haplutepts, while sunflower + pigeon pea (2:1) performed better in Typic Haplusterts.
- At Ballipur watershed (Varanasi), blackgram and sesame performed better in Udic Eutrudepts, while rice performed better in Vertic Fluaquents
- Bench mark sites were selected by most of the centres.

Traditional Land Use and Suggested Land Use at various Centres

Centre	Soil type	Traditional land use	Suggested land use
Akola, Varkhed watershed	Typic Ustorthents (Shallow soils)	Sorghum, cotton	Sorghum (CSH-14),cotton (hybrid cotton), sorghum (SPH-388) and black gram
	Typic Haplusterts		Sunflower paired row planting
Bijapur, Kaulagi watershed	Typic Calciusterts, Calci Haplusterts, Typic Haplusterts, Typic Ustifluvents, Lithic Ustorthents, Typic Haplusterts	Rabi sorghum, Sunflower, Pearlmillet	Groundnut + pigeon pea - 4: 2 Pearlmillet + pigeon pea – 2:1
	Lithic Ustorthents, Typic Ustorthents	Groundnut + pigeon pea (5:1), pearlmillet + pigeon pea (5:1)	Sorghum (CSH-9) + recommended dose fertilizer
NBSS&LUP, Nagpur, Panubali watershed	Lithic Ustorthents, Typic Haplustepts (non Calcareous), Typic Haplustepts (calcareous)	Sorghum, Cotton	Soybean (JS-335) + recommended fertilizer dose
	Typic Haplustepts (calcareous), Typic Haplustepts (Non Calcareous), Vertic Haplustepts (calcareous)		Cotton (LRK -516)
	Lithic Ustorthents, Typic Haplustepts, Lithic Ustorthents (calcareous)		Cotton (NHH 44)
	Typic Haplusterts (calcareous)		Castor (GSH-4) + 60 + 30 + 25 dose + 45 cm x 90 cm, Pearlmillet (GHB 235) + 75 + 25 + 60 + 45 cm x 10 cm) + green gram (GM4) (3:1), Cluster bean (GC-1) + 20 N + 40 P + 20 S + 45 cm x 10 cm
S.K.Nagar, Saleempur watershed	Typic Ustorthents (Non Calcareous), Typic Ustrochrepts (Calcareous), Typic Ustorthents (calcareous)	Pearlmillet Small Pulses	Field bean (Hebbal 3) + 25 + 50 + 25 + 45 cm x 15 cm *Macuna Utilis* (Medicinal plant) 10 + 20 + 20 + 200 cm x 100 cm, Ragi (GPU – 28) + 50 + 40 + 25 + 30 cm x 7.5 cm Soybean (KHS 6 –2) + 25 + 60 + 25 + 30 cm x 10 cm

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NBSS&LUP, Bangalore, Amanishivapurkere watershed	Kandic Paleustalfs Ultic Haplustalfs (more 2), Typic Dytrusteps	Fingermillet, Avare Small Millets Small Pulses	Pearlmillet (cv. RH RBH-8609)
Solapur, Sarole watershed	Lithic Ustorthents, Typic Haplustepts	Rabi sorghum, chickpea	Pigeonpea (ICPL 87)
	Lithic Ustorthents, Typic Haplustepts, Typic Haplusterts		Sunflower (SS-56)
	Typic Haplusterts		Fodder (Maize African tall)
	Typic Haplustepts, Typic Haplusterts		Black gram (TAU-1)
	Lithic Ustorthents, Typic Haplustepts		Green gram (Kopergoan –1)
	Typic Haplusterts		Sunflower + pigeonpea (2: 1)
	Typic Haplustepts, Typic Haplusterts		Castor (cv Kranti) + RDF (60: 40:30)
Hyderabad, Nallavelli watershed	Typic Rhodustalfs, Typic Haplustalfs	Sorghum, castor	First for black gram and sesame, first for rice
Varanasi, Ballipur watershed	Typic Fluaquents, Udic Eutrudepts, Vertic Fluaquents	Rice	Maize and mung bean

Technical programme for 2003-04 was implemented at all the cooperating centres. Total 245 interventions were undertaken across 16 centres in kharif 2003-04.

Soil Site Suitability Criteria

Soil site suitability Criteria were developed for 41 major crops (7 cereals, 8 pulses, 5 oilseeds, 5 vegetables, 5 horticultural crops, 7 plantation crops and 4 commercial crops) in respective regions. In rainfed agriculture, almost all the crops are grown in most of the regions to avert risk. Hence, soil and climatic parameters window may become wide.

Farmers' Trainings/ Farmer Days/Field Days 2002-03

- 28 trainings for farmers were organized under different themes at 9 centers and 645 farmers and 160 farm women were benefited.
- 16 Field days and 7 *Farmers' Days* and 1 farmer fair *Kisan Diwas* and *Kisan Rally* and 3 Group Meetings were organized by different centers wherein the farmers were appraised of importance of land resources, soil and water conservation use of bio-fertilizers, energy management (farm machinery), post harvest technology, alternate land use and live stock management. Total 2420 farmers were benefited directly.

Impact (Yield gains/Monitory gains) of Field demonstrations /Field experimentations

- In 2002-03, 76 Field demonstrations mainly on soil site suitability based crop planning and soil and water conservation conducted covering 256.7 ha area in 608 fields of small, marginal and medium farmers distributed in categories of SC, ST and OBCs.
- In 2003- 04, 272 Field demonstrations mainly on soil site suitability based crop planning and soil and water conservation conducted covering 121.81 ha area in 473 fields of small, marginal and medium farmers distributed in categories of SC, ST and OBCs.

Rapport building activities

Activity	Center
Village meetings	Akola, Anantapur, Arjia, UAS Bangalore, NBSS&LUP Bangalore, Bellary, Bijapur , Hyderabad, Kovilpatti, Rewa, Rajkot, S.K.Nagar, Solapur and Varanasi
Group meetings	Akola, Anantapur, Arjia, Bangalore (UAS), Bangalore (NBSS& LUP), Bellary, Bijapur, Hyderabad, Indore, Kovilpatti, Nagpur (NBSS& LUP), Rajkot, Rewa, Sardar Krishinagar, Solapur and Varanasi
Farmer's day/ Night meetings/ demonstrations	Akola, Anantapur, Arjia, UAS Bangalore, NBSS LUP bangalore,Bijapur ,Hyderabad, Kovilpatti, Rewa, Rajkot, S.K.Nagar, Solapur , Varanasi
Group meetings	S.K.Nagar,Solapur, Varanasi
Field days	Arjia, Kovilpatti, Rajkot, Varanasi
Farmers day	NBSS&LUP Bangalore, Hyderabad, Rewa , S.K.Nagar, Varanasi
Farmers rally	Varanasi

Publications

Referred articles	5	Soil pass book	1
Seminars /symposia papers	14	Technical Papers	4
Books	2	Technical Reports	13
Bulletins	3	Popular articles	8
Popular articles	15	Leaflet	4
Book chapter	4		

Hill & Mountain Agro-Ecosystem

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Introduction

Hill & mountain ecosystem are distributed in 23 states of the country with a larger area located in Himalayas extending in 2500 km length and 250 to 400 km breadth. The Himalayas are further classified in 3 major categories comprising (1) Western Himalayas: Jammu and Kashmir and Himachal Pradesh (2) Central Himalayas : Uttaranchal, and (3) North eastern Himalaya: north eastern states. Major production systems are rice based, horticulture and plantation based, agro-forestry based and silvi-agri-livestock-fisharies based. Physiographic constraints like undulating topography, severe water erosion, small fragmented and scattered holdings and difficulties in rain water conservation lead to low productivity and resource poor farmers. Degradation of ecosystem has been a national concern. The ecosystem receives highest rainfall but for most part of the year there is acute shortage of water. Therefore there is an urgent need to develop watershed based land use plan. Effective management of natural resources in this eco system will have positive influence on the land and water resources of plains by regulating water supplies and undisturbed soil base. With this view watersheds have been selected at 11 sites in different areas in the ecosystem.

Demographic structure	N-E Himalyas	Western Himalayas
Human population ('000)	12,126	21,647
Density (persons per km ^{2})	59.7	64.6
Total workers ('000)	5,691	6,341
Agricultural workers ('000)	3,747	3,373
Per capita arable land (ha)	0.32	0.10
Farming system	Shifting cultivation and settled	Settled
Livestock	Pig, mithun, yak and poultry	Cow, sheep, goat and buffalo
Dominant and ownership	Community and private	Govt. and private (mainly forest)

Resource base

Attribute	N-E Himalayas	Western Himalayas
Total geographical area (53.7 mha or 16.4%)	20.32 (37.7%)	33.50 (62.3%)
Climate	Extremely wet	Dry and cold
Latitude	21° 05'- 29° 03'N	29° 03'1"- 36° 05'8"N
Longitude	85° 05'- 97° 05'E	73° 02'6"- 83° 03'0"E
Elevation (m, above msl)	100- 5000	350- 8611
Annual rainfall (mm)	2800- 12000	350- 3000
Mean temp.(°C)	8- 22	8- 22
Physiography	Gentle slopes	Steep slopes
Crop growing period (days)	210->270	90- 210
Soils	Shallow to medium with low organic matter, red yellow lateritic, acidic reaction	Skeletal and calcareous, deep to shallow loamy forest soil, acidic to neutral and alkaline in reaction
Vegetation	Tropical moist deciduous, sub-tropical pine and temperate evergreen forest (Rhododendron spp., laurels, alder, birch and willows)	Tropical dry deciduous to moist, temperate and sub-alpine (conifers, chir, blue pine, deodar, fir, spruce, junipers and bgiyals)

Major land use pattern in Western Himalayas ('000ha)

States	Total geographical area	Reporting area	Forest	Permanent pasture and grazing	Net area sown	Others
1194	5567	3304	1049		568	593
J&K	22224	4505	2747	126	734	896
Uttaranchal	5113	5060	3430	254	660	716
Punjab*	213	213	123	-	68	22
Haryana*	383	383	38	11	116	218
Total	33500	13565 (100)	7387 (54.5)	1585 (11.7)	2146 (15.8)	2447 (18.0)
Total H&M	53822	30668 (100)	18062 (58.9)	1675 (5.5)	3818 (12.4)	7106 (23.2)
All India	328726	304891 (100)	68826 (22.6)	11054 (3.6)	142215 (46.6)	82796 (27.2)

Location of watershed of Lead and Co-operating centers

Centre	Watershed location	District	Geographic Location		Altitude (meters)	Area (ha)	Distance from centre (km)
			Latitude (N)	Longitude (E)			
Dehradun	Garhkot	Tehri	30° 15'	78° 30'	780-1680	348	124
Srinagar	Haptanar	Badgam	30° 50'- 33° 54'	74° 44' -75° 47'	1670-2000	355	30
Solan	Kiar Nangali	Solan	30° 52'	77° 10'	1100-1300	231	10
Palampur	Mc Gad	Lahaul Spiti	32° 39' -32° 41'	76° 40'- 76° 42'	2500-4440	438	-
Ranichauri	Henwal	Tehri	30° 15' -30° 20'	78° 25' -78° 30'	1000-2200	486	-
New Delhi	Una	Una	31° 23' -31° 26'	76° 18' -76° 21'	-	-	6
Ooty	Thambatti	Nilgiri	11° 20' -11° 21'	76° 41' -76° 42'	2000-2300	555	20
Kolkata	Mamring	Darjeeling	26° 55 -26° 58'	88° 17' -88° 22'	1290-2000	290	22
Johrat	Narang Kangri para	Ri-bhoi	23° 58° -26° 54'	91° 49' -91° 52'	390-420	1565	80
Barapani	Wah-rina	Ri-bhoi	-	-	1610-1760	647	45
Gangkok	Chalumthang	Gangtok	25° 15' -27° 12'	88° 27'- 88° 30'	-	194	44

Major land use pattern in North-eastern Himalayas ('000ha)

States	Total geographical area	Reporting area	Forest	Permanent pasture and grazing	Net area sown	Others
Arunachal Pradesh	8374	5495	5154	-	185	156
Manipur	2233	211	602	-	140	1469
Meghalaya	2243	2241	937	-	206	1098
Mizoram	2108	2088	1598	-	109	381
Nagaland	1658	1546	863	-	211	472
Sikkim	710	710	257	69	95	289
Tripura	1049	1049	606	-	277	166
Assam*	1632	1521	548	21	350	602
W.Bengal*	315	242	117	-	99	26
Total NEH region	20322	17103 (100)	10682 (62.5)	90 (0.5)	1672 (9.8)	4659 (27.2)

Constraints for Crop Production:

- Water scarcity and declining of natural springs
- Erratic rainfall and moisture stress
- Micro-situation variations in temperature and rainfall
- Small and fragmented landholdings
- Shallow soil depth, stoniness and poor base status
- High runoff and erosion
- Shifting cultivation
- Low literacy
- Resource poor farmers
- Lack of scientific know how for agriculture, horticulture, agro-forestry and forestry
- Traditional farming an lack of inputs such as quality seed/plant material
- Migration of adults
- Woman dominated farming
- Lack of marketing and transport
- Land tenure

Field demonstration

Month /Year	Subject of field demonstration	Host Institute	Place where field demonstration conducted	Area covered	Beneficiaries covered category /No.	Gain in terms of Quality and Quantity
June, 2002	Introduction of improved Varieties of Kharif crops viz. Mandua,maize, paddy, soyabean, blackgram, cowpea, okra, cowpea, okra, tomato, cucurbit etc.	CSWCTRI, Dehradun	Garhkot Watershed	4 ha	Watershed (75)	20-40 % crop yield was increased
Aug., 2002	Alternate land use as agro-horticulture by plantation of 1232 fruit plants of mango, guava, citrus, orange, malta, papaya, pomegranate	CSWCTRI, Dehradun	Garhkot Watershed	3 ha	Watershed (115)	Introduction for alternate land use for sustained productivity
Aug., 2002	Plantation of 125 fuel and fodder trees	CSWCTRI, Dehradun	Garhkot Watershed	0.25 ha	Watershed farmers (5)	To increase fuel and fodder
Oct., 2002	Introduction of improved Varieties ofwheat, toria, lentil, pea, onion, spinach, methi, etc. for higher yield	CSWCTRI, Dehradun	Garhkot Watershed	6.5 ha	Watershed farmers (125)	To increase crop productivity
Feb., 2003	Alternate land use as agro-horticulture by plantation of 335 fruit plants of apple, plum, almond, pear, walnut etc. as homestead and orchards	CSWCTRI, Dehradun	Garhkot Watershed	0.8 ha	Watershed farmers (25)	Introduction of alternate land use system
Summer, 2002	Improved Varieties of Pea (Palam priya) treated with Bavistine	CSKHPKV, Palampur	Mc-Gad Watershed	0.8 ha	Watershed farmers (20)	To increase crop productivity

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Summer, 2002	Karathane Balyton to control powdery mildew in pea and Atrazine/ Isoproturon for weed control and dithane M-45 for late blight in potato	CSKHPKV, Palampur	Mc-Gad Watershed	-	Watershed farmers (21)	Quality productivity
Summer, 2002	Grass seed (250g) – red clover, lucume, pescue etc. to each farmer	CSKHPKV, Palampur	Mc-Gad Watershed	-	Watershed farmers (32)	To increase grass fodder
Summer, 2002	Integrated nutrient management in potato, carrot, broccoli, and lettuce	CSWCRTI, Ooty	Thambawati watershed	0.6 ha	Watershed farmers (32)	Higher quality yield was obtained
Summer, 2002	Diversified land use by tea plantation	CSWCRTI, Ooty	Thambawati watershed	0.25 acre	Watershed farmers (32)	For high income
Summer, 2002	Poly green house and plantation of 15500 camation rooted cuttings	CSWCRTI, Ooty	Thambawati watershed	500 m^2	Watershed farmers (32)	To off season vegetable and floriculture
Summer, 2002	Terrace renovation	CSWCRTI, Ooty	Thambawati watershed	0.5 acre	Watershed farmers (32)	To increase productivity
Rabi, 2002	Introduction of improved Varieties of wheat	CSWCRTI, Ooty	Thambawati watershed	0.8 ha	Watershed farmers (32)	To increase productivity
Kharif, 2002	Introduction of short duration Varieties of black gram and French beans with nutrient (P)	NBSS & LUP, Jorhat	Narang-kangripara	-	Watershed farmers (32)	To increase productivity
Kharif, 2002	Improved Varieties of maize (P-4640)	ICAR Res. Comp. Centre Gangtok	Chalumthang	7.5 ha	Watershed farmers (32)	To increase productivity
	Ginger (40 kg) and cash crops of tuberose (4000 bulbs)	ICAR Res. Comp. Centre Gangtok	Chalumthang	-	Watershed farmers (50)	To increase productivity

Response of different interventions

Month /Year	Subject of field demonstration	Host Institute	Area covered	Beneficiaries covered category /No.	Bio fertilizers	Crop	Response (%)
Kharif May-June 2002	Response of Bio fertilizers on cabbage and tomato	Hill Campus Ranichauri	0.6 ha	Farmers (30)	*Azospirilum brasilense* *Aspergillus awamori* *Azo. & Asp*	Cabbage Tomato Cabbage Tomato Cabbage Tomato	30 46 65 72 70 80
June, 2002	Response of NPK and irrigation on Pea, cabbage capsicum and tomato	Hill Campous Ranichauri	0.2 ha	Farmers (10)	Irrigation NPK Irri.x NPK	Pea, cabbage, capisicum and tomato	28-42 35-58 65-72
Rabi Nov., 2002	Effect of NPK on improved wheat varieties	Hill Campus Ranichauri	2.2 ha	Farmers (51)	Data under collection	Data under collection	Data under collection

Field days/ Farmers days organized

Month /Year	Nature of activity organized	Host Institution	Place where field days organized	Beneficiaries	
				No.	Catagory
June, 2002	Field days for Kharif crop	CSWCRTI, Dehradun	Garhkot watershed	25	Watershed Farmers
August, 2002	Field days for Agri-horticulture	-do-	-do-	65	-do-
Oct, 2002	Field days for Rabi crops	-do-	-do-	30	-do-
Feb, 2003	Field days for temperate fruits	-do-	-do-	35	-do-
Summer,2002	Field days for tea cultivation and seed treatment	CSKHPKV, Palampur	Regional Research Station Kukumseri	32	-do-

Socio-economic Impact
(Adoption of technologies/ products developed)

Year/ Month	Technologies/ products adopted	Place where developed	Beneficiaries	Area covered (ha)	Gains/ Yield
Kharif, 2002	Across the slope ploughing, planting, line sowing etc. for in-situ moisture conservation	ICAR Institutes / SAUs	About 25% Watershed farmers adopted the technology	About 25% of the watershed area under agriculture	In-situ moisture conservation increased 10-15% crop yield
Kharif, 2002 and Rabi, 2002	Introduction of location specific improved crop varieties	ICAR Institutes / SAUs/ State deptts. of Agri.	Watershed farmers at various centres	About 20	25-40% increase in crop yield 25-60% increase in crop yield
	Integrated nutrient management	-do-	-do-	About 2	
2002-03	Agri-horticulture	-do-	Watershed farmers	3.8	Diversification of land use achieved
2002-03	Maize+ Ginger intercropping	ICAR Institutes	Chalumthang Watershed	0.4	Ginger 145 q/ha Maize 40 q/ha
	Plant protection measures and seed treatment	ICAR Institutes, State Universities	Mc-Gad and Chalumthang watershed	2	Potato 35-40% increase Pea 18% increase
	Diversified land use by tea plantation	CSWCRTI, Ooty	Thambati Watershed farmers	0.10	Diversification of land use
	Construction of Polyhouse	-do-	-do-	500 m^2	15500 carnation root cuttings planted
	Terrace renovation	-do-	-do-	1.0	Outward slope reduced from 10% to 1.5% by tea plantation

Publicatioins:

Ghabru, SK & Pardeep Kumar. 2002. Landuse planning for sustainable highland farming in western Himalayas. Presented at International Symp. on Nutrition & Environment in 21st Century, SSARM, Germany in Bad Lauchstaedt and Halle upon Saale, June 57, 2002.

Published in Arch. Acker-Pfl. Boden., 2002, Vol. 48, pp 385-394.

Leaflets/ Bulletins/ Training Manuals : One

Irrigated Agro-Ecosystem

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The irrigated agro-ecosystem broadly occurs in two distinct regions viz. one is Indo-Gangetic plain comprising of the states of Punjab, Haryana, Uttar Pradesh, Bihar, west Bengal and plains of Jammu and Kashmir and other region includes coastal area of Andhra Pradesh and Tamil Nadu. This ecosystem is major producer of wheat, sugarcane, cotton, chick pea, maize and ground nut. The net work of canal is the source of water supply. Major constraints of the ecosystem are poor water management, waterlogging, saline -sodic soils, low fertility of soils which calls for sustainable land use plan. With these points the project is in operation at 11 representative sites covering an area of 4700 ha and spread between 74°19'E to 88°5' E longitudes and 10° 18' to 30° 26' N latitudes covering states of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Madhya Pradesh, Maharashtra, and Tamil Nadu (Fig. 2).The salient achievements are summarized below.

Soil Resources

- 28 soil series have been identified at different cooperating centres.
- Soils are shallow to very deep, sandy to clayey, slightly to severely eroded, moderately acidic to strongly alkaline (pH 5.3 to 9.7); organic carbon content varies from very low (0.12%) to high (1.43%); available N and P are high, available K is low to high, whereas available Zn is deficient.
- Major soil constraints identified in the ecosystem are coarse (light) texture, water logging, low organic carbon content, calcareousness, poor available nutrient status (P & Zn), salinity and alkalinity.
- Soils classified as Typic Haplustepts, Typic Haplusterts, Entic Haplusterts, Vertic Haplustepts, Typic Ustorthents, Lithic Ustorthents, Lithic Haplustepts, Typic Haplustepts, Udic Haplustepts, Typic Natraqualfs, and Typic Halaquepts.

Water Resources

- The pH and EC of the water samples collected form different sources were higher in the post monsoon period than in the pre-monsoon period. An increase in salt concentration during post monsoon period may be due to carrying of salts by the percolating water which increases salt concentration of ground water. The water table depth was higher in winter months.

Crop and Cropping System

Major crops grown are rice, wheat, sugarcane, maize, potato, mustard, cotton, chick pea, onion, pigeon pea, sorghum, fodder crops and cauliflower. Cropping patterns generally followed by the farmers are rice-wheat, rice-rice, sugarcane-wheat and cotton-wheat.

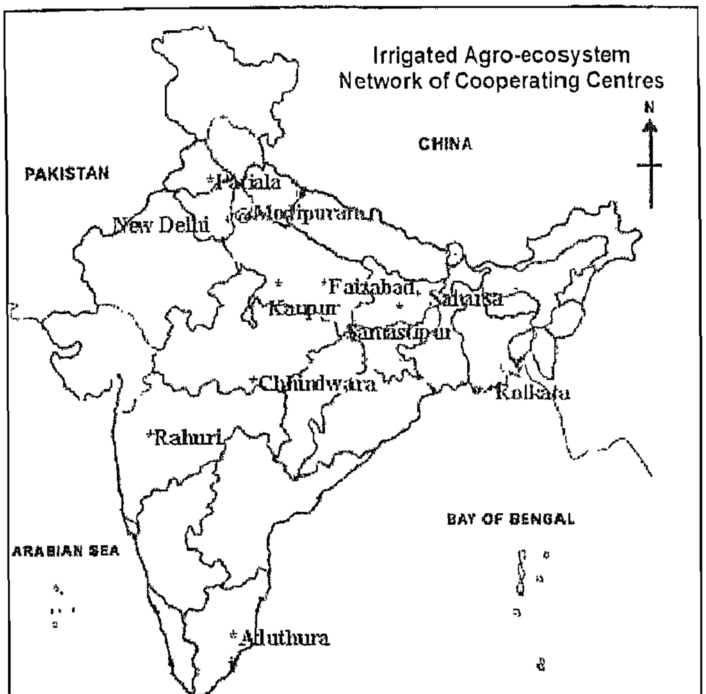

Fig. 2

Socio-economic Status

- 52 per cent of the total population is male and 48 per cent female
- Per cent literate: among males 58 and among females 48
- More than 50 per cent of the sample farmers were of marginal (< 1ha) and small category (1-2 ha)
- Major portion of the cultivated area is having irrigation (>40%) facilities either in the form of tube wells or canals or both.
- In adequate storage facilities
- Major socio-economic constraints are a) non-availability of labour for timely field operations; b) Inadequate availability of cold-storage facilities and high charges of storage; c) Severe problem of marketing of cane leading to its delayed harvesting; and d) Uncertainty in marketing of most of the farm produce

Development of Soil Site Suitability Criteria

- Soil site suitability criteria were finalized for the major crops including rice, wheat, bajra, sorghum, mustard, pigeon pea and gram.
- Soils, in general, are moderately suitable for wheat, bajra, sorghum, and mustard, and moderately to marginally suitable for rice, pigeon pea and gram (with limitations of excessive drainage and poor soil fertility).

Research Achievements

- Trend analysis for important agro-climate: Increase in maximum temperature at Saharsa (Bihar), whereas at Kanpur, increasing trend for rainfall was observed up to 1998 but a declining trend during later years.
- Except at Patiala, Modipuram and Rahuri, where 40-50% farmers fall under medium (2-4 ha) and large (>4 ha) categories, 70-80% farmers belong to marginal (<1 ha) and small (1-2ha) categories.
- Across the locations 80-90% households are dependent on agriculture for their livelihood.
- Predominant farming system of irrigated ecosystem is a mix of crops, animal husbandry, and horticultural crops.
- Out of the total net sown area, the percentage of irrigated area from different sources varies from 45% in Pusa to 100% in Patiala and Modipuram regions. The major source of irrigation is canal at Aduthurai (97%), Saharsa (80%) and Faizabad (68%). At other sites tube wells are the major source.
- No appreciable change has been observed in land use during last 10 years at any of the centres, indicating that under irrigated ecosystem the present land uses are stable.
- High variability among different centres exists with respect to climatic parameters. The mean minimum temperatures vary between 1.5 °C at Patiala and 19.8 °C at Aduthurai, whereas mean maximum temperatures range between 37.3 °C (Aduthurai) and 46 °C (Modipuram). The annual rainfall is 650 mm (New Delhi) to 1180 mm (Pusa).
- Similarly soil survey and land evaluation of operational sites has indicated a high variability among soil characteristics, depending upon climate, parent material and vegetation.

Field Experiments

Centre	Month/ Year	Subject of field demonstration	Host institution	Area Covered (ha)	Beneficiaries Covered	
					No.	Category
CSAUA&T Kanpur	Rabi	Alternate management practices in Wheat and Mustard	SAUA&T Kanpur	0.96	16	Marginal and small
NBSS&LUP, New Delhi	Nov.-Dec. 2002	Alternate management practices in Wheat	Regional Centre NBSS&LUP, New Delhi	2.0	08	Marginal and small
PAU, Ludhiana	Kharif & Rabi 2002-03	Crop diversification	PAU, Patiala	8.0	22	All categories
RAU, Pusa, Samstipur, Bihar	July, 2002 & Nov. 2002	Alternate Cropping Systems & Fertilizer use	Pusa Samstipur	2.0	16	Small

Field days/ Farmers days organized

Centre	Month / Year	Nature of activity organized	Host institution	Beneficiaries Covered	
				No.	Category
JNKVV, Chhindwara	Aug. 9, 2001 Nov.21, 2001 Nov.23, 2001 Feb.12, 2002 Sept.26, 2002	Improved package of practices and crops related problems	JNKVV, ZARS, Chhindwara	624	All category of farmers

Constraints and Suggested Interventions

- Low input of fertilizer should be countered by addition of organic manure and chemical fertilizers for the cultivation of maize
- Introduction and popularization of improved varieties was attempted to counter the low yield of crops, namely, fingermillet, maize, soybean, paddy and wheat obtained due to the cultivation of local varieties. The results were encouraging as these varieties increased the yield of crops by 20-40 per cent. The steeply outward sloping terraces need to be converted into inward sloping terraces so that tea could be planted in the riser slopes of the renovated terraces
- Application of phosphate at increasing levels upto 75 per cent of the recommended dose markedly increased the yield of pea and french bean by 26.8 and 45.2% respectively
- Application of P-solubilisers with SSP and MRP further accentuated the yield by 15.7 and 11.2% (pea) and 83 and 41.4 per cent (Capsicum) respectively.
- The lack of adoption of improved package of practices was a major production constraint in case of ginger which was overcome by conducting experiments with improved package of practices like seed treatment, delayed time of sowing versus traditional practices on ginger.

Coastal Agro-Ecosystem

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The coastal ecosystem is spread at a length of 8129 km with a total area of 10.8 million ha area. The ecosystem is highly fragile endowed with a variety contrasting conditions related to topographical and geomorphological features associated with salt affected, acid sulphate, marshy and waterlogged soils. The salt affected soils in the coastal areas are spread over 2.52 million ha comprising 30 per cent of total salt affected soils in India. Prudent land use policies are therefore essential to reverse the trends for better posterity in the region. This can be achieved with an interactive land use planning involving the best use of natural resources like land and water, by integrating use of advances in sciences, not only of agricultural and water sciences, but also of space research, information technology, GIS and emerging frontiers of new knowledge.

Integrated farming system comprises judicious combination of agricultural crops with animal husbandry, dairying, poultry, fishery and horticulture/alternate cropping systems which has immense scope in the coastal areas. The transfer of advance science and Technology input to coastal areas on the basis of their successful applications in the inland areas is not a straightforward job. Total involvement of people is essential for achieving success in all the production ventures leading to the improvement in their socio-economic status In order to develop perspective land use plans for agro-ecosystem, the Tamil Nadu Agricultural University is functioning as the Lead Centre in coordination with the network of ten Co-operating Centers in eight State Agricultural Universities and two ICAR institutes.

Agro-Ecological Sub Regions

Based on the NBSS&LUP (1995) approach the AESRs chosen for coastal ecosystem of Tamil Nadu, Pondicherry, Andhra Pradesh, Orissa and West Bengal states are AESR 18.1, 18.2, 18.3, 18.4 and 18.5. The AESRs selected for Gujarat state in the West Coast was 19.1 whereas for other states (Kerala, Karnataka and Goa) it was 19.3. The remaining AESRs do not have features/ climate specific to coastal ecosystem and hence they are not taken for the present project. The AESRs to be covered by the Co-operating Centers are given in Table 1.

Production Constraints

Agriculture and fishing are the major activities of the people living in the coastal regions of the country. Major constraints which influence the agricultural production include the climate (flooding and cyclone), excessive wetness (monsoon), excessive dryness (summer), water resources (fluctuation of water table, poor water quality), intrusion of sea water (monsoon), soils (salinity, alkalinity, acidity and reduction conditions), environment (untreated effluents, agro-chemicals) and poor socio-economic status of the farming community. The crop production constraints specific to each AESR are given in Table 2.

Table 1. Details of different co-operating Centres

AES R		Centre	Village/ watershed	Block/ Commend Area	District	Longitude	Latitute	Area (ha)
18.1		TNAU, Ramnathpuram	Therpogi	Vchipuli/ Ramnand	Ramnathpuram	$78^0$52'E	$9^0$12'N	200
18.2		GAU, Navsari	As project fund not released project has not been implemented					
18.3		UAS, Dharwad	Mirjan	Kumta	Uttara Kannada	$74^0$25'28"E	$14^0$29'34"N	619.8
18.4		KAU, Trivandrum	Kakkazham Thotapalli Elankunnapuzha	Ambalapuza Pusakkad Vypeer	Alapuzha Alapuzha Ernakulam	*	*	680 1309 975
18.4		ANGRAU, Anakapalli	Godivada & Pedavuppalam	S. Rayavaram	Vishakapatnam	*	*	567
18.5		OUAT, Bhubaneshwar	Talajanga	P.S.	Puri	$55^0$45'E	$19^0$51'N	1000
19.3		NBSS & LUP, Calcutta	Adhla halapara & Uttar Angadhbario	Canning I	24 Parganas (south)	$88^0$36'36" to 88^0 50.6'E	$22^0$17'1" to $22^0$19'1"N	416
19.3		ICAR, Regional Complex, Goa	Curea & Batin	Tiswadi	North Goa	$73^0$51' to $73^0$55'E	$15^0$20' to$15^0$30'N	937
19.3		ANGRAU, Bapatla	Madanaru	Kottapatnam	Prakasam	$78^0$45' to $81^0$30'E	$13^0$31' to $17^0$08'N	3972
19.1		PAJANCOA & RI, Karaikal	Thiruvettakudy	Kottucherry	Karaikal	$78^0$43' to $79^0$52'E	$10^0$49' to $11^0$01'N	612

*Information to be collected

Table 2. *Crops and their production constraints*

Name of the cooperating centre	AESR	Major landforms	Major occupation	Major crops	Production constraints	Crop production constraints
1. TNAU, Ramanathapuram	18.1	Coastal sand Coastal alluvium (Upland & Lowland)	Agriculture Aquaculture Goat rearing Salt making	Paddy Cholam (Jowar) Comba (Bajra) Ragi	Since slope is very less, water stagnation is the common problem during rainy season, early season drought & later water stagnation due to erratic monsoon.	High water table Poor quality water Poor soil physical conditions Aridity during summer
2. GAU, Navsari	19.1	Coastal alluvium	Agriculture Aquaculture Cattle rearing	Rice, Hill Millet, Sugarcane, Fruit Crops, Tuber Crops.	Sea ingress salinity, flooding during rains scarce and costly labour and highly saline ground water.	Soil salinity Poor quality ground water Poor soil physical conditions
3.UAS, Dharwad	19.3	Dissected hills Uplands Lowlands	Agriculture Aquaculture Goat rearing Salt making	Paddy Ragi Black gram Groundnut	In salt water irrigated area yields are drastically reduced. Erratic rainfall, flood and disease incidence results in losses coconut production, Areca nut not fetching fair price.	Soil salinity High water table Poor ground quality water Low soil fertility
4.KAU, Trivandrum	19.3	Coastal plain Lowlands Swamps	Agriculture Aquaculture Duckery	Rice Coconut Vegetables Banana,Fruitcrops -Pepper,Mango	*Region suffers from acute* drought	Waterlogging High water table Soil acidity Poor quality water Low soil fertility
5.ANGRAU, Anakapalle	18.4	Coastal sandy plain Back Swamps Coastal alluvium	Agriculture Cattle rearing Salt making	Paddy Pulses Bajra Ginger Fodder crops	Assured irrigation facilities are scarce in area	Waterlogging in lowlands Poor quality ground water Soil acidity Low soil fertility
6.OUAT, Bhubaneswar	18.4	Coastal alluvium Mudflats	Agriculture Cattle rearing	Paddy, Cononut, Cashew, Sunflower,	Flooding in rainy season, lack of irrigation facilities in dry season	Inundation of water during rainy season Soil salinity Poor quality ground water Low soil fertility

Con...

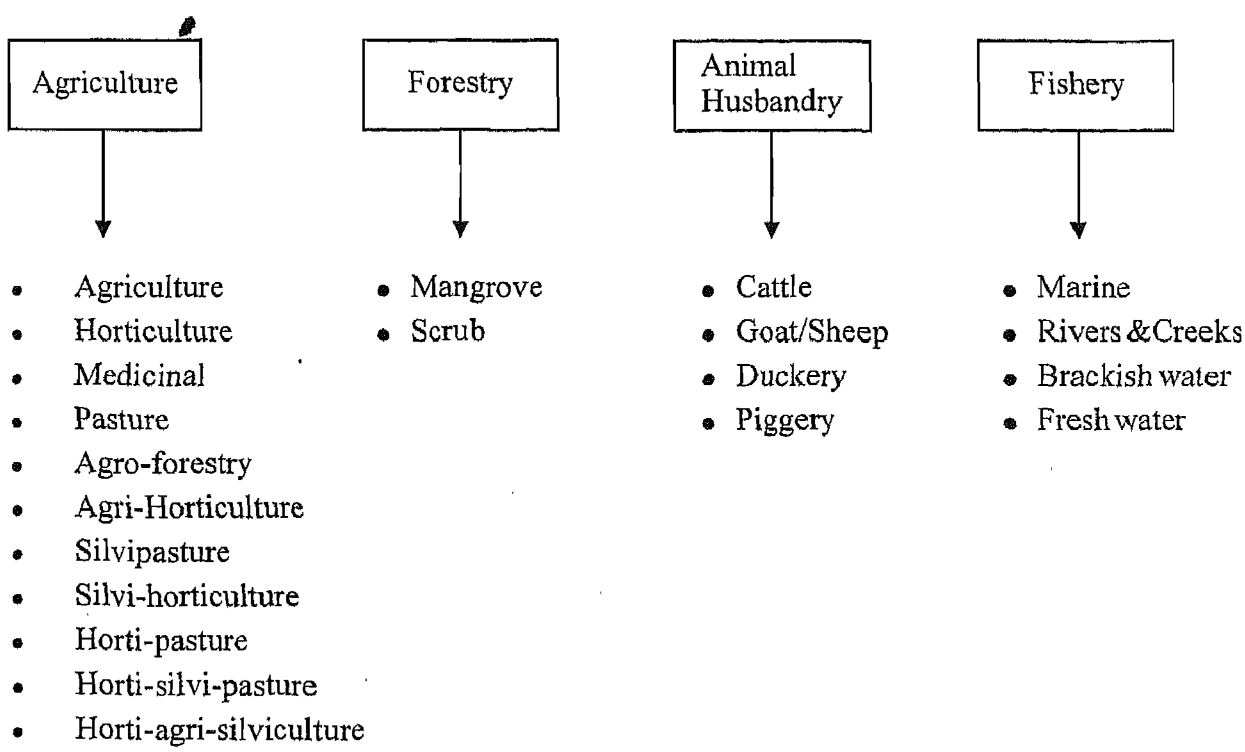
7. NBSS & LUP, Kolkata	18.5	Coastal alluvium	Agriculture Aquaculture	Rice Vegetable Chilli Betel leaves Water melon	Poor internal drainage due to high salinity, Lack of irrigation water, illiteracy, high rainfall in short duration, flooding, water logging	High water table Soil salinity poor soil fertility Poor water quality
8.ICAR Research Complex, Goa	19.3	Dissected hills Midlands Lowlands	Agriculture Salt making Fisheries Cattle rearing	Paddy Coconut Cashew	Lack of irrigation facility, Costly labour, Lack of milling facility, Stray cattle, Small land holdings.	High run-off losses in hills Waterlogging in lowlands Soil salinity Poor quality ground water
9.ANGRAU, Bapatla	18.3	Coastal sand Coastal alluvium (Lowland, Upland)	Agriculture Aquaculture Cattle rearing Goat rearing	Paddy Subabul Eucalyptus Casuarina	Low literacy, No guidance for organic farming and INM, People are shifting to aquaculture from agriculture, Land holdings of poor people are not under cultivation.	Poor soil physical conditions in sandy soil Soil salinity Poor quality water in coastal alluvium
10. PAJANCOA & RI, Karaikal	18.2	Coastal sand(Dunes, stabilized dunes) Coastal alluvium (Lowland, Upland)	Agriculture Goat rearing Cattle rearing Aquaculture	Rice Pulses Cotton Ginger	Water scarcity, drainage problem, low production potential	Poor soil physical conditions in sandy soil Soil salinity Poor quality water in coastal alluvium Poor soil fertility

Development of Perspective Land Use Plans

The focus on the improvement of coastal areas lies in the development of perspective land use plans, which should be compatible with land and water resources for sustainable productivity. The land use plan can combine crop production with sericulture, agriculture, dairy, poultry, aquaculture, forestry etc. The potential land use option for the coastal regions are given below.

The socially acceptable and economically viable land use options specific to AESR and their subdivisions can be developed. For instance, the long term study conducted at Canning (West Bengal) showed 30 per cent increase in yield by adopting package consisting of deepwater rainfed rice + fresh water fish (rainy season combined with brackish water fish in summer) and brinjal on the bund (throughout the season) over traditional system mono-cropping with rainfed rice. The package is socio-economically viable and sustainable, as tested in the Sundarbans area (Canning). Low rice fields, prone to saline water inundation from the adjoining rivers and lying barren during summer have high production potentiality under this package. The package can be extended to other areas under similar ecosystem.

The crop (19 agricultural, 25 horticultural), 8 tree species, 9 medicinal plants, 5 forage crops and 5 animal components) potentially suited to coastal agro- ecosystem were identified (Table3). The soil-site suitability criteria for these crops was developed based on literature information, results of field experiments and input from experts.



Potential land use options for coastal lands

Table 3. List of crops for which soil-site suitability criteria developed

Agricultural crops	Horticultural crops	Trees Plants	Forage crops and Animal component
Rice	Mango	Acacia	Black Kollukattai
Wheat	Banana	Casuarina	White Kollukattai
Sorghum	Guava	Neem	Guinea grass
Bajra	Pineapple	Palmyrah	Para grass
Ragi	Pomegranate	Teak	Rhodes grass
Red Gram	Ber	Terminalia	
Black Gram	Watermelon	Bamboo	
Green Gram	Coconut	Pungum	
Cowpea	Arecanut	Medicinal Plants	Animal Components
Soybean	Cashewnut	Aloe	Cows
Groundnut	Rubber	Basil	Buffaloes
Gingelly	Moringa	Datura	Poultry
Sunflower	Brinjal	Glory lilly	Fish
Mustard	Bhendi	Indian Ginseng	Duckery
Oil Palm	Cabbage	Periwinkle	
Cotton	Cassava	Eucalyptus	
Tobacco	Cauliflower	Senna	
Sugarbeet	Chilli	Vettiver	
Sugarcane	Cucurbits		
	Onion		
	Potato		
	Radish		
	Tomato		
	Tuberose		
	Jasmine		
	Pepper		

Salient Achievements At Different Centres

Land evaluation for the suitability of field, horticultural crops, medicinal plants and tree species was carried out. GIS technology has been effectively used in generation of thematic maps and land evaluation. The field experiments included introduction of new crops/ animal components, introduction of new varieties and improved land management techniques. The results of the studies are presented below.

Introduction of new crops/ animal components

- Introduction of marigold after kharif paddy in AESR 19.1(Gujarat) gave a net profit of Rs. 9000 ha^{-1} in a period of 4 months .
- The economical intercropping systems suitable for AESR 19.1 in Gujarat state include (i) Sapota + Paddy (ii) Sapota + Sugarcane (iii) Sapota + Onion and (iv) Mango +Brinjal
- Introduction of Bhendi as an intercrop in ridge gourd gave 25 to 28 quantal of ridge gourd and 5 to 8 quantals of bhindi per hectare with a gross income of about 23,000 ha^{-1} (AESR 18.3)
- Mixed cropping of turmeric and colocacia is found economical than growing them as monocrops. A net profit of Rs. 40,000 per hectare is expected by this combination in south coastal Andhra Pradesh (AESR 18.3)

- Cultivation of bitter guard in the bunds of paddy fields was found to give a weekly yield of 100 kg ha^{-1} vegetable in coastal areas of Kolkata (AESR 18.5)
- Introduction of sunflower in rice fallow acid saline soils (pH 4-5, EC 8.0-1.5 dSm^{-1}) in 24 Parganas district of West Bengal (AESR 18.5) was found to be a good crop introduction
- Goat rearing with high yielding Gangapyari in coconut plantation was found to be remunerative in North coastal Andhra Pradesh (AESR18.4)
- Among the crops introduced in coastal regions of AESR 18.1 (Tamil Nadu and Pondicherry) groundnut, cowpea and sesame gave the yields of 833 kg/ha, 425 kg/ha and 534 kg/ha respectively
- Bhindi and amaranthus were reported to give higher yields among vegetables grown in AESR 18.2 of Karaikal region

Introduction of new varieties of crops

- Introduction of new varieties of wheat (GN 496) in rabi season in coastal region of Gujarat (AESR 19.1) gave an increased yield of 900 kg ha^{-1} then local variety
- 'Dhandi' rice variety gave 15 per cent increase in grain yield in coastal regions (AESR 19.1) of Gujarat
- Fodder Jowar (var. SSG 898) gave monthly yield of green forage @ 75-100 t ha^{-1}in coastal South Andhra Pradesh (AESR 18.3)
- Salt tolerant paddy varieties CSR 10 and CSR 27 recorded 1.5 to 2 times grain yields compared to local varieties in Goa state (AESR 19.3)
- Improved varieties of rice (Lalat and Swarna), brinjal (Utkal Tarini) and chillies (Pant C-1) produced bumper yields compared to local varieties in AESR 18.4, Orissa

Land Management Techniques

- Mulching with black polythene (50 micron) after kharif paddy was to be useful in irrigating brinjal with saline water up to EC 8 dS m^{-1} without any yield reduction
- Cultivation of Paddy in muddy fields after paddy in region (AESR 18.5) was possible without any land preparation and only with two light irrigations
- Replacement of low value crops like horsegram with groundnut after kharif rice with residual soil moisture and application of fertilizers (NPK 20:40:40 kg ha^{-1}) gave bumper yield of 2450 kg ha^{-1}(AESR 18.4, Puri district, Orissa) and a net return of Rs.24,000 ha^{-1}
- Foliar nutrition with fertilizer nutrients (NPK) increased the yields of rice, green gram, black gram and groundnut by 1 t ha^{-1} and 1500kg ha^{-1} respectively in coastal areas of Ramanathapuram, Tamil Nadu (AESR 18.1)

Future Activities

Efforts are continued for assessing the suitability of a new enterprise in pilot site and in bench mark site of each AESR. Land use models specific to each AESR will be generated. Land qualities and socio-economic factors (socio indices) will be used as inputs in the land use models. The utility of models (MGLP, LUPAS and others) will be employed for generation of the land use models. Since the duration for the project is short, the validity of the models will be taken up by the concerned institutes after the compilation of the project. A seminar will be conducted at the end of the project to discuss on the outcome of the project and formulate land use policies specific to each AESR on the outcome of results of the project.

Arid Agro-Ecosystem

Balak Ram

Central Arid zone research Institute, Jodhpur

Introduction

Highly fragile and inhospitable hot arid agro-ecosystem is characterized by low, highly erratic and unpredictable rainfall; extremes of seasonal temperatures and frequent droughts. The region is dominated by vast sandy tract (with low to high sand dunes and inter-dunes) intercepted with almost barren low hills and rocky/gravelly pediments and saline depressions. Light textured sandy soils with poor fertility status; saline, deep and meagre ground water potential; absence of integrated and perennial drainage system; inaccessibility, lack of infrastructure development and poor socio-economic status of inhabitants are other constraints. Agricultural lands though constitute nearly 62 % of the total geographical area but its production potential is very low. Net sown area and double cropped area constitute 48.7 % and 11 % respectively. 26 % area is occupied by different category of wastelands. The increased biotic pressure and improper use of land and water resources over the years accelerated wind erosion/deposition, water erosion, salinity/alkalinity/sodicity and waterlogging hazards and new wastelands are created. The above scenario infer that there is still scope for alleviating the economy of farming community by way of enhanced and sustained production of food, fodder and other value addition crops through proper use and efficient management of natural resources coupled with proven technologies and management practices.

In order to fulfill the above requirements and very objectives of the NATP (Mission Mode) Project on Land Use Planning in arid agro-ecosystem, eight watersheds/cluster of village representing agro-ecological sub regions have been selected to address area specific issues and came out with sustainable land use plans through integrated approach with evaluation of biophysical resources and socio-economic attributes on detailed level justified with field experiments at choosen bench mark sites in each watershed. Among them Salodi, Shishoo and Changeri watersheds are in Rajasthan; Gangadara and Kukma in Gujarat; Ghari Bhagi in Punjab, Ludas in Haryana and Sirappur Theri in Tamil Nadu (Fig. 3) covering altogether an area of 3195.5 ha (Table 4) and managed by 54 scientific personnel (Table 6). Kukma and Sirappur Theri are farming part of coastal desert while rest ones are located in 'Thar Desert'. These are being coordinated by Lead Centre, CAZRI, Jodhpur.

Status of Natural Resources

In general, the mean annual rainfall covering all the study areas varies from 350 mm in Ghari Bhagi to 550 mm in Changeri. The mean minimum and maximum temperatures are 1.4° C (Shishoo) and 45.0° C. Detailed soil survey and mapping of all the watersheds have been completed on cadastral map scale and 44 soil units are identified and characterized. The soils of all these areas are coarse to medium texture and ranging from find sand in Salodi to sandy clay loam in Ghari Bhagi. Most of them are poor in organic carbon, low in phosphorus and medium in potassium, calcareous in nature and

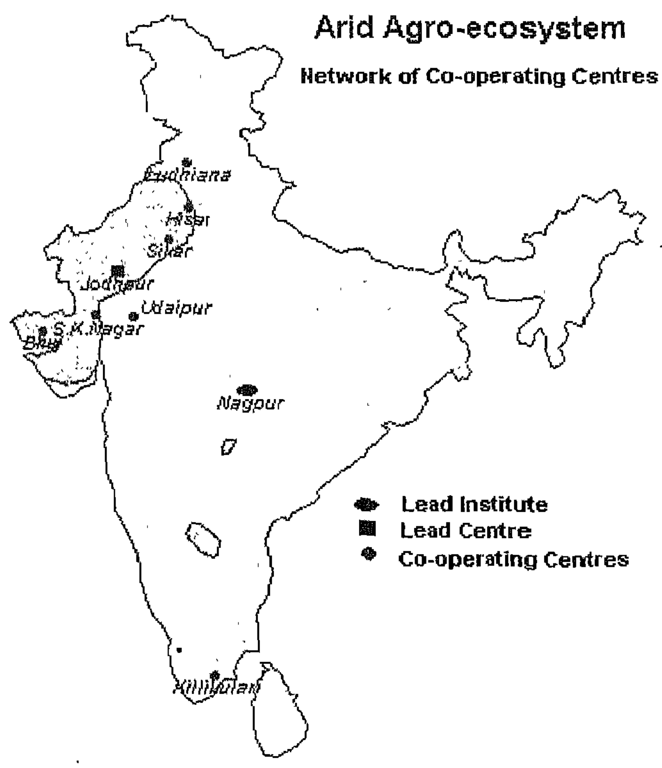


Fig. 3

slight to moderately saline. Depth to ground water varies from 8 m in Hisar to 100 m in Bhuj. The ground water yield is poor and quality is fresh to saline (EC 0.08 to7.73 dSm^{-1}). Lowering of water table is another constraint. Water erosion is predominant in Kukma, Shishoo, Changeri and Gangadara watersheds while wind erosion is prevalent in Sirappur Theri and Salodi watersheds. Except Ludas and Ghgari Bhagi where canal irrigation is available, other watershed areas are served with limited groundwater irrigation. Only Gangadara watershed has forest area. Salodi and Kukma have sizeable area under barren and uncultivable waste. Changei, Kukma and Gangadara watershed have 10% to 18% area under culturable waste. Only Sirapur Theri has area under plantation crops. Ghangeri watershed has highest fallow land (28%). Double cropped area varies from 0.03 in Sirappur Theri to 68.3% in Ghari Bhagi. The resource maps are digitized and vector data base has been created under GIS environment.

Socio-economic Status

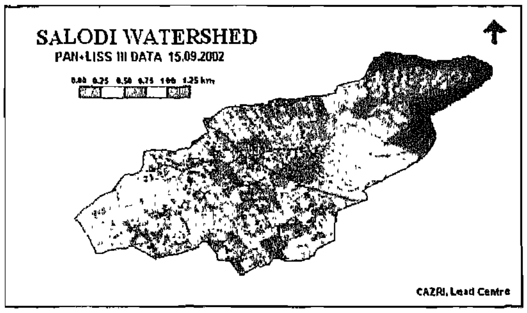
The total population of all the study areas is 9421 with 1503 households and a literacy of 58%. Livestock population is 9530. The cultivators, agricultural labourers and BPL families constitute 13.71%, 17.34% and 14.6% respectively. Semi medium (28.19%) and small (17.02%) category of farmers are dominant. Marginal, medium and large farmers are 15.05%, 13.4% and 3.42% respectively. Landless people constitute 21.48%. Participation of women is higher in household (73%), livestock (50%) and agricultural (48%) activities while their role in decision making is 62%, 50% and 31% only in the above activities. In cottage industries and horticultural activities their role in participation as well as in decision making is very poor. Only in Sirappur Theri women are involved in bidi and matches making. Poor economic status, lack of awareness, illiteracy among women, poor adoption level of improved farming technologies and lack of extension activities are other constraints for agricultural backwardness and deteoration of land and water resources.

Field Demonstration

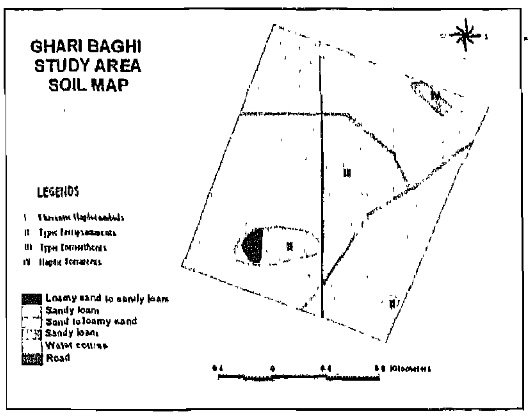
During two crop calendar years (2001-02 to 2002-03), 230 field experiments were conducted in major soil group in the watersheds covering 213.4 ha area with improved package of practices and complimented with training to nearly 1500 farmers on various aspects through 33 field days/ farmer's training programmes. The demonstrated crops were pearlmillet, mung bean, moth bean, cluster bean, cowpea, wheat, mustard, cotton, cumin, isabgol, sesame, groundnut, castor, moringa, ber, pomegranate and cenchrus ciliaris. There was severe drought in year 2002 which has adversely affected the acreage and production of crops. Details are given in Table 5.

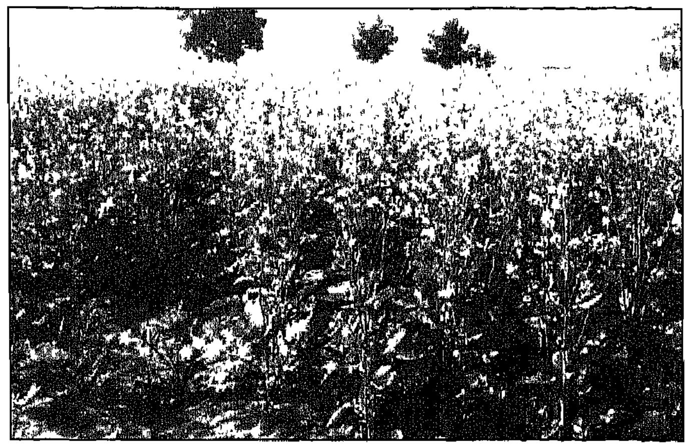
Table 4. General information about the watersheds

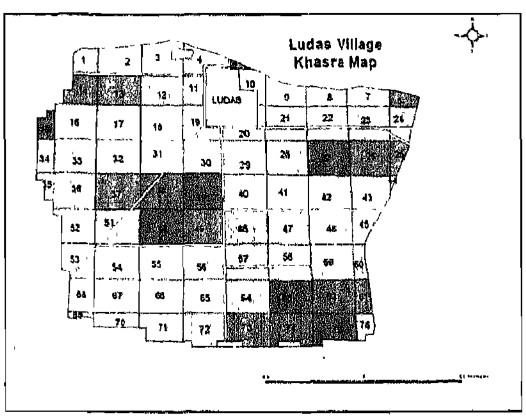
Sr. No.	Centre	AESR	Village/ Watershed	Catchment Area	District	Latitude \ Longitude	Area of the watershed (ha)
1	Lead Centre CAZRI, Jodhpur	2.3	Salodi	Luni River	Jodhpur (Rajasthan)	26^0 24'35" to 26^{0}26'03"N 72^0 49'28" to 72^0 52'15"E	567.0
2	PAU, Ludhiana	2.3	Ghari Baghi	Bhakhra Canal	Bathinda (Punjab)	30^0 06'28" to 30^0 09'32"N 74^0 54'38" to 74^0 59'19"E	282.5
3	CCSHAU, Hisar	2.3	Ludas	Western Yamuna Canal	Hisar (Haryana)	29^0 08'07" to 29^0 09'39" N 75^0 37'58" to 75^0 39'45" E	242.0
4	RAU, Sikar	2.3	Shishoo	Mendha River	Sikar (Rajasthan)	27^0 30'48" to 27^0 32'03" N 75^0 19'04" to 75^0 20'25" E	245.0
5	GAU, S.K. Nagar	2.3	Gangudara	Banas River	Banaskantha (Gujarat)	24^0 26'00" to 24^0 27'26" N 72^0 20'55" to 72^0 22'52" E	370.0
6	NBSS & LUP, Udaipur	4.2	Changeri	Banas River	Udaipur (Rajasthan)	24^0 46' 17" to 24^0 49' 04" N 74^0 07'17" to 74^0 08'57" E	257.0
7	RRS (CAZRI), Bhuj	2.4	Kukma	Pur Nadi	Bhuj, (Gujarat)	23^0 10'45" to 23^{0}13'42" N 69^0 47'00" to 69^0 48'18"E	956.0
8	TNAU, Killikulam	8.1	Sirappur Theri	Tamraparini River	Thoothukudi (Tamil Nadu)	08^0 24'12" to 08^0 24'57" N 77^0 54'21" to 77^0 55'15" E	250.0

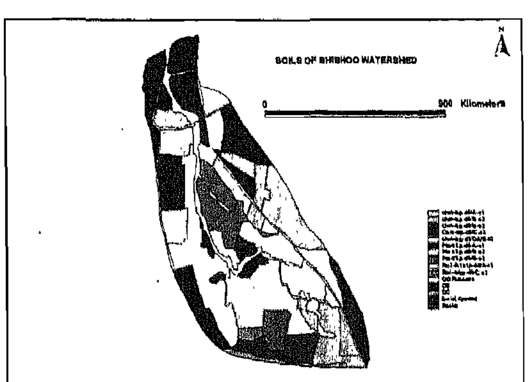

SALODI WATERSHED
PAN+LISS III DATA 15.09.2002
CAZRI, Lead Centre


Improved Practices


GHARI BAGHI STUDY AREA SOIL MAP
LEGENDS
Loamy sand to sandy loam
Sandy loam
Sand to loamy sand
Sandy loam
Water course
Road




Ludas Village Khasra Map
LUDAS

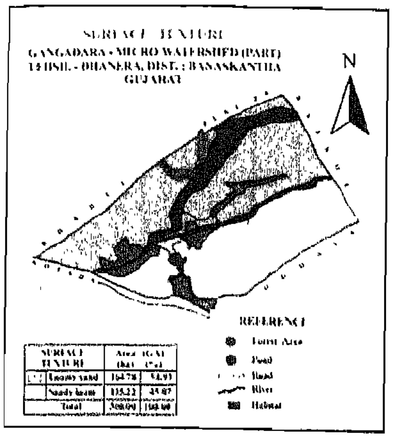

SOILS OF BHISHOO WATERSHED
Kilometers

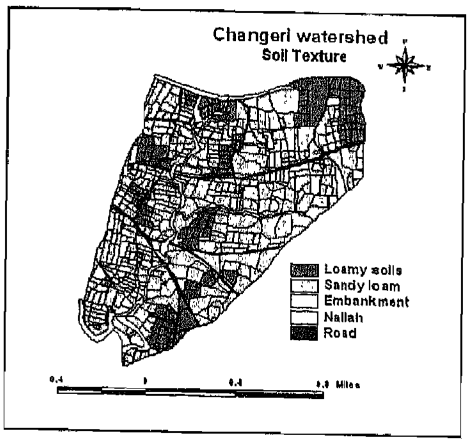
Research Achievements:

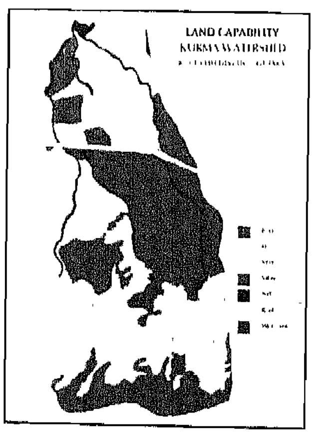
- Lead centre has organized one Planning Workshop and two Annual Review Workshops
- All the 7 co-operating centres as well as lead centre have identified watershed covering total area of 3169.5 ha. The detailed khasra/survey No. maps have been prepared and digitized.
- Detailed inventory and mapping of Soils and Land Capability for all the watersheds/study area has been completed.
- Socio-economic survey of 612 farm families covering entire study area has been completed and comprehensive data has been generated.
- Weather conditions over different watersheds have been worked out and their trend over the past ten years has been analyzed.
- Basic information on human and livestock population, occupational pattern, literacy, land holdings, land forms, drainage, slope and aspects, surface and ground water resources, vegetation and cropping pattern have been collected.
- Trend in land use, cropping pattern and crop production over the past ten years has been worked out.
- Study has been done on quality, depth and yield of ground water covering the bench mark sites of the study areas.
- Watershed wise different resource maps have been prepared, digitized and spatial database has been created under GIS environment.
- Soil Site Suitability Criteria has been developed for 5 cereals, 4 pulses, 7 oilseeds, 3 spices, 4 fruits, 3 cash crops and 2 fodder crops of the arid agro-ecosystem.
- PRA, group discussion, training programme on various aspects and field day were organized for cultivation of rabi, kharif and horticultural crops, insect pest management, rodent control, fodder treatment and animal husbandry.
- About 1485 farmers of different categories are benefited through various activities/ interventions.
- Data on Land Use, cropping pattern and crop productivity for the past 10 years have been collected and analyzed to asses the trend over the period.
- Economics of the major crops of the arid agro ecosystem has been worked out.
- Monitoring of health of soils and ground water quality has been done for the period 2001-2003.
- About 307 field experiments on kharif and rabi crops have been conducted in the farmer's fields using improved package of practices and significant higher yield have been obtained.
- 18 farmers day/field day/training programme have been organized on various aspects and thereby benefiting about 1500 farm families.
- Published 10 research papers, 7 popular articles, 8 abstracts and 2 leaflets.

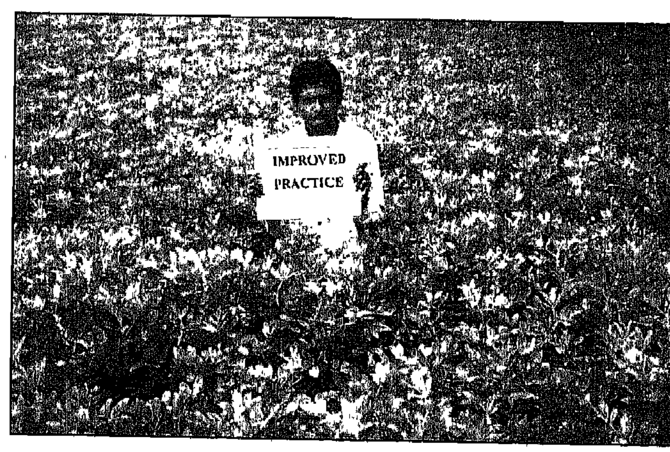
Table 5. Field Demonstration

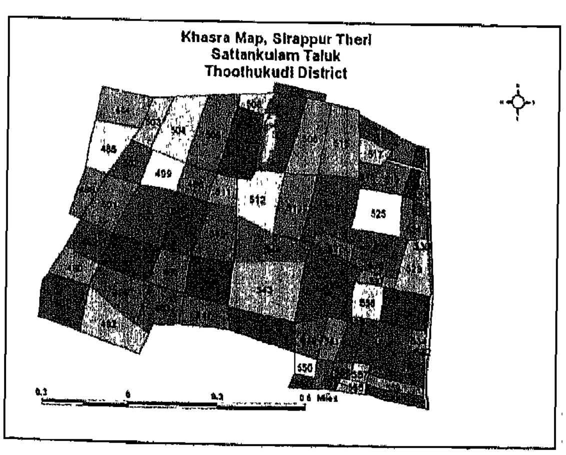
Watershed adopted	Hybrid variety	Interventions	Farmer beneficiary	Area covered (ha)	Gain in quality and quantity compared to before NATP (q/ha)	
					Before	After
Salodi, Jodhpur	**Wheat :** Raj - 3077, Raj - 3765 **Cumin :** RZ - 19, RZ - 209 **Mustard :** Bio -902, RH – 30 **Pearl millet:** HHB-67, MH-169, Raj-171 **Mungbean:** K-851 **Mothbean:** RMO-40 **Clusterbean:** RGC-936	Improved varieties, timely and proper method of sowing, proper seed rate, fertilizer and irrigation management, weed control and disease/insect pest management.	9	10.8	29.28 5.28 11.73 13.21 7.38 4.42 7.04	36.89 5.85 14.72 17.16 9.00 5.21 8.39
Jassi Pauwali, Bathinda	Wheat : WEL - 2329 Cotton : F - 1054	Fertilizer management	4	1.6	34.10 15.30	37.10 23.70
Ludas, Hisar	Mustard : RH - 309 Wheat : PBW - 343	Improved package of practices	2	0.80	9.25 32.40	10.40 35.80
Shishoo, Sikar	**Pearl millet :** HHB - 67, ICMH - 356 **Cluster bean :** RGC - 197, RGC – 936 **Moong bean :** RMG - 62 **Mustard :** Bio - 902 **Gram :** RSG - 44, GNG - 63 **Barley :** RD – 2052, RD - 2035 **Wheat :** Raj - 3077	Fertilizer management, Improved varieties, seed inoculation and thiourea spray	12	7.60	5.00 5.50 4.30 8.00 10.00 28.00 30.00	9.83 6.65 7.72 13.4 16.1 52.2 39.6
Gangadara S.K.Nagar	Pearl millet : MH – 169 Cluster bean : GC - 1 Castor : GCH - 4	Improved package of practices	9	3.6	15.50 5.60 8.42	19.27 6.99 10.25
Changeri, Udaipur	Groundnut : Chandra Maize :	Irrigation management	13	2.4 2.7	4.60 11.0	18.20 29.35
Kukma, Bhuj	Castor : GCH – 1, GCH – 4 Sesame: Weston - II	Nutrient management and improved varieties	8	3.2	36.24 11.10	72.15 14.20
Sirappur Theri, Thoothukudi	Groundnut : VRI - 2	Nutrient management and application of Bio-digested press mud	3	1.2	9.52	13.43


GANGADARA - MICRO WATERSHED (PART)
GUJARAT
N
REFERENCE
River


Changeri watershed
Soil Texture
Loamy soils
Sandy loam
Embankment
Nallah
Road


LAND CAPABILITY
KURMA WATERSHED


IMPROVED
PRACTICE


Khasra Map, Sirappur Theri
Sattankulam Taluk
Thoothukudi District
499
512
525
550

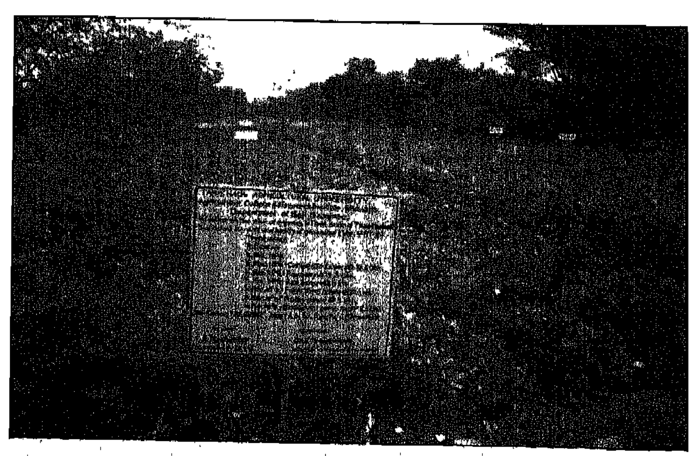


Table 6. List of PI, CCPI and collaborating scientists

Co-PI/CCPI	Participating Scientists	Designation
Dr. Balak Ram	Lead Centre CAZRI, Jodhpur	Principal Scientist (Geog.) & PI
	Dr. A.S. Rao Co-PI	Principal Scientist (Agrl. Met.)
	Mrs. Pramila Raina	Principal Scientist (Soil Fertility)
	Dr. M. Patidar	Sr. Scientist (Agronomy)
	Dr.(Mrs).Usha Rani Ahuja	Sr. Scientist (Agrl. Econ.)
	Ms. Ankita Rastogi	Research Associate (Remote Sensing)
	Sh. Gopal Singh	Senior Research Fellow (Agronomy)
Dr. B.D.Sharma	PAU, Ludhiana	Sr. Soil Scientist & CCPI
	Dr. S. S. Mukhopadhyay	Pedologist
	Dr. J.S. Brar	Soil Chemist
	Ritu Walia	Senior Research Fellow
Dr. M.S. Kuhad	CCSHAU, Hisar	Registrar-cum-Sr. Pedologist & CCPI
	Dr. V.P.Goyal	Sr. Pedologist
	Dr. D.S. Ruhal	Sr. Extension Specialist Soil Sc.
	Dr. Kuldip Singh	Sr. Soil Scientist
	Dr. M.S.Grewal	Sr. Soil Scientist
	Dr. A.S. Dhindwal	Sr. Soil Agronomist
	Dr. B.S. Panwar	Sr. Soil Scientist
	Dr O.P.Sangwan	Prof. (Soil Science)
	Sh. A.K.Jain	Soil Scientist
	Dr. Daya Ram	Assoc. Prof. (Geography)
	Dr. Satyawan	Asstt. Agronomist
Dr. G.L.Yadav	RAU, Sikar	ADR and Prof (Agronomy) & CCPI
	Sh. Mahendra Singh	Asstt. Prof. (Soils)
	Sh. S.D. Singh	Entomology
	Dr. A.L. Babel	Soils
	Dr. C. Ram	Entomology
	Sh. B.L. Sharma	Eco.
	Dr. Mahabir Singh	Plant Pathology
	Dr. H.P.Singh	Agronomy
	Dr. B.L.Jat	Agronomy
Dr. M. V. Patel	GAU, S.K.Nagar	Associate Professor & CCPI
	Dr. K. A. Thakkar	Dy. Director of Extension Education
	Dr. B. B. Patel	Associate Professor
	Dr. V. R. Patel	Associate Professor
	Prof. R. P. Pavaya	Assistant Professor
	Sh. N. J. Jadav	Assistant Professor
	Sh. D.M. Patel	Agricultural Officer
	Sh Ramesh Patel	Sr. Research Fellow
Dr. B.L.Jain	NBSS&LUP, Udaipur	Principal Scientist & CCPI
	Dr. Aditya K Singh	Sr. Scientist
	Dr. R.S.Singh	Sr. Scientist
Mrs. Pramila Raina	RRS (CAZRI) Bhuj	Principal Scientist (Soil Fertility) & CCPI
	Ramesh Chandra Tiwari	Sr. Research Fellow
Dr. V. Subramanian	TNAU, Killikulam	Professor, Dept. of Soil Science & Agricultural Chemistry
	S. Dinesh Kumar	Sr. Research Fellow

Salodi Watershed

Balak Ram

Central Arid Zone Research Institute, Jodhpur

Location: The watershed is located near village Salodi, District Jodhpur between 26° 24'35" to 26° 26'03"N and 72° 49'28" to 72° 52'15"E covering 567 ha area.

Climatic features: Average annual rainfall: 375 mm, number of rainy days: 23, rainfall received during cropping period: 374 mm; mean annual temperature: maximum 24.8 to 41° C and minimum 10.2 to 27.7°C.

Soils: The soils of the watershed have developed from both aeolian and fluvial sediments. Under the influence arid climate has played a major role for the development of soils. The soils of watershed are characterized by variable depth and texture. Out of the total area of watershed soils of Pal series constitute 25.32 %, Chirai series 14.27 %, Shergarh series 28.69 %, Alluvium 8.40 and shallow miscellaneous soils 14.64 % respectively.

Land use and cropping pattern: Out of the total geographical area of the watershed cultivated lands constitute 74.7 %, barren rocky/stony waste 10.02 %, water bodies (nallah and tank) 1.61%, uplands (gullied) 7.93 %, settlements 2.55 %, roads 3.06 %, *oran* 0.01 % and wells 0.12 % respectively. Irrigated double-cropped area constitutes 14.07 %, net sown area 57.1 %, current fallow 15.16 % and 2 years fallow 2.44 % as per three years average (1998-99 to 2000-2001). The intensity of cultivation decreases from west to east. Bajra, bajra + moth, moth, guar, castor and chillies are important kharif crops which respectively constitute 56.31, 8.2, 7.47, 2.02, 1.51 and 3.05 % of the total cropped area. Sweet potato is also taken. Wheat, mustard, cumin and onion are rabi crops which constitute 10.76, 4.14, 2.08 and 0.51 % of the total cropped area respectively.

Ground water: Depth of water in dug well ranges between 40-60 m while that of tube well water ranges from 80-120 m. The EC of ground water ranges from 0.65 dSm^{-1} in Shergarh series to 1.85 dS m^{-1} in Pal series. The pH ranges from 7.92 to 8.44 and sodium adsorption ratio (SAR) of ground water ranges from 5.75 in Pal series to 16.50 in Chirai series.

Socio-economic Status: Rainfed monocropping with bajra, guar, moth and moong crops is the dominant cropping system. However in limited area irrigated cropping with wheat, mustard and cumin crops is practiced. According to size of holdings the farmers can be classified as: marginal 8.13%, small 16.26%, semi-medium 50.68%, medium 21.68%, large 3.25%. The watershed has total population of 2383, out of which 52.7 are male and 47.3% female. The Literacy among male is 40 % while only 4.79% female are literate. Main workers are 38.4% while non-workers constitute 60.8% of total population.

Watershed specific constraints:

- High erratic and low rainfall
- Frequent droughts

- Wind and water erosion
- Deep and meagre ground water potential
- Traditional agricultural system
- Lack of technological innovation and penetration of extension activities

Significant Achievements

- A project planning workshop and two Annual Review Workshops were organized for proper implementation and achieving targeted progress.
- Salodi watershed with 567 ha area in Jodhpur district has been selected as study area. Khasra wise watershed map has been prepared and digitized.
- Basic information on climate, landforms, soils, demography, hydrogeology, vegetation, land use and cropping pattern have been collected. Older alluvial plain and sandy undulating older alluvial plain are dominant landforms.
- Weekly weather data for the past ten years have been collected and analyzed. Compared to 360 mm average annual rainfall, the region received 422.6 mm rainfall in 2001-02. In 2002-03 the monsoon failed and only 50.6 mm rainfall was received bringing severe drought. The year 2003 became favorable and the region received 418.1 mm rainfall till date.
- Detailed soil survey and mapping has been completed. Three major soil series viz. Pal, Chirai and Shergarh have been identified. Soil texture varies from fine sand to sandy loam. 39.59 % area qualifies for land capability class III, 37.09 % for class IV and 14.64 % in class VI.
- Study on ground water quality, depth and yield was undertaken. Most of the wells are medium in salinity and sodium hazard. EC value ranges from 0.65-1.85 dSm^{-1}.
- Socio-economic survey of 89 farm families has been completed. Average family size comes to 6.86, literacy 31.4 % and average size of land holding 4.56 ha. Semi-medium and medium farmers are dominant. Women participation in livestock and crop cultivation found more than 80%. But their role in decision making is 20-30 %.
- Field wise data on land use and cropping pattern have been collected for the period 1998-99 to 2001-02 and separate maps have been prepared for each year.
- Trends in land use as well as area production and yield of principal crops of Jodhpur district have been analyzed using data from 1990-91 to 2000-01. The area under culturable waste has declined by 38 % while irrigated area has increased by 114.5 %. The acreage of cumin, wheat and mustard has increased.
- Soil site suitability criteria have been developed for 5 rainfed, 3 irrigated, 2 horticultural crops, 4 trees and 2 grasses.
- Total 8 group discussions, 6 training programme on crop cultivation, 7 method demonstrations and one field day were organized. These activities benefited 900 farmers. The average knowledge and adoption level of farmers has increased by 65.0% in wheat, 60.25% in cumin and 52.0% in mustard cultivation.
- 47 field demonstrations on rabi, kharif and horticultural crops (ber and pomegranate) and perennial grass (*Cenchrus ciliaris*) have been undertaken. The yield of wheat, cumin, mustard and pearl millet has increased by 18%, 13%, 23% and 10.46% respectively. Net returns from improved practices were higher by 10.3% in cumin, 87.8% in wheat and 222.8% in mustard.
- Digital analysis of IRS LISS III merged PAN data of kharif and rabi season (2000-2002) of Salodi watershed has been carried out. Using GIS, different thematic maps have been generated showing the trend in land use as well as problematic and potential areas.

The khasra /survey maps as well as soil maps of all the cooperating centers have been digitized and special data base has been created under GIS environment.

Achievements of Field experiments

Season	Crop/ No. of Field Experiments	Varieties	Interventions	Average Yield (kg/ha)
Rabi 2001-02	Wheat (14) Cumin (16) Mustard (12)	Raj -3077 , Raj – 3765 RZ - 19 , RZ - 209 Bio -902 , RH – 30	Improved package of practices Improved Varieties Method of sowing Date of sowing Insect pest management	3685 560 1255
Kharif, 2002	Pearl millet (3) Ber Pomegranate *Cenchrus ciliaris*	HHB-67		1315 - -
Rabi, 2002-03	Wheat (5) Cumin (5)	Raj -3077 , Raj – 3765 RZ - 19 , RZ - 209		3459 592
Kharif, 2003	Pearl millet (7) Mungbean (4) Mothbean (4) Clusterbean (2) Castor (2)	HHB-67, MH-169, Raj-171 K-851 RMO-40 RGC-936 GCH-4		1576 827 432 956 2101

Farmers day / farmers training organized

Period	Subject of the training	Category and No. of Participants Trained			Impact/ feedback of trainings
		Cate.	No.	Beneficiary	
27 Nov, 2001	Training Programme on rabi crop cultivation	Marginal /Small /Semi-medium /Medium /Large	65	Farmers	A Large number of farmers agreed for demonstration of improved practices of crop cultivation and also agreed for participatory research for better Land Use Planning. The knowledge and adoption of different practices of crop cultivation by the farmers was increased. They adopted improved varieties of crops (e.g. Wheat, cumin, mustard, pearl millet, moong, moth, guar and castor etc), time and method of sowing i.e. Line sowing, recommended dose of fertilizer, seed treatment with fungicide, Irrigation at critical stages of crop growth and use of insecticide as the results, Crop yields were increased. Four farmers adopted agri-horticulture and agro-pastoral system for better utilization and resources.
27 Nov, 2001	Five demonstration cum group discussion were organized on method of seed treatment, sowing method of mustard crop, control of nematodes, use of weedicides and insect/pest control		76	Farmers	
30 Nov, 2001	Distribution of printed material Leaflets (In Hindi)on cultivation of Mustard and Cumin		100	Farmers	
30 Nov, 2001	Farmers were interviewed randomly for collecting information regarding behavioral aspects on adoption of Agricultural Technology in context with Land Use Planning.		50	Farmers	
27 Aug, 2002	One group discussion cum training was conducted on farmer's field, regarding plantation of horticultural plants and method demonstration for making layout of orchard, digging the pits and plantation.		20	Farmers	
19 Nov, 2002	Training on Rodent management for minimize the damage by rodents in field crops		44	Farmers	
14 Dec, 2002	Method demonstration on enrichment of poor quality of fodder through urea treatment		60	Farmers	
18 Feb, 2003	Distribution of printed material Leaflets (In Hindi) on cultivation of wheat and Cumin		200	Farmers	
18 Feb, 2003	Face to face discussion of farmers and scientists were made on control of disease in cumin.		55	Farmers	
19 May, 2003	Training programme on Gum extraction from *Acasia Senegal* trees		19	Farmers	

Ghari Baghi Watershed

B.D. Sharma

Punjab Agricultural University, Ludhiana

Location: The watershed is located near village Ghari Baghi, in Bhantinda district between 30° 06'28" to 30° 09'32"N and 74° 54'38" to 74° 59'19"E covering 282.5 ha area.

Climatic features: Average annual rainfall: 350 mm; Temperature: mean annual 32.10 °C mean summer 38.6 °C and mean winter 25.50 °C.

Soils: Major soils identified and area occupied as percent of watershed area are: Fluventic Haplocambids (0.33%), Typic Torripsamments (1.55%), Typic Torriorthents (94.4%), Haplic Torriorents (0.37%) and unclassified (3.35%). In general the soils are very deep, slight to moderately alkaline (EC 0.09 to 0.34 dSm^{-1}), sand to sandy clay loam in texture deficient in organic matter and low in phosphorus and cationic micronutrients.

Land use and cropping pattern: Major area is under agriculture (95.4%) followed by Industry (Brick kiln), 2.37%, Infrastructure (Road network/Canal network), 0.51/0.22 %, Plantation (Road sides), 0.08% and Settlement 1.31%.

Socio-economic status

	Demographic features	SC	ST	OBC	Others	Total
1.	No. of household	5	0	0	21	26
2.	Total human population (No.)	33	0	0	110	143
	a. Male >14 years	16	0	0	56	72
	b. Female > 14 years	14	0	0	45	59
	c. Children < 14 years	3	0	0	9	12
3.	Literacy rate (%)	54	0	0	56	55.5
	a. Male	36	0	0	35	35.2
	b. Female	12	0	0	16	15
	c. Children	9	0	0	4.5	5.5
4.	Number of cultivators	5	0	0	27	32
5.	No. of families BPL				1	1

Infrastructure facilities

1. Communication (Post office/ Telephone)	Yes
2. Road (kaccha/ pucca)	Mostly pucca, Some connecting roads are kaccha.
3. Transport mode	Train, Bus, Car, Tractor, Auto rickshaw
4. Market Type (ex. Local Shandy/ Cooperative etc.,). and produce sold (ex. Grain, vegetable etc.,)	Govt. approved middlemen buy the produce viz. grains, vegetables, fish, milk, meat, fodder, cotton balls etc. and surface soils for brick kiln purposes.
5. Agro processing units available	Yes, Manual (11)
6. Bank or credit societies available	21
7. Godowns/ warehouse available	Yes, one for agro-produce and one for bricks.

Watershed specific constraints

- Absence of package of practices for terraced dune cultivation
- Land degradation due to creation of steep slopes on dune peripheries
- Negative competition between rice and cotton for coverage
- Soil degradation due to fish farming on the sand dunes, brick kiln activity, land leveling

Significant achievements

- 245 ha area near Ghari Bhagi village, Bathinda district, Punjab has been chosen as study area and detailed map has been prepared (Scale 1:2640) and digitized.
- Detailed soil survey and mapping has been done. Ten soil profiles are studied. Coarse textured sand to sandy loam is dominant category. Leveling of sand dunes is a serious ecological threat.
- Detailed study of surface and sub-surface distribution of micro-nutrients has been done and maps prepared.
- Analysis of 12 water samples from the tube wells in the study area was carried out. 12 % water samples have marginal RSC (2.5 to 5.0) $meqL^{-1}$.
- Study on trend on land use changes reveals shift from crop husbandry to fish farming and from cotton to rice. 10 % area of the region is under non-agricultural uses like brick kilns, sand dunes and rest 90 % under irrigated farming.
- Socio-economic survey of 63 households has been done, data analyzed and findings are documented.
- Soil site suitability criteria have been developed for wheat, mustard, cotton, rice, gram and citrus crops.
- 14 field demonstration are conducted on cotton, cluster been, wheat and mustard crops. The yield of wheat and cotton has increased by 42 % and 32 % respectively (Table -1).
- Information has also been compiled on biodiversity

Achievements of field experiments

Type of Soil	Crops/Experiments conducted in 2002			
	Kharif		Rabi	
	Crop	Yield (q/ha)	Crop	Yield (q/ha)
Sandy	American Cotton (LH-1556)	16.54[a] 15.24[b]	Wheat (PBW-343)	42.10[a] 40.97[b]
Sandy-loam	Desi cotton(LD-327)	12.20[a] 10.42[b]	Wheat (PBW-343)	46.75[a] 43.11[b]
Sandy	Desi cotton(RG-8)	9.1[a] 7.5[b]	Wheat (PBW-343)	38.17[a] 36.24[b]
Sandy loam	American cotton (F 846)	15.75[a] 12.40[b]	Wheat (PBW-343)	48.24[a] 45.28[b]
Sandy loam	Castor	11.35[b]		

[a]Recommended dose [b]Farmers practice

Ludas Watershed

M. S. Kuhad

C C S Haryana Agricultural University, Hisar

Location: The watershed is located near village Ludas, District Hisar between 29° 08'07" to 29° 09'39" N 75° 37'58" to 75° 39'45" E covering 242 ha area.

Climatic features: Average annual rainfall: 448 mm, number of rainy days : 28, mean annual temperature: mean maximum 31.6 °C and mean minimum 15.8°C

Soils

Physiography	Soil Taxonomy	Area (%)	Land Capability
Nearly level plain	Coarse loamy, calc., Typic Ustorthents	27.6	IIe
Partially level ed sandy plain	Typic Ustipsamments	40.6	IIIe
Plains	Coarse loamy, Typic Haplustepts	31.8	II

Vegetation: Major plants encountered are Kikar, Neem, Peepal, Shisham, Jandi (Khejri) and Jhar-beri.

Crop and their area: Major irrigated crops and their area are cotton (355 ha), wheat (307ha), /w mustard (35 ha), chari (28 ha), barley, berseem and jai (22 ha). The rainfed crops grown are bajra (70 ha), guar (24 ha) gram and moong (15 ha).

Source of Irrigation: Canal is the major source of irrigation (405 ha), followed by tube well (101 ha) and sewage water (77 ha).

Socio-economic status: Classification of farmers according to the size of holding given below indicates that majority of them are small and semi-medium.

Farm size particulars (Based on gross cropped area)

Holding (ha)	Number of cultivators	%
Marginal (< 1 ha)	50	9.09
Small (1-2 ha)	100	18.18
Semi-medium (2-4 ha)	110	20.00
Medium (4-10 ha)	50	9.09
Large (>10 ha)	10	1.82
Land less	230	41.82
Total	550	100.00

Demographic features

S.No.	Particulars	SC	ST	OBC	Others	Total
1.	No. of household	197	---	250	103	550
2.	Total human population (No.)	1805	---	1986	737	4528
	a) Male≥14 years	380	---	415	168	963
	b) Female≥14 years	340	---	387	134	861
	c) Children <14 years	1085	---	1184	435	2704
3.	Literacy rate	52%	---	62%	67%	59%

Other important socio- economic data : Number of households: 550, total population: 4528, literacy rate 59%, Cultivators 7% agricultural Laborers: 34%, net irrigated area: 93% (canal, tube well, sewage), double cropped area 44%, livestock population 878 , role of women in agriculture and animal husbandry 55% and role of women in decision making 12%.

Watershed specific constraints

- Lack of agro-processing machines
- Scarcity of irrigation and credit facilities
- Lack of godowns/warehouses
- Hesitation to adopt non-vegetarian farming like fishery and pigary

Significant achievements

- Selected 242 ha area of Ludas village, Hisar district as study area. Detailed murabba wise map has been prepared and digitized.
- Collected basic information on demography, infrastructure facilities, farm size, land use, cropping pattern and common property resources.
- Carried out socio-economic survey of 60 households representing all the categories.
- Weekly weather data on temperature, rainfall, for the period 1970-1993 as well as weekly data from 1998 to 2002 on temperature, rainfall, vapor pressure, relative humidity, wind speed, sunshine and evapo-transpiration collected and analyzed.
- Detailed soil survey and mapping has been Completed, *Typic Ustipsamments, Typic Ustorthents* and *Typic Haplustepts* are important soils.
- Water quality parameters of the bench mark sites and from tube wells, canal and sewerage have been studied and found worth irrigation.
- Trend analysis of cropping pattern and crop productivity has been complete for 1991-92 to 2002-03.
- Soil Site Suitability criteria developed for wheat, pigeon pea, cotton, paddy and barseem.
- Present land use and the status of land use for last 5 and 10 years has been worked out.
- Conducted seven field demonstration of cotton, mustard, wheat, cluster been and pearlmillet crops in different soil types and obtained significant higher yields over the control.
- Organized a Kisan Mela. The exposure to improved technologies benefited 150 farmers

Achievements of field experiments

No. of Field Experiments	No. of Crop Experiments	Variety	Interventions/ treatments	Yield (kg ha^{-1})	
				Control	improved practices
Rabi (2) 2002-03	Mustard (4)	RH-30	Improved package of practices	925	1040
	Wheat (5)	PBW-343		3240	3580
Kharif 2002	Cotton	Raja Sikandar		1372	1665

Shishoo Watershed

G.L. Yadav

Rajasthan Agricultural University, Agricultural Research Station, Fatehpur, Dist. Sikar

Location: The watershed is located near village Shisoo, District Sikar between 27° 30'48" to 27° 32'03" N and 75° 19'04" to 75° 20'25" E covering 245 ha area.

Climate : Average annual rainfall 450 mm, number of rainy days <20, Mean annual temperature: a/t maximum 44.5 °C and minimum 1.4 °C

Soils: Classification of soils according to texture and their extent is as: Loam 36.24 %, Sandy loam 26.78%, Loamy sand 06.83%, Sandy19.57%. Pasture land occupy 05.85% and waste land 04.95% of watershed area.

Vegetation: Natural vegetation consists of trees viz. *Prosopis cineraria*, *Acacia nilotica*, *Azadirachata indica*, *Salvadora persica* and *Ficus religiosa;* shrubs: *Ziziphus spp.*, *Cappris decidua*, *Calotropis procera* and *Leptadenia pyrotechnica* and grasses: *Cynodon dactylon*, *Saccharum spontenium* and *Cenchrus spp.*.

Cropping pattern: Major crops grown in the area are pearl millet, cluster bean, cowpea, moong in kharif season and wheat, barley, gram and mustard in rabi season. Crop + animal mixed farming system is common. Bajra gram, Bajra-Mustard, / lower guar- wheat, bajra fallow, guar-fallow, moong-fallow, Cowpea-fallow are important crop rotations being followed.

Ground water: The ground water is slightly brackish as indicated by the pH value ranges from 7.0 to 8.10, EC from 0.77 1.10 dSm^{-1} and RSC from 0.6 1.6 meq L^{-1}.

Socio-economic information: Total Population: 5814, Scheduled Caste 53, Scheduled Tribe 174, Literate 1886, Total workers 1492, Livestock population 5667. According to size of holding there are majority marginal, 57.38% followed by small 32.79%, semi-medium 8.20% and medium 1.20% farmers.

Watershed specific constraints

- Low and erratic rainfall.
- Extremes of temperatures in summer and winter.
- Poor soil fertility and water erosion.
- Undulating topography and gully formations.
- Poor yield of crops and poor socio-economic status.

Significant Achievements

- Selected Shishoo watershed (520 ha) in Sikar district and prepared as well as digitized detailed khasra map.
- Basic information collected on land use, cropping, demography and infrastructure facilities
- Weekly weather data for the past 10 years (1991-2000) on temperature, rainfall, humidity, sunshine and wind velocity are collected and analyzed.
- Detailed soil survey and mapping has been done. Three major soil series viz. Chomu, Palsana and Ranoli identified. About 58% area qualifies under land capability class III,

17% in class IV and 15.29 % (gullied area) class VI.

- Socio economic survey of 61 households has been completed and valuable data on various aspects are generated.
- Water samples of chosen benchmark sites have been analyzed for quality, depth to water and yield.
- Soil site suitability criteria has been developed for pearl millet, wheat, barley, mustard, sesame, groundnut, cowpea, cluster been, moth been, green gram, chickpea and fenugreek.
- 39 field demonstrations on rabi and kharif crops conducted and significant higher yield obtained over the control.
- There is good impact of various activities and farmers started adopting the improved technologies in their fields.

Achievements of field experiments

No. of Field Experiments	No. of Crop Experiments	Variety	Interventions/ treatments	Yield (kg/ha)	
				2001-02	2002-03
Rabi (26) 2001-02& 2002-03	Wheat (6)	Raj-3077 Raj-3765 Raj-1482	Improved Varieties Nutrient management	3920 3960 4810	3820 3860 5090
	Barley (6)	RD-2052 RD-2035	Thiourea application Seed inoculation Sulphur application	4890 1440	5220 1560
	Gram (6)	RSG-44 GNG-663	Rhizobium culture + 40 kg N + 40 kg p_2o_5 Fertilize application	1410 1470	1570 1610
	Mustard (6)	Bio-902 RH-30 Pusa bold		1180 1220 1430	1310 1340 1420
Kharif, (23) 2002	Pearlmillet (12)	HHB-67		962	1054
	Mungbean (4)	K-851 RMG-62		- -	669 749
	Clusterbean (3)	RGC-197 RGC-936		603 665	694 728

Gangadara Watershed

M.V. Patel

Gujarat Agricultural University, S.K. Nagar

Location: The watershed is located near village Gangudara, District Banaskantha between 24^0 26'00" to 24^0 27'26" N and 72^0 20'55" to 72^0 22'52" E covering 370 ha area.

Climatic features: Average annual rainfall: 550 mm, Mean temperature: Maximum 40.02^0 C and minimum 9.63^0 C.

Soils: The soils developed from alluvial deposition are very deep and sandy to loamy sand. Typic Ustorchrepts (Very deep, calcareous sandy loam soils) occur in 45 % area where as Typic Ustorthents (Loamy sand, very deep gently sloping with moderate erosion) occupy remaining 55 % area. The soils are characterized by high infiltration and permeability and low moisture holding capacity. Soils are low in organic matter and N, medium to high in available P_2O_5 and K_2O.

Vegetation: The natural vegetation consists of Neem (*Azadirachta indica*), Piludi (*Salvadora spp.*) Deshi baval (*Acacia arabica*), Khijdo (*Prosopis cineraria*), grasses like Dhaman (*Cenchrus cilliaris*), Chidho (*Cyperus rotundus*) and Dharo (*Cynodon dectylon*) species. Ber and Ker (*Capparis aphyla*) are the common shrubs.

Cropping pattern: Generally farmers adopt mono cropping system but in some area mix cropping is also followed. In kharif season under rainfed condition pearlmillet, mothbeen, cluster bean, green gram, jowar and castor are grown. During rabi mustard, amaranthus, wheat, cumin, isabgol are common crops. During summer pearl millet is also grown.

Ground water: The ground water is moderately sodic with pH ranges from 7.6 8.5, EC from 0.95 to 2.65 dSm^{-1}, RSC nil to7.10 me/l and SAR 2.71 to 9.03.

Socio-economic status: Average size of land holding is about 2 ha. The holdings are fragmented and scattered all around the village. Density of population is 190 per sq. km. Literacy level in male and female is 54.8 and 22.5 per cent respectively. The sex ratio is 932. Working force is 31.77 % of total population and cultivators and agricultural labors are respectively 51.9 and 22.5 percentage of total working force.

Watershed specific constraints

- Inadequate ground water facility
- Indiscriminate use of land
- Inhospitable climatic conditions
- Erratic and irregular rainfall pattern
- Severe wind and water erosion
- Small land holdings
- Lack of irrigation facilities
- Considerable lack of scientific know-how of agro-forestry, horticulture and vegetable cultivation

Significant achievements

- Gangudara watershed (370 ha), on right bank of Banas river, in Banaskantha district has been selected as study area. Detailed khasra map has been prepared and digitized.

- Data are obtained on land use, cropping pattern and crop production. Trend analysis of land use, cropping pattern and yield has also been completed.
- Weekly weather data on various aspects for the period (1982-2001) has been collected and analyzed.
- Detailed soil survey and mapping has been completed on 1:4000 scale. Three major soil series has been identified which are mainly *Entisols* and *Inceptisols*. About 87.47% soils qualify for land capability class IIe and 12.53% for class Ie.
- Socio-economic survey of 74 households has been completed and very good information has been generated on farm assets, animal resources, crops and crop production, income, holding size, population and occupational pattern.
- Analyses of 25 water samples of the chosen benchmark sites was carried out. The ground water quality is moderately saline (EC 0.95-2.65 dSm^{-1}) and dose not possess much sodic hazard.
- Soil site suitability criteria has been developed for groundnut, mustard, cumin castor, pearl millet, sorghum, cluster been and green gram.
- 27 field demonstrations on rabi and kharif crops have been conducted and significant higher yield was obtained over the control.
- Field day and farmers training programme were organized in watershed area. About 160 farmers were benefited.

Achievements of field experiments

Centre	No. of Field Experiments	No. of Crop Experiments	Variety	Interventions/ treatments	Yield (kg/ha^{-1})	
					2001-02	2002-03
GAU, S.K. Nagar	Rabi (18) 2002-03	Mustard (3)	GM-02	Improved package of practices and Recommended dose of fertilizer		2098
		Cumin (3)	GC-3			800
		Isabgol (3)	GI-2			1532
	Kharif, 2002	Pearlmillet (3)	MH-169		2594	
		Clusterbean (3)	GG-1		766	
		Castor (3)	GCH-4		1967	

Changeri Watershed

B. L. Jain

NBSS&LUP Regional Centre, Udaipur

Location: The watershed is located near village Changedi, District Udaipur, between 24° 46' 17" to 24° 49' 04" N and 74° 07'17" to 74° 08'57" E covering 257 ha area.

Climatic features: Average annual rainfall 550 mm, PET 1380 mm per annum, Mean annual temperature: Maximum 24.8 41.0° C and minimum 10.2-27.7°C

Soils: Soils of the Mavli tehsil are moderate to deep, well drained, fine loam to clay, slight to moderate erosion, slight to moderate salinity and sodicity in isolated patches. These soils belong to sub groups Typic Ustochrepts/ Vertic Ustochrepts. The soils adjoining Changeri watershed are moderately shallow, well drained, calcareous, fine loamy on very gently sloping plains with interspersed monodocks as loamy surface and slightly eroded, associated with moderately shallow, well drained, calcareous, fine loamy soils, moderately eroded, slightly saline sodic.

Land use and cropping pattern: Total geographical area of Mavli Tehsil is 63,000 ha. Net sown area is 34.3%. Fallow land constitutes 11.8% and cultivable waste 26.2%. During kharif main crops are maize and groundnut occupying 73% and 8.5% area respectively. The average productivity for maize is 15.0 and for groundnut 20.0 q/ha. During rabi wheat and mustard are predominant crops with 24.4% and 7.0% of cultivable area. The rabi crops are mainly grown under irrigated conditions.

Ground water: Out of 41 water samples collected in Sept. 2001, only 7 wells (17%) are of low salinity (<0.5 dSm^{-1} EC), 16 wells are moderately saline with EC 0.5-1.0 dSm^{-1}, 15 wells are saline (EC 2.0 dSm^{-1}) and 3 wells are highly saline (EC >2.0 dSm^{-1}). Salinity and pH of well waters increased as a result of pumping during rabi

Socio-economic status: Out of 233 ha area covered in watershed for 128 farm families cultivated area constitutes 165 ha (71.1%) and fallow land about 67 ha (28.9%). Irrigated area in watershed is 73 ha (31.6%) while orchard is only in 2 ha area. In micro watershed there are 421 farm holdings out of which 69% are of less than 0.5 ha, 13% are between 0.5 and 1.0 ha, 11.7% are between1.0 to 2.0 ha, and 6.7% are more than 2.0 ha. The total area of micro watershed is 257 ha. With respect to land ownership 49.2% farm families have < 1 ha, 23.4% have land in between 12 ha, 22.2% have land in between 25 ha and 2.3% farm families have > 5.0 ha area.

Watershed specific constraints

- Soil depth
- Limited ground water potential
- Lack of knowledge of innovative practices/technologies

Significant achievements

- Changeri watershed near Khempur village in Mavli tehsil, Udaipur district, selected as study area. Khasra wise detailed map has been prepared and digitized.

- Data on land use, cropping pattern, population and other physical parameters have been gathered. Cultivated area is 70 %, fallow 30 % and irrigated area 46 %. Major crops are maize 35 %, groundnut 5.2 %, mustard 30.6 % and wheat 9.2 %.
- Weekly rainfall data from June to October from 1996-2000 collected and analyzed. The data indicate variation of 224-705 mm with 1 to 3 dry weeks during kharif.
- Socio-economic survey of 128 farm families has been completed to identify constraint in adoption of new technologies. 49.2 % farm families have land < 1 ha, 23.4 % 1-2 ha, 22.2 % 2-5 ha and 28 % >5 ha.
- Detailed soil survey and mapping has been done on 1:4, 000 scale with 6 units classified as Lithic Ustorthents (44%) and Typic Haplustepts (55 %). 44 % soils are shallow, 33 % are moderately shallow to moderately deep and 21.4 % are deep. Soil maps have been digitized and thematic maps for various soil parameters prepared.
- Data on ground water quality and depth collected and analyzed.
- Crop suitability of maize, pearlmillet, sorghum, castor, soyabean, sesame, sunflower, groundnut, barley, wheat, safflower, mustard and chickpea has been evaluated.
- 41 field demonstrations of rabi and kharif crops have been conducted, thereby benefiting 220 farmers. The yield of mustard increased by 27.65 %, wheat 23 % and groundnut 18%.

Achievements of field experiments

Centre	No. of Field Experiments	No. of Crop Experiments	Variety	Interventions/ treatments	Yield (kg/ha)
					2001-02
NBSS&LUP, Udaipur	Rabi (43) 2001-02 & 2002-03	Wheat (5)	Raj-3077	Soil depth Irrigation level Fertilizer	5420
		Mustard (9)	BiO-902	management Improved varieties	1900
		Cumin (10)	RZ-19	Soil depth Irrigation	1100
	Kharif, 2002	Maize (10)	BiO-902	Soil depth Irrigation	2070 2935
		Groundnut(9)	AK-12-24	Soil depth Irrigation	1547 1820

Kukma Watershed

Pramila Raina

Central Arid Zone Research Institute, Jodhpur

Location: The watershed is located near village Kukma, District Bhuj, between 23° 10'45" to 23°13'42" N 69° 47'00" to 69° 48'18"E covering 956 ha area.

Climatic features: Average annual rainfall 375 mm, mean annual temperature: Maximum 24.8 41.0 °C and minimum 10.2- 27.7 °C.

Soils: Classification of soils according to texture given below indicates that gravelly sand and gravelly loamy sand occupies maximum area. According to land capability the class IIIes constitutes 29.3 %, IV es 30.3 %, VI es 19.76 % and VII es 13.7. In about 58% area the texture of surface soil is coarse sand to coarse loamy sand.

Vegetation: The watershed area has dominance of *Prosopis juliflora* shrubs and very few plant of *Prosopis cineraria, Acacia Senegal,* Acacia *arabica* and *nilotica* tress. At the Bhuj Radio station and Regional Research Station Kukma (Bhuj) farm many *Azadiracta indica* and Eucalyptus trees have been planted. The *Ziziphus nummularia* and *Capparis decidua* shrubs are very common in the area.

Land use and cropping pattern: Out of the total 956 ha area of the watershed, monocropped land occupied the largest area (35.78 %). Rocky and gravelly waste with scrub (168 ha, 17.57 %), fallow land (163 ha, 17 %), Hill (131 ha, 13.7 %), irrigated land (85.9, 8.98 %) and , water bodies occupied (14 ha,1.46 %).In the watershed area only 8.98 % area is irrigated in rabi season and also occasionally in kharif season for growing crops and fodder. The major crops are groundnut, cotton, sesame castor, guar and mung bean in kharif season and in rabi season crops like wheat, mustard, castor, isabgol, cumin, chillies, coriander and vegetables. Major sources of irrigation are well followed by water harvesting structures constructed by farmers themselves. Irrigated area is limited and occurs in the eastern part of watershed in buried pediments and colluvial plains.

Ground water: The major part of Kukma watershed is under rainfed cropping. Nearly 20 wells are located in the vicinity of drainage line in the colluvial and alluvial zone. Water samples were collected and analysed for their pH, EC, cation & anion content, RSC and SAR values. Results revealed that EC values of ground water are 0.8 to2.30 dSm^{-1}. The ground water is slightly brackish. The RSC values ranged from 0.8 to3.2 meq L^{-1}. The eastern part of watershed has some wells of good potentiality of ground water.

Socio-economic status: Socio-economic survey of seventy five farm families out of 180 families of watershed has been completed while using proportionate random sampling technique. Seventy five respondents were interviewed and the data collected were categorized in six categories based on gross cropped area. Marginal (< 1ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-10 ha), large (>10 ha). Regarding crop production problems, reasons for changes in land use pattern, soil moisture conservation practices, role of women in various activities viz. agriculture, horticulture, livestock, household and social activities and employment generation were studied.

Watershed specific constraints: Large-scale capital investment is needed for construction of check dams and water harvesting structures for restructuring agriculture. There is an urgent need to suggest landform based alternate land use. It could be both for silvi-pasture and agri-horticulture. Farmers having wells on their farm are supplying flood irrigation and higher doses of fertilizers which result in degradation of the quality of soil as well lowering of water table. *Therefore introduction of the new varieties* requiring less irrigation, sprinkler irrigation, judicious use of fertilizer, use of farm yard manure and bio-fertilizer should be propagated.

Significant achievements

- Kukma watershed in Bhuj district has been selected and khasra map has been prepared and digitized.
- Information on landform, geology, vegetation, land use, cropping pattern, ground water resources, and human and livestock population have been gathered and analyzed. The watershed has nine landforms. Rocky gravelly buried pediments is dominant. Cultivated area is only 35.78 % and irrigated area is 8.98%.
- Ground water quality has been assessed. The EC value ranges from 0.8 to 5.0 dSm^{-1} and depth of water 85-110 metres.
- Socio-economic survey of 75 farm families has been completed Maximum respondents belong to medium and semi-medium categories. Literacy ranges from 48-57% and average land holding 6.19 ha per household.
- Detailed soil survey and mapping has been completed. Three major soil series identified in watershed area are Kukma, Nani Relendi and Ghad series. The soils are coarse sand to sandy loam and loam, and shallow to moderately deep and deep. The soils are affected with moderate to sever water erosion and moderate salinity. 29.3% watershed area qualify for land capability class III, 30.3% for class IV, 19.76% for class VI and 13.7% for class VII.
- 26 field experiments have been conducted on groundnut, castor, sesame, pearl millet, wheat, cumin, and mustard crops. The yields of castor, cumin, and mustard have increased by 16%, 14.5% and 18% respectively over the control.

Achievements of field experiments

Centre	No. of Field Experiments	No. of Crop Experiments	Variety	Interventions/ treatments	Average Yield (kg/ha) 2002-03
RRS (CAZRI), Bhuj	Rabi (12) 2002-03	Wheat (4)	Vr-503	Improved package of practices and their impact on different soil depth	4166
			Mico		5183
			GJ-2		1093
		Cumin (4)	MG-2		3490
		Mustard (4)	Basanti		3920
			Varun		2690
	Kharif (8), 2002	Sesame (2)	Weston-II		1420
			G-1		1170
		Groundnut (4)	G-2		1723
		Castor(2)	GCH-2		4720
			GCH-4		7215

Sirappur Theri Watershed

V. Subramanian

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Location: The watershed is located near village Sirappur, District Thoothukudi, between 08^{0} 24'12" to 08^{0} 24'57" N and 77^{0} 54'21" to 77^{0} 55'15" E covering 250 ha area.

Climatic features: Average annual rainfall 675.7mm, most of the rains occur during north east monsoon (October to December), mean annual temperature: maximum 35.5^{0} C and Minimum 22.3^{0}C.

Physiography: Sand dunes (low to medium), sandy undulating area and sandy plain are major landforms of *Theri* lands which belong to the Quarternary period. Lithology of the area indicates the presence of consolidated ferruginous sandstone below 3-6 m. Basement rock is charnokite.

Soils: The soils are sandy covered with sand hummocks and dunes. Extent of different mapping units and their limitations are presented below

Mapping, Units	Land Capability Subclass	Area (ha)	Main Limitations
1. Sp a C-D, 3-4	IV se	209.73	Sandy texture, sand dunes and hummocky landforms, severe to very severe wind erosion, excessive drainage, acidic soil reaction, very low water and nutrient retention capacity
2. Sp a B 2	III se	40.70	

Vegetation: The natural vegetation consists of Tree species viz. *Borassus fiabelliber, Acacia planifrons, Acacia arabica, Azadirachta indica, Prosopis julifiora* and herb and shrub species viz. *Dodonaea viscose, Sphaeranthus indicus*

Land use and cropping pattern: Out of the total 348 ha land 320 ha is rainfed. 10 ha is irrigated and 18 ha is under orchards. Out of the total rainfed land only 20% is under cultivation. Cashew, drumstick and groundnut are dominant crops. Other crops like bajra and ragi are also grown under rainfed condition. Banana and vegetables like chillies, cucumber, snake guard, brinjal and tomato are taken with irrigation.

Socio-economic status: Nearly 50 % respondents had primary or middle school education and 30 % respondents found illiterate. Most of the farmers are coming under large farmer's category but due to low production potentials, social status of farmers is poor. Majority of population belong to Nadar community. Majority of the communities inhabited not in aggregates and they show less vigil on the uplift of the area. Arid agricultural is the primary source of income with less productivity. Other important allied occupation is animal husbandry. Land use is stray in dune complex. Though agriculture is the prime occupation in the sandy plains, the net profit is unattractive. Easy marketing facilities are not available besides improper transport facilities. The middleman involvement is dominated and hence the sale of the farm produce is in divergence.

Watershed specific constraints

- Low, erratic and unpredictable rainfall
- Sandy hummocky soils with low fertility status
- Poor ground water potential
- Economic status of farmers is very poor
- Lack of knowledge of innovative practices/technologies

Significant achievements

- 250 ha area of Sirappur village of Sattankulam taluk in Thoothukudi district has been selected as study area. Detailed survey map has been prepared and digitized.
- Details on various parameters like geology, land use, cropping pattern, vegetation and human and livestock population has been collected. The area has typic reddish sand dunes and sandy plain locally called 'Theri lands'.
- Weekly rainfall data from 1991-2001 have been collected and analyzed. The data indicates May-June as hottest months and 675 mm as mean annual rainfall occurring mainly in the months of November.
- Detailed soil survey and mapping has been completed. The soils are siliceous, isohyperthermic, very deep Typic Quartzipsamments. These soils are excessively drained, non calcareous, redish, acidic, sand soils occurring in gently sloping to moderately sloping sand hummocky landforms. Sirappur I series with sandy surface, 3-10 % slope and severe to very severe wind erosion occupy 83.75 % area. Sirappur II series with sandy surface, very gently sloping, moderately erosion sandy soils occur in 16.25 % area.
- Socio-economic survey of 35 farm families has been completed.
- Soil site suitability criteria have been developed for crops like groundnut, cashew, mango, moringa and sapota.
- Four field experiments have been undertaken on groundnut and significantly higher (41.9 %) yield has been obtained.

Achievements of field experiments

Centre	No. of Field Experiments	No. of Crop Experiments	Variety	Interventions/ treatments	Yield (kg/ha)
					2002-03
TNAU, Killikulam	Kharif, 2002 (4)	Groundnut (4)	VRI-2	Recommended NPK (17:34:52 kg/ha) Bio-digested pressmud @ 7.5t/ha	1343

II

Integrated Natural ResourcesAppraisal

Contribution of All India Soil and Land Use Survey in development planning

S. N. Das

All India Soil and Land Use Survey IARI Buildings, New Delhi

All India Soil and Land Use Survey (AISLUS) is an apex institution in the country conducting Soil Survey since 1958. It operates soil survey and land resource inventory in the country from it's Head Quarter at New Delhi through four regional centres located at NOIDA, Kolkata, Bangalore, Nagpur and three sub-centres situated at Ranchi, Hyderabad and Ahmedabad. It has strength of 509 staff including a fleet of 85 field parties. Remote Sensing Centre with advanced computer systems has been established with the assistance of FAO/UNDP in 1982.

The mandate of the organization is to provide detailed scientific database on soil and land characteristic to various State User Departments for planning and implementation of soil and water conservation on Watershed based Programme for Natural Resources Management.

The data base generation has been conceptualized to meet the need for planning at National/State/Basin, District/Catchment and Village/ micro-watershed level. The scale of base map employed for generation of data base varies from 1: 4,000 (Cadastral Map)/1: 15000 (Aerial Photograph) to 1: 50, 000 (SOI toposheet, aerial photograph and satellite imagery).

The activities of AISLUS are distinct from other central organizations. The major activities and the performance of AISLUS are as under:

1. Rapid reconnaissance survey (RRS) in the catchments areas including the catchments of centrally sponsored schemes River Valley Projects (RVPs) and Flood Prone Rivers (FPRs) for prioritizing sub-watersheds based on adjudged sediment yield/run off potential for planning soil conservation and integrated watershed management programmes. An area of 191 m ha has so far been covered under RRS of which 34 m ha area falls under very high and high categories of watersheds.
2. Detailed soil survey (DSS) in high and very high priority sub-watersheds to provide a sound database for planning and execution of soil and water conservation measures and recommendations for sustainable agricultural development consistent with soil and land characteristics and terrain features. An area of 12 m ha has been covered under DSS out of 34 m ha of priority area for soil and water conservation measures.
3. District wise land degradation mapping (LDM) on 1 : 50,000 scale using remote sensing technique. An area of 40 m ha has been covered under land degradation mapping. It could be a base for planning, implementation and monitoring of schemes on Alkali Soils, Shifting Cultivation and Development of Ravines, Salt Affected and Waterlogged lands.
4. Development of map library for RVP/FPR catchments and Soil Information System for data banking using GIS and RDBMS.. Digital Watershed Atlas of India has already been developed using advanced technology.
5. Consultancy projects related to watersheds prioritization, monitoring and evaluation using Remote sensing and GIS. Since 1994, 12 projects from State Irrigation Departments, National Hydroelectric Power

Corporation, NWDPRA and IGBP has been completed.

Demand Based on Going Activities

Survey activities under RVP/FPR and approved Catchment

1. Rapid Reconnaissance Survey of Jhelum and Chenab Catchment-Special Project of PMO
2. Detailed Soil Survey of Priority Watersheds of Banas Catchment
3. Detailed Soil Survey of Priority Watersheds of Nizamsagar Catchment
4. Detailed Soil Survey of some selected watersheds of GOA
5. Rapid Reconnaissance Survey of Dhaleswari Catchment
6. Rapid Reconnaissance Survey of Dickrong Catchment
7. Rapid Reconnaissance Survey of Upper Indravati Catchment
8. Rapid Reconnaissance Survey of Jai-Bhareli Catchment
9. Rapid Reconnaissance Survey of Kapili Catchment
10. Resurvey of Gomti Catchment
11. Refixation of priority for Halon and Upper Narmada irrigation project of NVDA
12. Land Degradation Mapping of whole Jharkhand State
13. Land Degradation Mapping of districts of NES
14. Detailed Soil Survey of 5 villages of Dadra Nagar Haveli
15. Resurvey of Nagarjun Sagar Catchment
16. Soil Survey of Baishali and Hazaribagh district of Bihar and Jharkhand
17. Resurvey ofTista and Mahananda Catchment

Consultancy Project

18. Development of Decision Support System using Remote .Sensing and GIS, Consultancy Project received from IGBP
19. Evaluation of the impact of Watershed Management using Remote sensing and GIS for three watersheds of Tilaya Catchment-Consultancy Project received from IGBP
20. Land Degradation Mapping of Chamba District using RS - Consultancy Project received from Space Application Centre; Ahmedabad
21. Watershed Reconciliation of Narmada Catchment-Consultancy Project received from NVDA, Bhopal
22. Soil Mapping of 13 districts from Haryana State Remote Sensing Application Centre : 2 years project
23. Soil mapping of 40 districts from Remote Sensing Application Centre, UP 4 years project
24. Soil Mapping of 38 blocks of Gujarat from National Remote Sensing Agency, Hyderabad - 1 year project
25. one district from Indian Institute of Remote Sensing, Dehra Dun - 3 months project

Proposals Under Consideration

In addition; the following requests have been received which are likely to be taken up under consultancy mode.

1. Remote Sensing Application Centre; Madhya Pradesh made a request for soil mapping and digital soil data for 38 districts.
2. Remote Sensing Application Centre, Manipur made a request for both Watershed Prioritization and Soil Mapping of entire Manipur.

Demand of Soil Database from NGO/ Private and Other Agencies

1. Agriculture Finance Corporation made a request for Soil and Land information for 22 districts of Jharkhand
2. Water and Power Consultancy Service made a request for Soil and Land information for some districts of Jharkhand

3. Gram Vikash Kendra, Nalanda, Bihar made a request for Soil Analysis
4. Soil Survey data of Chhatisgarh by Consultancy Engineering Service, New Delhi
5. Digital Soil Map of Tamilnadu - Chief Engineer, PW, Bangalore

Development of Digital Data Base

The voluminous database so far generated by AISLUS is meant for RVP/FPR scheme for watershed development. It could serve as a base for planning, implementation and monitoring schemes of DAC, viz, Alkali Soils, Shifting cultivation, Horticulture Development programme, NWDPRA are major activities of National Land Conservation Board. All these soil and land information generated through conventional means needs to be brought under digital environment using GIS and RDBMS that will facilitate not only management of voluminous map and statistical information but also will allow manipulation, updating, analyzing retrieval of information as per the needs of the decision and policy makers. It will ultimately serve as a National Database for planning, implementation and monitoring of watershed management programmes in the country. AISLUS has contemplated to develop Map Library in respect of all the RVP and FPR catchments using GIS and RDBMS. Digital Watershed Atlas of India has already been developed using GIS.

Documentation of Soil Survey Data

The soil survey information is documented in the form of reports and maps for the benefit of users. The hard copy of reports and maps are provided to the State Government Departments of Agriculture, Forests and Soil Conservation who are involved in planning and implementation of soil and water conservation in the catchments of River Valley and Flood Prone catchments. So far 1177 reports have been published comprising 243 reports on Rapid Reconnaissance Survey, 905 reports on Detailed Soil Survey and 29 reports on Land Degradation Mapping.

Data Content

The reports published by AISLUS based on various kinds of soil survey and mapping provides information of different levels. The data content of various reports is briefly given below for the benefit of users.

Rapid Reconnaissance Survey Report: It contains both spatial and non-spatial information (1: 50000) of priority watersheds in the catchments, erosion intensity mapping unit, broad level information on physiography, slope, soil depth, surface and sub-surface texture, land use and land cover, erosion, existing management practices. The erosion intensity mapping (EIMP) unit is governed by physiography and each physiographic situation is associated with natural habitat. Thus each EIMU polygon could be considered as an eco-region for development purposes. Various thematic maps could be generated out of the data content that would be very useful for macro level planning in the catchments.

Detailed Soil Survey Report: It provides both spatial and non-spatial information on soils of priority watersheds at detailed level (1 :4000/15000). Spatial distribution of soils at phases and types of soil series, soil classification, land capability classification, soil irrigability classification, land irrigability classification, hydrologic soil grouping, and paddy suitability with statistical information comprises the soil data base. Each soil polygon contains basic information, viz., name of soil series, soil depth, surface texture, stony and gravelliness, slope and erosion class along with suggestive soil and water conservation measures. Besides, various soil morphological attributes, viz., depth of different genetic and diagnostic horizons, soil colour, texture, structure, gravels and coarse fragments, pores, roots, artifacts and soil physical and chemical parameters, i.e., soil pH, EC, organic matter, cation exchange capacity, base saturation, water holding capacity, bulk and particle density, percent pore space, moisture equivalent, percentage of sand, silt and clay, etc. are described in the report. These informations are pre-requisite for formulation of watershed management plan at micro level.

Land Degradation Mapping: The report of land degradation mapping contains both spatial and non-spatial information on degraded lands in a district. Spatial distribution of various kinds of degraded lands mapped using remote sensing techniques is available in the report that is useful for development of degraded land on location specific approach. Besides, distribution of degraded lands under major land use and major landform along with severity of degradation could be derived out of the legend developed for mapping purposes.

Important Publications

The important publications of the organization are as below.

1. Soil Survey Manual
2. Manual on Priority Delineation Survey
3. Watershed Atlas of India
4. info-aislus
5. Soil Analysis - Working Manual
6. Soil and Land Information for Watershed Development
7. Soil Survey Status of India

National Mapping Mission

National Mission on Soil and Land Degradation Mapping envisaged by DAC to harmonize the soil survey activities in the country by pooling financial resources from the concerned departments and to avoid duplication of activities. AISLUS has submitted an EFC memorandum on National Mapping Mission for soil and degraded lands. It has been formulated in consultation with various ministries and departments, namely, Department of Land Resources, Ministry of Environment and Forests, Ministry of Water Resources, Department of Space, Department of Agriculture and Cooperation, ICAR and Planning Commission. AISLUS will be the nodal agency for coordinating the mission programme.

Indian Scenario of Soil Survey and Land Use: Issues, Opportunity, Challenges and Strategies

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It is frequently the case that there is a considerable time gap between the initiation of research effort in a particular field and the realization of research results to give a practical action to those findings. Adequate attention to those areas is focused only when the problem starts acquiring a considerable dimensions where ignoring action would be almost catastrophic. This has indeed been the case with soil survey and land use planning, the area of most concern and interest to all of us. We are now at a stage where any further slackness on our part to ignore proper consideration of soil resources to achieve sustainable development not only in agriculture but also other allied sphere including the environment.

The 21st century is a century of challenge and opportunity. Everyone has a concern about the sustainability. The concept of sustainability of a system, may be defined as a system that uses manages and conserves the natural resource base for the satisfaction of the needs of the present and of the future generations in a manner that respects environmental, social and economic requirement. When applied to soil resource, the sustainability relates to productive capacity of soils. It needs to be maintained and indeed to be enhanced over a period of time for meeting the food, fodder, horticulture and fuel requirement of the people. And the efforts that improving the productivity will not lead to adverse environmental consequences.

The per capita availability of agricultural land stands reduced from 0.4 hectares in 1950-51 to 0.20 hectares in 1980-81 and 0.14 hectares in *2000-2001*. It is estimated that the total agricultural land will further reduce from 142 m ha in *2001-2002* to 100 m ha by 2020, by which our population is estimated to be around 130 crores. About 40-50 m ha of agricultural land would be diverted to meet the need of other civilian amenities and thus the per capita agricultural land will stand further reduce to 0.077 ha (i.e. 90 ft x 90 ft. area). It is, therefore, apparent from the trends that the future production gains will have to come largely from increased productivity.

We are experiencing that our resource has been fast deteriorating. The NBSS estimate indicates that the land degradation due to various causes amounts to 187.0 m ha. Barring 23 m ha land, which is categorised slightly degraded, 164 m ha area needs immediate attention. In the country, 67 million hectares are notified as forest land. Under the Indian Forest Act, this area is not available for cultivation or another use. However for ecological security, the National Commission on Agriculture recommended that a minimum area of 33 per cent need to be kept under forest. It would further appear that of the 67 million hectares of forest lands, nearly 25 million hectares land is in various stages of degradation.

It is further seen that there has been a rapid decline in the common land property owned by the villages over the past few decades (Jodha, 1990). A study spread over 82 villages in different parts of the country showed that in a span of about 30 years, there was a reduction in common land property by 31-55 per cent due to increase in the population pressure with accompanying their allied demands. The physical degradation of these areas was reflected in the disappearance of a number of plant and tree species, which the villagers used to gather from the common lands. Some of these lands in yester years were also used for grazing the cattle. Now there is crisis for grazing land. Similarly, the number of watering points declined significantly indicating the overall reduced capacity of soils to absorb and to retain water.

Erosion by water leading to the loss of top soil is the most important degrading process. According to Dhruvanarayana et al. (1990) nearly 6,000 million tonnes of soil are displaced and transported annually. In red soils such displacement is about 4-10 t/ha/yr and in black soils is 11-43 t/ha/yr. The gully erosion is recorded on nearly 4 million ha and hillside erosion on about 13 million ha. Soil erosion and sedimentation not only reduce the soil productivity, but they pose a serious threat to multipurpose reservoirs. The sediment deposition rates are often recorded much higher than those presumed at designing stage of reservoirs.

A survey in Maharashtra state showed that black soils having a depth of 60 cms or more and contributing 45 per cent of an area in 1910 was reduced by 15 per cent after 90 years. Reduced soil depths have led to reduced soil water storage and increased proneness to run off and drought conditions leading to reduced productivity. The control of soil degradation is, therefore, a real challenge in any effort to ensure sustainability in production systems. Although major gains in food production in the past four decades have come from the areas where the irrigation facilities are made available. However, the sustainability of these production systems is being questioned now.

As early as 1928, the Royal Commission on Agriculture in India stated that many troubles might arise in the irrigated projects of India with regard to water logging and formation of salty lands due to failure to properly correlate a new irrigation system with the natural drainage of the track. We, now, experienced that where a careful drainage survey has not been accomplished and the irrigation projects implemented without the provisions for drainage measures. The problem of increasing salinity and impeded drainage came on the surface with land degradation on these accounts.

It would appear that land degradation problems are serious in both the irrigated and in the rainfed areas of the country. Due to rapid growth of industrialization, the soil resources are increasingly used for the disposal of wastes including sewage and industrial effluents. The health hazards associated with these and with the use of increasing quantities of farm chemical pose additional concerns.

Pollution of groundwater through accession of nitrates moving with water and through the soils are already a problem in some of the intensively cultivated areas. Soil characteristics very largely determine the behavior and fate of applied chemical and wastes. We will need to increasingly understand and to manage our soils in a way so as to keep adverse effects of environments to a minimum. In seventies and eighties, the U.S. citizens were demanding clean water and clean air and in the nineties, they are already insisting for clean soils.

Where do we go from here?

Every student of soil science has learnt that different soils have a varying potential to support types and intensity of production system without degradation. A pastureland may be able to support a certain population of animals indefinitely without degradation, but if the number of cattle increases and no other management precautions are undertaken, the land will deteriorate. In general traditional land uses and production systems have evolved over a long period of time and have been generally suited to both the environment and the socio economic system. However, frequent changes in socio economic conditions may result in relatively unsustainable land use systems.

The main aim of our effort in generating the soil database is to ensure its sustainable use. It would require the allocation of soils for different uses that provide the greatest sustainable benefits. It includes the biophysical characteristics of land units. They determine their suitability for agricultural production. They are used to decide which crops can be grown in which cropping systems, and how many livestock of a specified type can be supported. Suitability is related to soil and climatic characteristics, which determine production and inputs needed for a peculiar crop, cropping system and livestock. For instance, a specific crop can be grown on many land units, but will produce differently using different quantities of inputs depending upon the bio-physical feature of the unit. To obtain realistic estimates of land use options available to stakeholders, it is important that the spatial and temporal variability in the availability of natural and other production resources be quantified satisfactory at the desired scale. The reliable estimation/projections of the availability of the current and future resources in different land units are also necessary. The development of appropriate policies, which would encourage better responsive land use planning and management structure and approaches are the need of the day. The basic task of building up a good inventory of soil resources at several scales is needed to plan and execute measures that will ensure sustainability. At the national/state level, an inventory of major land resource areas/agro climatic regions on the scale of 1: 250,000 are basis for making decisions on major issues relating to agricultural planning. The National Bureau of Soil Survey and Land Use Planning have recently brought out such information with fullest support from state department, universities and other research organizations. The operational scale of decision making to ensure optimum resource use, the minimum decision area, can be taken as one hectare. This would imply that one centimeter square on a soil map of 1: 10,000 scale would represent this area. Maps of this scale are needed to design appropriate soil conservation measures to recommend specific crops; to decide fertilizer policy and to undertake water conservation measures to provide an efficient use of the extension services.

The Bureau has already completed 70 districts on 1 :50,000 scale and now is conducting demand driven soil surveys on 1:50,000 or 1:10,000 scale. A good inventory of resources is fundamental for evolving its sustainable use. Through resource inventories, the soils are grouped on the basis of their distinctive features into different classes which relate to soil potential. For relating soil survey information for land use planning requires ancillary data and research to match the soil conditions to the performance of crops and cropping systems or other selected uses. Information on soils has been collected in the past and is available in the soil survey reports. These report or databases by themselves will be of little value unless the information contained in them is translated or properly interpreted to formulate proper plans for the use of resources.

It is a fact that the interpretation of soil survey information for alternate uses is a tedious job and need expertise in the line. Fortunately with technological advances we now have, the availability of computer based geographical information systems (GIS) that make it possible to utilize information about soils, climate and topography, etc. more meaningfully and easily than was possible a few years ago. The computerized data can easily be retrieved as and when required. These systems permit useful planning process. The GIS product permits generation of maps in different themes/attributes to evaluate a number of alternate land uses within an agro-climatic region. We can prepare maps of erosion hazards, soil depth, slope, and fertility, etc. Similarly from the knowledge of soil characteristics and agro-ecological regions with crop productivity the efficient cropping zones can be identified. These new tools have opened up many possibilities for the interpretation and use of soils and related information for planning and development. Increasing use of these techniques holds the promise to resilience the soil resource and to promote sustainable land use system.

The interpretation of soil survey information for land use planning requires interaction with specialists having expertise in the alternate land uses on the one hand and the farmers on the other. There is necessity to evolve suitable mechanism to generate confidence with land users (mostly farmers). This is an area where we have failed miserably in the past.

Implementation of landuse plans based on the capability of soils is undoubtedly a massive task. But as a Chinese proverb goes "if you are to peel a bag of potatoes, the only way to do is to pick up one potato and start peeling it". This I believe has to be the approach towards improving the land use practices. This implies the use of land according to its capability, the adoption of practices to be such that would result in increasing the productivity of crops, fodder grasses and other forest species on sustainable basis and without degradation of natural resource base. In all these projects the database obtained through soil surveys in respect of topography, soils, hydrology, vegetation, present land use, land use capability and the socio economic conditions, finds much utility.

During 2001-2002 the work done by NBSS was reviewed by a team headed by Dr. Bhumbla. Some of their observations have relevance for our future efforts. I quote "the team was of the view that while detailed information was obtained on soils and related features, there was invariably less than desired or no interaction with the local people who prepares the master plans of his land. The team further observed that in most of the watersheds studies, requirements and availability of green and dry fodder had not been taken up (pasture development). No conscious efforts were made to educate the farmers on the benefits of alternate land uses and for improving the common lands. In a few cases where the alternate land uses had been encouraged, people adopted it. It is seen overall that scientific information base and its extension were very largely confined to food crops and very little towards alternate land uses. This would appear to me the major area for future efforts".

Our research base and capacity for advisories in the area of alternate land uses is extremely weak. This is no wonder because in the past 5 decades almost our entire research efforts were directed to a few food crops and for more favorable environments. Our database on lands supporting activities other than food crops is very limited or the area under different pastures is not reported. I am sure it would not be an exaggeration if I say that the terms like pasture lands, grazing land or village common lands have become synonymous with wastelands. Just as the farmers owing good lands need advises:

- As to what crops to grow
- What are the improved varieties
- How much fertilizer and how and when to apply
- What are methods of disease and pest control etc.

The farmers owning poor lands want to know how they can best use their lands and for better incomes. Issues of alternate land use must be high in our agenda. The concept of sustainable use of resource is a dynamic one. What might be sustainable by today's standards, might not be so, after a couple of years. So the land use policies must commensurate such dynamism.

The immediate concern is the issues of large-scale diversion of best agricultural lands for non-agricultural purposes particularly, urban and industrial. In many developed countries the concept of prime agricultural lands would prohibit their diversion for non- agricultural uses. I would like to repeat what Dr. L. Swindale said in his Tamhane Memorial lecture delivered a few years before during Annual Convention of the Indian Society of Soil Science. The high population densities in India, particularly in the Indo-Gangetic plains and along the coasts, there is good reason to suggest that the fairly urgent need has arisen to act to preserve prime agricultural lands." As we strive to move towards more rational use of our limited resources the land use policies will need to provide for incentives and disincentives to encourage optimal use. For the sake of generating discussion on the subject may I venture to suggest that based on soils information in each watershed, areas be delineated where land owners could be compensated for shifting from annual cropping to a more appropriate land use involving permanent vegetation such as trees, etc. Although we have made some beginning in this endeavor, our success in achieving goals of sustainable resource use are not in immediate sight. A crucial factor in our success will be the development of trained human resource at all levels. I am particularly concerned that the State Agricultural Universities have practically very little or no expertise in the area of soil survey and land use planning. Development of this expertise and establishing proper links are our efforts. How to do it, is a high question mark. Similarly a whole new culture conscious of resource conservation and management would need to be enthused in our extension personnel which has hither to be largely confined to input based strategies. I would not consider it out of place to plead for a cadre of soil and water conservation personnel (Land Care Army; Soil Health Inspector) at level that would provide the landowners a liberal access to advise in this important and highly technical area. Gentleman, I should like to end up by saying that the path to our goal, no doubt is long and tortuous, but given the stake involved, our only option is to move fast and in the right direction.

I say so,

Because, despite all the advances made by science and technology during past 100 years, we live in a world where human suffering has never been greater. It is estimated that everyday some 40,000 children die of hunger or malnutrition or its related disease; more than 150 m people in the world lack the nourishment to sustain a healthy life; there are more than 200 arm conflicts (internal-external) fought/being fought since the end of 2nd World war to acquire fertile land and its associated natural resources particularly water and forest. It has been calculated that at the present rate of destruction, the world tropical rain forest will disappeared in almost fifty year's time. All that means for the delicate balance of the global climate and ecosystem. A recent policy framework of FAO on multifunctional characters of agriculture and land use suggests that there are four key functions: food security, environment, economic and social emphasizing conservation of land, water, plant and animal genom which are environmentally sound and technically appropriate. Thus the challenge to us is to contribute in providing resource survey information best match with multiple functions of agricultural land use and production system.

Integrated Natural Resources Appraisal: Remote Sensing & GIS approach - A case study

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Department of Space has conducted a major project named as "Integrated Mission for Sustainable Development (IMSD)" in large part of the country on 1:50,000 scale to address drought, environmental degradation and sustainable development. There is an intensive use of Satellite Remote Sensing derived information in mapping; and conventional data sets & local wisdom for addressing action plans for land and water resources.

IMSD is a sound and scientific methodology for efficient and sustainable management of natural resources. The mission was initially launched in 1987, as a technology demonstration-cum-exploration study to counter recurring droughts. Within four years IMSD made giant strides with the support of the Planning Commission. The study was extended to 174 districts, spread across 25 states of the country, covering nearly 45% of the geographical area. In addition to this, 92 drought prone blocks were short listed for special study upon a specific request from the Ministry of Rural Areas and Employment.

The mission adopts an integrated and holistic approach to sustainable development. The IMSD study aims at generating site specific 'Action Plans' for realistic and scientific management of natural resources. Remote Sensing data, field data, contemporary technology and socio-economic profile of the people, all serve as vital inputs.

Resource mapping and assessment

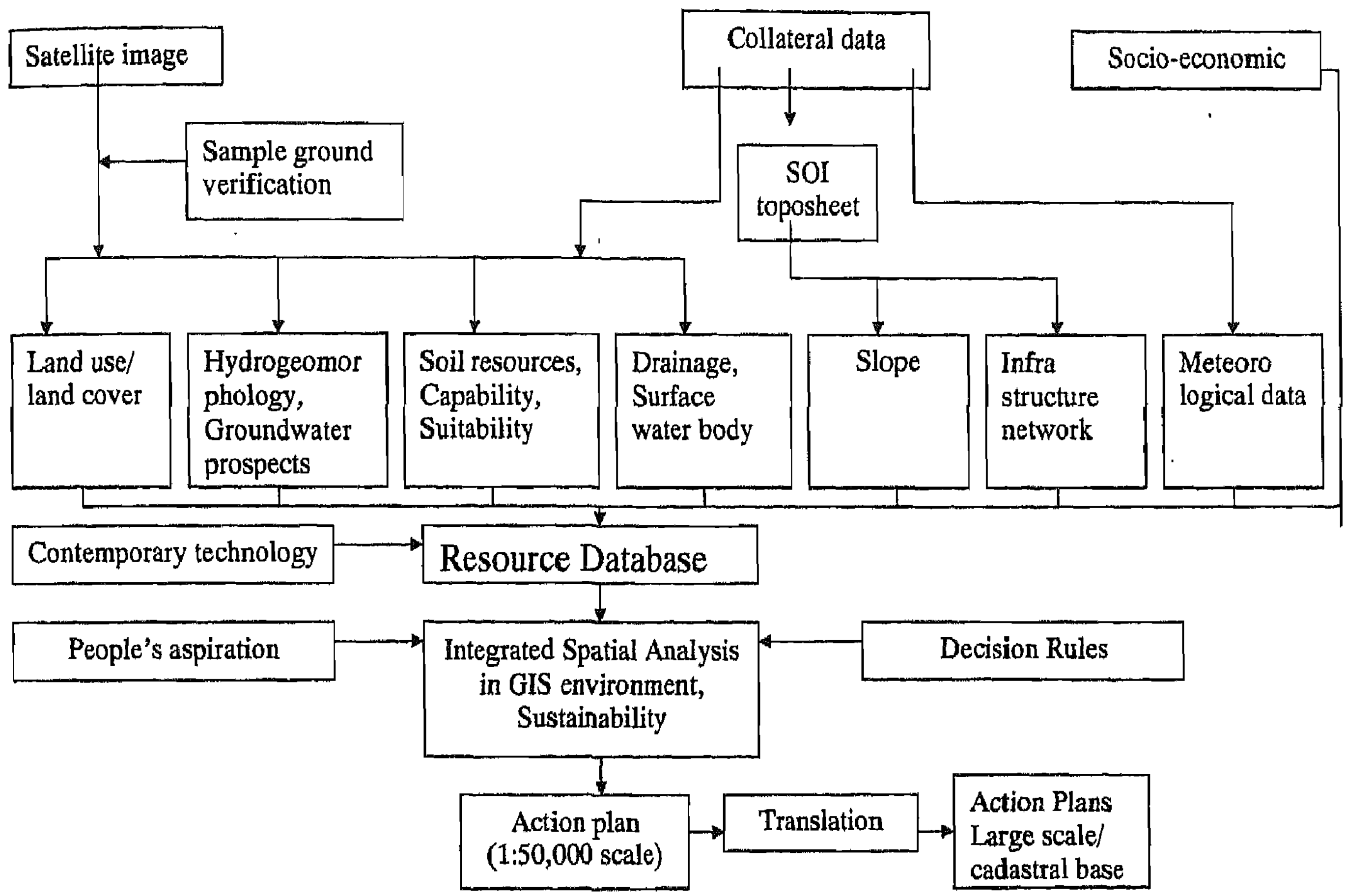
Satellite images are used as a major source of data for deriving factual information on renewable and non-renewable resources. Thematic maps showing current land use/land cover, types of wastelands, forest covers/types, surface water resources, potential ground water zones, landforms, rocky types, soils etc., are generated. Other information on slope, drainage, transport network, settlements, rainfall, temperature, humidity, population, socio-economic conditions are collected from secondary sources viz., census topographical maps and existing records of the district, state and central agencies/departments.

Since one resource is interlinked with the other in an eco-system, the resources (in association with one another), and their linkage/mutual interdependence are studied in detailed by a team of interdisciplinary experts.

Integration of data

Information derived through remote sensing and non-remote sensing methods are then finally integrated (Figure). All thematic maps plus collateral information are integrated using geographical information systems. This results in identifying a set of coherent micro level composite land units across the study area specific developmental plans are arrived at, in consultation and coordination with experts from various central/state departments, agricultural

IMSD Methodology



universities, research institutions, district level officials and the local farmers. This ensures the technical feasibility and social acceptability of such action plans.

The case study of Neem-ka-Thana block shows the spatial integration of different layers viz. Hydrogeomorphology, soil, slope, watershed, water quality and landuse/landcover for water resources development and land resources development. Under water resources development, besides the ground water prospects, sites for water harvesting structures and sites for type of wells are suggested. In land resources development plan, forest area, wasteland areas, agriculture areas have been addressed with appropriate action, finally depending upon the degradation in different watersheds prioritization of watershed has been attempted to take appropriate action.

Remote Sensing in Natural Resources Appraisal and Land use Planning

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Introduction

The State of Rajasthan is characterized by large climatic and topographical variations. Western part of the State is arid, covered with large tracts of sand dunes and sandy plain, the eastern part is semi arid to sub humid alluvial plains drained by Chambal, Banganga, Gambhir, Banas and Mahi rivers where as the southern part is occupied by the scattered hills. The Aravalli hill range running south to north mark the dividing line between the arid and semi arid regions. The western arid region is characterized by high temperatures and strong wind regime causing wind erosion in sand dominated areas. Excessive irrigation in Indira Gandhi Nahar Pariyojna (IGNP) and Chambal Command Areas have resulted in development of water logging and salinisation. In south eastern part of the state area drained by Chambal and its tributaries has been infested with ravines. Irrigation with brackish water has increased sodicity in agricultural fields. Irregular rains and frequent droughts have resulted in environmental degradation and livestock and human migration. In spite of these constraints improved agricultural inputs have increased acreage and per hectare production of crops. But increasing population pressure have put great pressure on natural resources which has resulted into their degradation. Thus there is need to identify the degraded areas and identify technology for conservation and sustainable management of natural resources.

To adopt suitable strategy for the task; detailed inventory of natural resources status is required, based on which planning for their conservation and development can be thought. Remote sensing technique by virtue of synoptic view, repetitive coverage, data availability in different spectral bands with multi resolution options have proved to be most reliable tool for the purpose and have been helpful in providing valuable data base for planning development of natural resources. Different Government departments viz. watershed, agriculture, forestry, ground water, mines and geology, animal husbandry and pasture development have approached the SRSAC and this Department, using remote sensing technology has provided database for execution of development programs. The areas where remote sensing technology has helped the State Government for implementation of development programs have been described below.

Land Resources Development : Watershed Approach

Soil, water and vegetation are the key components of any eco-system and basis for agricultural activities. Conservation and management of these natural resources also help in providing infrastructure facilities and livelihood in the form of food, fodder, fuel and employment. During recent years remote sensing has offered immense information on natural resources, which has been used for their development. Natural resources development planning is based on watershed approach. This requires spatial distribution and characterization of watersheds at micro level. Watershed delineation has been done using satellite data as well as aerial photographs. It comprises of catchments, sub-catchments, watershed, macro watershed and micro watershed level delineation, which usually covers upto 4th order stream. In all 13 River Valley Catchments have been identified in the State, using remote sensing inputs. The watersheds have been characterized upto micro level in respect of degree and direction of slope, land uses viz.. Cultivated, wastelands and drainage density. Prioritization of watershed has been done. These watershed delineated on 1:50,000 scale have been carved into Panchayat Samiti wise and made available to all user agencies viz. Watershed Development and Soil Conservation, Forest, Ground Water, District Rural Development Agencies (DRDA), Non-Governmental Organization (NGO's), Special Schemes Organization (SSO) along with area statistics.

While delineation of macro and micro watersheds are available, the package of practices to be adopted in broader sense within the watershed are available in 1/3rd areas of 18 districts under Integrated Mission for Sustainable Development (IMSD). The action plans have been generated on land use land cover, hydro-geomorphology, soils, slope, drainage/ watershed and transport network in conjunction with secondary data by integration of information generated through remote sensing technology

The Land Resource Development Plan for watershed development comprised of :

(i) Agro-forestry (Single cropped area devoid of ground water)

(ii) Agro Horticulture (Double cropped areas having ground water/ surface irrigation)

(iii) Silvi Pasture (Not suitable for agriculture)

(iv) Horti-Pasture (Pasture lands with water for supplemental irrigation)

(v) Fisheries Development (Surface water bodies, round the year)

(vi) Index catchment (Sandy areas with ephemeral drainage)

(vii) Forest gap plantation

(viii) New forest areas in wastelands

(ix) Forest protection

(x) Fodder and fuel wood plantation

(xi) Sand dune stabilisation

These technologies have been adopted in a number of micro- watersheds in different districts of State (Table 7). The information on land resources are available on 1:50,000 scale where as execution work has been under taken on 1: 8,000. The development plan provides a scientific approach and uniform guidelines for development under various schemes, which will definitely bring out results for sustainability.

Water Harvesting

Remote Sensing offers information on geomorphology, lithology, recharge sites and ground water potential which if coupled with resistivity survey can pin point most prospective zones. Remote sensing also provides existing water bodies like, ponds/tanks/dams/check dams based on which planning for their development and better utilization can also be carried out. With the help of aerial photographs sites for water harvesting structures, nallah bunding, etc. are also suggested. Irrigation, Watershed Development and Soil Conservation Departments, Panchayat Samitis and NGO's have intensively used these sites for constructing anicut/ nallah bunding/ ponds, etc. in various part of State.

Data Base Generated

Following valuable data base using remote sensing has been generated under various projects and made available to all concerned.

(i) Macro and Micro Watershed delineation (1:50,000)

(ii) Watershed Atlas of Rajasthan (1:4,00,000)

(iii) Water Harvesting Structures Master Plan (1:50,000)

(iv) Land & Water Resource Development Plan (1:50,000)

(v) Wasteland mapping (1:50,000)

(vi) Lift Irrigation sites (1:50,000)

(vii) Ravinous areas delineation (1:50,000)

(viii) Ground Water Atlas of Rajasthan (1:4,00,000)

(ix) Resource Atlas of Rajasthan

Land Resource Department, Government of Rajasthan has issued directions that all Watershed Development allocations through DRDA's should only be based on Watershed Atlas of Rajasthan prepared by State Remote Sensing Application Centre, Jodhpur.

Representative of Sate Remote Sensing Application Centre have been nominated in all District Level Watershed Development Committees such that it will be easier to impress upon utilization of Land Resource Development Plan as input for Watershed Development and other natural resources development activities.

Future thrust areas using remote sensing

(i) Watershed and Water Resource Development Planning through remote sensing.

(ii) Oran / Gauchar development planning.

(iii) Ground water recharge- Selection of sites.

(iv) Selection of sites for Fisheries development

Table 7. Micro watershed development planning

S. NO.	District	Panchayat Samiti Block	Macro Watershed No.	Micro Watershed No.	Total No. Of Micro Watershed
1	Ajmer	1.Silora 2.Sri Nagar	12 3	2 & 5 10,14,15,16,17, 18,21 & 22	2 8
2	Barmer	1.Siwana 2.Pachpadra	12 16 17	1 1& 2 1, 2 & 3	1 2 3
3	Baran	1.Shahbad	8	1,2,3,4,5,7, 8,9 & 10	9
4.	Dungarpur	1.Dungarpur	9 10 11	1,5 & 6 1 1 & 2	3 1 2
5.	Jaipur	1.Chaksu 2.Phagi	7 8 1 3	4 2 12 4	1 1 1 1
6.	Nagaur	1.Parbatsar	22	1	1
7.	Pali	1.Sojat	17 20 21	5 & 6 7 1,2 & 3.	2 1 3
8.	Udaipur	1.Sarada	19 22 23 24	1,2,3,4 & 5 1& 2 1& 2 1,2,3,4,5,6,7,8 & 9	5 2 2 9
9	Jodhpur	1.Shergarh/ Balesar	1	1,2,3,4,5,6,7,8, 9,10,11,12& 13	13
	Total	--	--	--	73

Framework of Integrated Natural Resources Assessment: Concept, Methodology and Contribution of CAZRI

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Introduction

Integrated natural resources assessment is synonymous with assessment of land resources. Land can be defined as an area of the earth's surface, the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area. This includes the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by humans (Rossiter, 1996).There is need to recognize role of different components of land for an integrated approach of land· classification and suggesting its use potentials.

The need for an appropriate system of analysis of land resources was felt when Industrial Revolution in the West increased the demand for different kinds of natural resources for processing industries, both agricultural and non-agricultural, and the previously uncharted land had to be explored to find their use potentials. Available literature suggests that the concept of land resources analysis had a nebulous beginning in the land economic surveys carried out in North Michigan State, USA, in the 1920s and the '30s, as also in the regional surveys of the resources in the British Empire, especially in Africa. Veatch (1937) first put forward the idea of a "natural land type", and classified the land into a progressively lower order system of 'Division', 'Physiographic Unit', 'Unit' and 'Land Type', where the higher-level units were the progressive amalgam of the lower level ones. Milne (1935) established a relationship between landform, slope and soil processes in East Africa through the concept of catena.

It was recognized that all the components of land should receive more or less equal weightage, and the functional interrelationship between the components used for assessment of potentials of the land. For example, though soil is an important resource, landscape approach has to be followed for better understanding of the properties and their availability. Likewise plant ecologists would like to recognize vegetation as the major component, and other components like climate, soil, terrain morphology and hydrology are important to the extent that these influence the vegetation composition at different hierarchical levels (Zonneveld, 1970). Similarly, crop scientists would prefer a system that primarily evaluates land for crop performance. Thus, FAO (1976) developed "A Framework for Land Evaluation", by a team consisting of a pedologist, a crop ecologist, an agronomist, a climatologist and an economist (Dudal, 1986). The system is highly pedo-centric. In fact, different land components can be explored, assessed and mapped in three different ways: (a) independently, as a stand-alone investigation to fulfil the requirements of a particular discipline; (b) as subordinate of a single/group of components, usually to substantiate or strengthen the results of the host component; and (c) as an equal partner with the other land components. Integrated land resources analysis follows the third approach.

Land Classification Systems for Land Resources Appraisal

Land resources, a deductive logical process, includes drawing inferences on the characteristics of landform, soil, vegetation, water, etc., as well as integration of these terrain layers to suggest their constraints and potentials for different uses. In-built in the process is the requirement of a set of procedures for stepwise and hierarchical analysis of the landscape features and abstraction of the information on attributes as one moves up the hierarchical ladder, and a set of criteria for amalgamation of the spatial variability in an information layer at progressively smaller scale. Most of the present-day land classification systems are structured in a hierarchical manner, encompassing units relevant for individual land use functions at a large scale and up to the units at continental to sub-continental level at a smaller scale (Moss, 1975). We shall discuss here the systems that have directly influenced the process of development of a land resources appraisal system at the Central Arid Zone Research Institute.

Land System Approach

The foundation of the modern concept of land resources appraisal and land system mapping was laid by C.S. Christian and G.A. Stewart (1953, 1968) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, when they carried out Land System mapping for Katherine-Darwin region of the country (Christian and Stewart, 1953). Land system was defined as an "area or group of areas throughout which a recurring pattern of topography, soils and vegetation can be recognised" (Christian and Stewart, 1953). According to them, landform, soil and vegetation are the inter-dependent components of the natural landscape. Hence, these components can be studied together, not only for a better understanding of the spatio-temporal context of the individual resources, but also for a holistic view of the total landscape. Based on the recurrent pattern of characteristics of the above three components the landscape could be divided into the following progressively lower level units:

- Very extensive scale
- Land system
- Land unit
- Site.

Christian and Stewart (1953, 1968) suggested that the patterns of variability in landform, soil and vegetation could be better understood and rapidly mapped through an interpretation of aerial photographs, and that the boundaries of these resources should be drawn by respective experts on the same aerial photographs, followed by selective ground-truthing. The suggested scale for representing landscape at 'very extensive scale' was 1:1M, while that for 'land system' was <1:250,000, and for 'land unit' 1:10,000 to 1:250,000. Each land unit and land system was named according to the type location where they existed.

Considering that the system was a flexible hierarchical one with genetic connotation, and encompassed the three major terrain parameters, i.e., landform, soil and vegetation with equal weightage, it not only became a standard for land resources analysis in Australia and New Zealand, but also spread widely across the continents within a decade (UNESCO, 1965; Brink et al., 1966; Bawden, 1968, Thomas, 1969; Murdoch et al., 1971). Modifications were made in the system based on local needs and variability. A critical appraisal of the approach is provided in Ollier (1977).

When Central Arid Zone Research Institute (CAZRI), Jodhpur, was established in 1959, C.S. Christian was its Adviser, appointed by the Government of India. CSIRO was the major training organisation for the Institute. This helped the nascent Institute to get exposed to the new land system mapping and analysis through aerial photo interpretation and rapid field survey (Christian, 1959). The central Luni basin was the first area surveyed and mapped through the system (Anonymous, 1968).

While working with the land system mapping technique it was gradually felt by CAZRI that the large landscape variability and high level of human interference in the Indian arid zone as compared to that in Australian arid zone called for some modifications in the system, especially in terms of the level of mapping, number of information layers and systematic of field survey and aerial photo interpretation. It was noticed that the system had a limitation of reproducibility as well as objectivity of classification and definition of the fundamental units. Mabbutt (1968) suggested the change over from a genetic to a parametric approach for landscape analysis, and argued that the rapidly increasing computing power of machine would justify data collection and representation through the parametric approach wherein each unit was a synthesis of a set of quantifiable attributes. Parametric approach helped to quantify the landscape properties in a better way, and thus received good attention. Dalrymple et al. (1968) developed a nine-unit land surface classification model that combied the genetic and parametric approaches, while Conacher and Dalrymple (1977) used the model for geomorphic-soil research and land classification.

UMA Approach

CSIRO, Australia developed a concept of Unique Mapping Area (UMA), in which the number of resource layers was increased to include the water resources and land. uses. Different resource scientists drew the boundaries of their respective resources individually from aerial photographs and site-based information. Field checking of the attributes of the components, followed by overlaying of the component maps resulted in UMA boundaries. Nomenclatures for different land systems and land units were based on a set of attributes for a particular layer.

The UMA methodology was also tested by CAZRI in the Indian arid zone (Abichandani and Sen, 1977). It provided more detailed and quantified information than that through land system mapping, and helped to subdivide a parcel of land on the basis of variations in the attributes of its different components. This, however, proved to be its major drawback because, apart from compartmentalization of the land into different assemblages of attributes, it could provide little information that were of use to the planner for a holistic view of the land resource potentials. The nomenclature was found to be cumbersome because it was an assemblage of the codes for different physical attributes, and hardly conveyed a totality view of the land. The Institute also tested the method followed under the ecosystem approach, but found it more biased towards vegetation component.

MLRU Approach

In pursuance of a system that could represent the arid landscape of India more comprehensively, the scientists of CAZRI discussed the different methodologies with a number of experts, including Dr. H. Th. Verstappen and Dr. J.J. Nossin from ITC, Holland, and Dr. J.R. McAlpine and Professor J.A. Mabbutt from Australia, all of whom spent considerable time at the Institute. The Institute then developed a system called Major Land Resources Unit (MLRU) that enshrines the philosophy of Land System and UMA, but at the same time is more flexible and reflects better the land use systems available in this region (Abichandani et al. 1975 a, b; Abichandani and Sen, 1977). MLRU was defined as an area or a group of areas having recurring patterns of landform, soil and vegetation, as also a recurring pattern of human activities, and resource potentials. It was recognised that each MLRU was homogenous in respect of all the biotic and abiotic resources that influence the resource development. The purpose of identification of MLRU was to evaluate the physical potentials of the land, potential hazards to different use systems (including agricultural and non-agricultural land uses), risks to the environment, etc., as well as to find out suitability of the land for different uses.

As with the Land System and UMA approaches, the MLRU mapping considers aerial photo interpretation (now satellite remote sensing) an integral part of the activities. As in UMA approach, the knowledge of local terrain conditions is essentially gained through field campaigns, but also from secondary sources. However, unlike in the Land System and UMA approaches, specialists in the MLRU system interpret the remote sensing data individually and carry out field survey independently to ensure an unbiased assessment of a particular resource (e.g. landform, soil, vegetation, water), and draw the individual resource boundaries, including those of the land utilization pattern. In the next step the individual resource data and maps are pooled together and interpreted jointly by the team of experts to find out homogeneity of the resources and the patterns of recurrence. The system does not over-emphasise any single component like landform, soil or vegetation, but puts equal weightage to all of them. The system is oriented towards resource conservation and development.

Since 1973 the Division of Basic Resource's Survey (now called the Division of Natural Resources and Environment) is engaged in land resources assessment and mapping through the concept of MLRU. The system was first tested in Bikaner district of Rajasthan, where the recurring patterns of landform, soil and vegetation were mapped under the name Major Biophysical Resource Units (MBRU), their problems and potentials were assessed, and recommendations for each unit was provided (Abichandani et al., 1974, 1975 a, b). The system was then followed in Jodhpur district (Anon. 1982). The district approach was considered appropriate for land resources appraisal for suggestions on development. It was decided to carry out the survey at the scale of 1:50,000, and to collate the data for final representation at 1:250,000 scale.

The approach was found to be well suited to the conditions of Indian arid zone, and has great potentials for suggesting development activities. The data in the early reports provided information on existing and potential physical and human resources and suggested broad recommendations for cropland, pasture land, forest, or for water resources, but these were not supported by land treatment plans, market analysis or cost-benefit analysis. This was rectified during the early 1980s, when the Government of Rajasthan requested CAZRI to prepare a master plan for development in the upper Luni basin. Scope of the integrated resource analysis was then enlarged to include land treatment plans for soil and water conservation to provide design and structure of the proposed storage reservoirs, an assessment of agro-meteorological conditions for crop growth, specific information on suggested crop varieties, range species, etc., analysis of market forces (Shankarnarayan, 1978). Thus, it was felt necessary to provide linkages to the bio-physical delimitations of the MLRUs, and further strengthen the concept through appropriate analysis of socio-economic conditions. The integrated natural and human resources appraisal reports on Guhiya catchment (Shankarnarayan, 1982) and upper Luni basin (Shankarnarayan and Kar, 1983) provided the needed improvements.

Subsequently the aspects introduced to strengthen for a holistic approach were: spatial variations in agro-climatic and hydro-meteorological aspects, slope variability and its implications, variations in hydrogeological properties and groundwater characteristics, range condition analysis, livestock composition, agronomic evaluation, analysis of social conditions, indicators of economic development, market analysis, infrastructure development, input supply and production potentials.

Above themes are now regularly investigated in the studied districts. The framework of investigation is depicted in Fig. 4. Field collection of data is site-based. Information is sought to be collected on several attributes of a land component. For example, landform characterisation at a site considers sediment thickness, parent material, sediment characteristics, slope, granulometry, drainage, erosion/deposition pattern, etc., while that for soil seeks the information on soil depth, colour, texture, structure, organic matter, carbonate content, water-holding capacity, pH, EC, series, land capability, etc. Site data on vegetation includes canopy cover, height, density, abundance, DBH, etc., of trees and shrubs, as well as herbage cover and yield. The site-based attribute data is analysed in the laboratory to make a mosaic of land component information that is abstracted into the

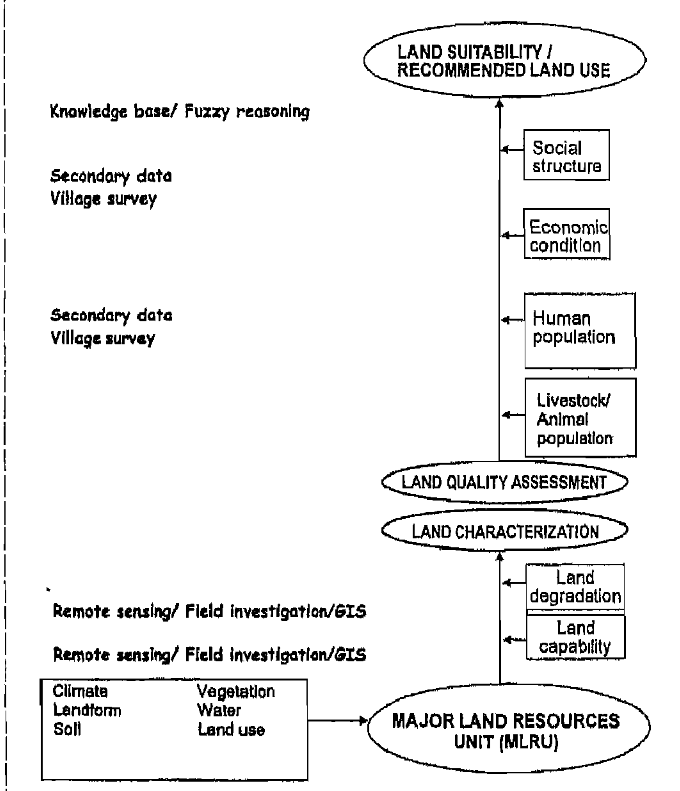

Fig. 4. Framework of integrated natural and human resources appraisal at CAZRI, Jodhpur.

map of a specific land component (i.e., landform, soil, vegetation, surface water, groundwater, present land use and land degradation) at 1:50000 scale, suitable for amalgamation into a map of Major Land Resources Unit. Thus, geomorphology of an area is represented by the major landforms, while soils are depicted through soil series, and vegetation through an association map of tree, shrub and grass cover using Clementsian approach. Hydrological aspect is represented through maps on surface water and groundwater. The map on surface water includes existing water harvesting structures (*nadi*, *khadin*, tank, canal), defined catchments and watersheds, as well as index catchments. Suggested sites for soil and water conservation are also shown. Groundwater is represented through maps on hydrogeological formations, water depth and water quality at 1:250,000 scale. Present land use is depicted through a classification of croplands (including intensity of cultivation vis-à-vis fallow), wastelands, pastures and other uses. Apart from these, land degradation pattern is depicted through a map on the various kinds and degree of erosion (wind and water), water logging and salinization, while the capacity of the land to sustain different uses is shown through land capability classification. Small-scale maps on the onset and withdrawal of monsoon, rainfall pattern, temperature and potential evapotranspiration are also provided, as also the distribution of major crops grown in the area.

As we have noted earlier, this step is followed by integration of the component data and maps to construct the MLRUs. The boundaries of MLRUs are drawn at 1:250000 scale, and the MLRU data set is scrutinised with respect to the patterns of land capability and land degradation. The physical attributes of each of the MLRUs are then spelt out, and the land quality, in terms of its problems and potentials assessed.

Data sets and reports on human and livestock populations, as well as socio-economic conditions, are then interpreted to find out how these factors influence the resource use patterns. While the land quality assessment helps to find out suitability of the units for different uses, analysis of the socio-economic data sets helps to recommend viable land uses in those units.

The composite maps on MLRU and other maps that are derived from the study of an area convey following characteristics:

- A recurring pattern of abiotic and biotic resources, including landform, soil, vegetation, water and land use, as well as broad degradation pattern within a climatic belt;
- An analysis of human and livestock composition as well as of the socio-economic conditions;
- Distinct resource potentials and limitations under the given set of conditions; and
- Recommendations for proper utilization of the land resources

Discussion

The overview of the land classification system developed at CAZRI vis-à-vis some other major integrated land classification systems shows that the MLRU concept has gained from the experimentations with the Land System mapping and its derivatives. It has been able to maintain its distinctive character and provide guidance to the district authorities. The structured, hierarchical method of analysis of biophysical resources is in-built in the system. The conceptual framework of the system being followed and that being expected for its implementation is shown in Fig.5. Flexibility of the system allows it to be periodically updated with respect to the technologies and also in respect of the modules to be attached for integrated analysis. Thus, the system originally started with aerial photo interpretation, gradually switched over to visual interpretation of satellite images, and now mixing the results from digital remote sensing. Geographic Information System has started replacing manual drawing of the final maps, which has vast implications for modelling efforts. There is always an emphasis on adequate field data however, and this has helped researchers to explain the ground situation as well as the needs of the area in a more convincing way to the bureaucrats, policy planners and development agents.

Equal weightage given to different land components, and the freedom given to discipline scientists to analyse respective land components in an unbiased manner, as well as the flexibility to add attributes that are peculiar to a study area, has helped in integrating a wealth of information that summarises better the landscape situation.

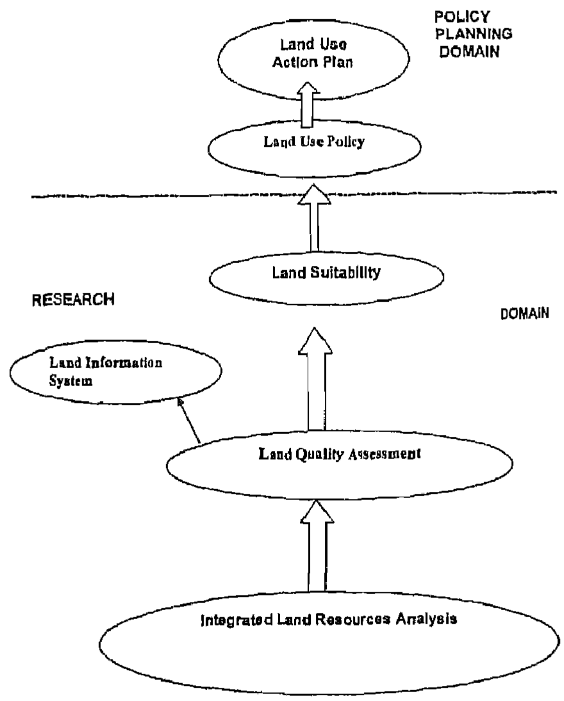

Fig. 5. Domains of land resources research and development.

The system is not too burdened with drawing inferences for crop-specific recommendations only. Suitability of the land for different agricultural and non-agricultural land uses, hazards to crop production and risk to the environment are also looked into.

It is increasingly felt that the land resources information must be managed according to scale, and that land use decisions must be made at different hierarchies of information because the society is also stratified with different information needs for different sectors (Grandstaff, 1992; Eswaran et al., 2000). One of the drawbacks of the MLRU system is that it did not develop a hierarchical system of classification, though the individual discipline scientist gathers data and abstract them through a hierarchical process and provide data for integration to formulate MLRU. The non-hierarchical system of MLRU was a historical necessity, driven by the technology available during the time of its inception. Although it was mandated to gather good amount of data from sites spread over a district/catchment, there was no appropriate mechanism to integrate the data at attribute level and gradually abstract them to the level of MLRU. Human mind cannot usually integrate more than 6-8 layers of data and maps. Therefore, it was decided to abstract the attribute level data first to the level of major land components, and then to integrate the component layers. Thus, e.g., soil series abstracted the huge data on attributes like soil texture, structure, depth, pH, EC, nutrient status, carbonate content, etc. Since the system worked well at the district level, and the attribute level data collected from sites lost their importance after these were used for characterization of the major components, the huge amount of analysed site data gradually went into oblivion.

Table 8 provides the land component hierarchies and the scales at which these operate, as well as the strata where MLRU captures the component data. It is suggested that MLRU be placed in a hierarchical order, commensurate with other similar systems and the needs of the society. This is proposed in Table 9. Upscaling and downscaling from MLRU will be easier once the hierarchy is established.

The modern computing power of the GIS has shown huge potentialities of manipulating the site data for a more precise mapping of the attributes, and their integration and modelling for several practical purposes. This calls for a need to strengthen the systematic collection and analysis of the site-based information. Bullock (1993) has listed a range of soil attributes that may be collected for direct application to several land use decisions. Attribute data are regularly collected by CAZRI on different land components. A system has to be developed for proper storage and use of the data, especially for attribute mapping and modelling purposes.

It is also necessary to use GIS in a more meaningful way than for digitisation of the existing maps and their printing through computer. For example, decision strategy analysis through GIS can provide the analyst with a clear and unbiased choice between the alternatives, provided the available data is adequate for drawing reasonable inferences. The uncertainty management techniques can help in moving to soft probabilistic results, especially where land conditions behave more as a fuzzy set. Multi-criteria evaluation through Boolean overlay (especially in case of vector approaches) and weighted liner combinations (especially in case of raster system) are usually the most sought after methods, but these

Table 8. Hierarchy of land components and the scale suggested for their mapping

Mapping scale	Landform	Soil	Vegetation	Drainage	Land use (unirrigated)	Land use (irrigated)
1: 10M 1 : 1 M	Morpho. province Morpho. region↑	Great Group Soil family ↑	Order Alliance ↑	Basin	Crop assoc. region/ wasteland	Command level
1:250000 1:50000 ↑	Major landform	Soil series	Association	Catchment Watershed ↑	Major land use	Distributary level
1:50000 1:10000 ↑	Landform subunit	Soil series	Sub-association	Watershed	Subclasses	Murabba level
1:10000 1:1000 ↑	Facet	Poly-pedon		Sub-watershec ↑	↓	Field level
	Site (Landform element)	Pedon	Site			

Note: Shaded area is the domain of MLRU.

Table 9. A proposed hierarchical land classification system for MLRU, based on similar international hierarchical systems

Christian & Stewart (1953)	Eswaran et al. (2000)	Proposed for MLRU (2003)
Very Extensive (1 : 1M and smaller)	Agro-ecological Zone (>1 : 10 M)	Land Resources Province (>1 : 10 M)
Very Extensive (1 : 1M and smaller)	Land Resources Region (1 : 1M – 1 : 10 M)	Land Resources Region (1 : 1M – 1 : 10 M)
Land System (1 : 250000 – 1 : 1 M)	Major Land Resource Area (1 : 250000 – 1 : 1 M)	Major Land Resource Area (1 : 250000 – 1 : 1 M)
Land Unit (1 : 50000 – 1 : 250000)	Resource Management Domain (1 : 25000 – 1 : 250000)	Major Land Resources Unit (1 : 50000 – 1: 250000)
Land Unit (1 : 1000 – 1: 50000)	Farm Recommendation Domain (1 : 1000 – 1: 25000)	Land Resources Subunit (1 : 10000 - 1 : 50000)

Figures in parentheses are the appropriate scales for mapping.

may frequently lead to different results with substantial risk involved and are, therefore, a big gamble. Possibly the ordered weighted average technique that offers a complete spectrum of decision strategies along the primary dimensions of degree of trade-off involved and degree of risk in the solution, is more appropriate for resource management decisions. However, caution is needed in accepting the results from GIS operations as the final decisions.

The most important need of the time is effective integration of the socio-economic information with the biophysical data set. While integration of information on natural resource base has progressed satisfactorily, its linkage with the socio-economic data set is inadequate and needs to be strengthened. Any recommendation on land use needs to be based not only the physical potentials of the land, but also on a sound analysis of the social fabric, the opportunities and aspirations of the people, the economic and infrastructural facilities available, and the way these can be integrated with the available natural resource base. Without such analytical studies the recommendations run the risk of being a failure. As Burrough (1996) has rightly commented, "In order to achieve better unification we need to look more at the interactions between how the various tools for land evaluation can be used in different circumstances, and how physical, economic and social factors must be combined.

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Status and Achievements of Integrated Natural Resources Appraisal by CAZRI

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Introduction

Developing countries are primarily dependent on the rational utilization of natural resources for their immediate advancement and better production. To formulate plan for development, decision has to be taken as to which resources can be efficiently and easily developed and can contribute to the national needs in short and long terms. To make these decisions wisely and to set priorities, we should have thorough knowledge of our resources, their characteristics, distribution, magnitude, limitations, present status of utilization and scope for future development. This calls for integrated resource survey where the information about different resources is brought together and considered collectively for policy making. A multi-disciplinary team of scientists examines the whole complex of land. The primary function of integrated natural survey team is to collect information on biophysical resources for their optimal utilization. This helps to formulate land use planning. The major aims are following:

- Conduct integrated natural resources survey in relation to landforms, soil, vegetation, surface and ground water and present land use
- Identify problems, bring out potential and limitations of natural resources
- Suggest measures for their rational utilization

Integrated survey provides a more facile appreciation of the region as a whole for planning and development. Technologies and ameliorative measures are suggested to make these areas more productive and less vulnerable to desertification. Suitable sites/areas are earmarked for development of land and water resources. Thus, integrated surveys not only provide an insight to the complex inter-relationship of the environment but also provide a basis for land evaluation that is to determine the usefulness of the natural environment for human use and project consequences of human activities.

Historical Approach

Integrated survey of natural resources of arid zone was initiated in the year 1960-61, soon after the Division of Basic Resources Studies came into being at Central Arid Zone Research Institute. Plant ecologist, geomorphologist and social scientist were first key person to carry out survey work. The Division comprised of 8 sections viz Geomorphology, Plant Ecology, Soil Science, Analytical Chemistry, Plant Physiology, Hydrology, Geology and Cartography. On the recommendations of First Audit Achievement Committee, the Division was renamed as Division of Basic Resources Survey in 1967 and the section of climatology and analytical chemistry were separated from the Division, which stressed that this division should be concerned with integrated surveys. The survey team consisted of Soil Scientist, Hydrologist, Plant Ecologist, Geologist, Geomorphologist and Cartographer.

The Second Audit Achievement Committee (1972) recommended that problems of the region must be specifically and clearly identified and recommendations for rational use of resources be given. Accordingly the concept and methodology of Major Land Resources Units (MLRU) came to existence to address the above issues and to provide an integrated mechanism for development planning. Soils, landforms, surface and ground water, vegetation and land use were main components of integrated survey. After 1990, land degradation survey was also added.

Aerial photographs were used to identify, characterize and delineate the spatial distribution of natural resources and from the year 1972 satellite imageries have been adopted. The remote sensing technology enhanced the capability for identification of resources more quickly and in updated form. The adoption of GIS has given further impetus to integrated natural resources mapping.

Status of Appraisal

The integrated survey of Central Luni Basin was taken up on reconnaissance level using topographical maps (scale 1:253,440 and 1:126,720) and aerial photographs. The study resulted in significant findings on vegetation, soil, hydrogeology and dynamics of landforms. Encouraged with the results the survey of nine Development Blocks viz. Saila, Ahor and Jalor in Jalor district; Siwana ,Balotra and Chohtan in Barmer district; Sumerpur, Pali and Rohat in Pali district and Luni Development Block in Jodhpur district on semi-detailed basis using topographical maps on scale 1:63,360. Success in integrated survey attracted not only the Rajasthan Government but other states also. Consequently the integrated survey of Challakere taluk, Chitradurg district in Karnataka State (Anonymous, 1970) and Santhalpur Pargana in Banaskantha district of Gujarat States were taken up on the request of respective State Governments. Slowly the district, watershed and tehsil level surveys were taken up with toposheets on 1:50,000 scale and aerial photographs. Detailed survey on cadastral scale was also started simultaneously, initially for Range Management and Soil Conservation areas of CAZRI and the village level survey for Operational Research Project (ORP) areas and other development works.

Till date 2,98,829 km^2 gross area and 2,64,769 km^2 net area of arid zone of India has been surveyed, valuable database generated and resources maps prepared. This includes 43,919 km^2 area under reconnaissance level, 2,19,478 km^2 area under semi-detailed scale and 1,381 km^2 area under detailed scale (Fig.6). Details of state wise survey are presented in Table 10. In Rajasthan 53.93 % of total area and 88.42 % of total arid area has been surveyed and mapped. Similarly 31.17 % of the total area of Gujarat and 98.25 % of its arid area has been surveyed. In Haryana, Punjab and Karnataka states 27.38 %, 8.12 % and 24.12 % of their respective arid areas have been completed.

Table 10. Status of integrated resources appraisal

S.No.	State	Area (mha)	% of the total area of the state	% to total arid area of the state
1	Rajasthan	18.46	53.93	88.42
2	Gujarat	6.11	31.17	98.25
3	Haryana	0.35	7.95	27.38
4	Punjab	0.12	2.34	8.12
5	Karnataka	0.21	1.08	24.12

Reconnaissance Survey

As mentioned earlier, CAZRI had taken up integrated survey in Central Luni Basin on reconnaissance scale in 1960. This was followed in Challakere taluk of Chitradurg district in Karnataka State during 1968-1969, Bikaner district during 1972-1974 (Anonymous, 1974) and Mahendragarh district, Haryana during 1981-1982 (Shankarnarayan, 1985). So far an area of 43,919 km^2 has been completed and details are given in Table 11.

Table 11. Status of reconnaissance survey

S.No.	District/tehsil	Area (mha)	Duration
1	Central Luni basin (Rajasthan)	1.10	1960-1964
2	Challakere taluk Chitradurg district (Karnataka)	0.21	1968-1969
3	Bikaner district (Rajasthan)	2.73	1972-1974
4	Mahendragarh district (Haryana)	0.35	1981-1982

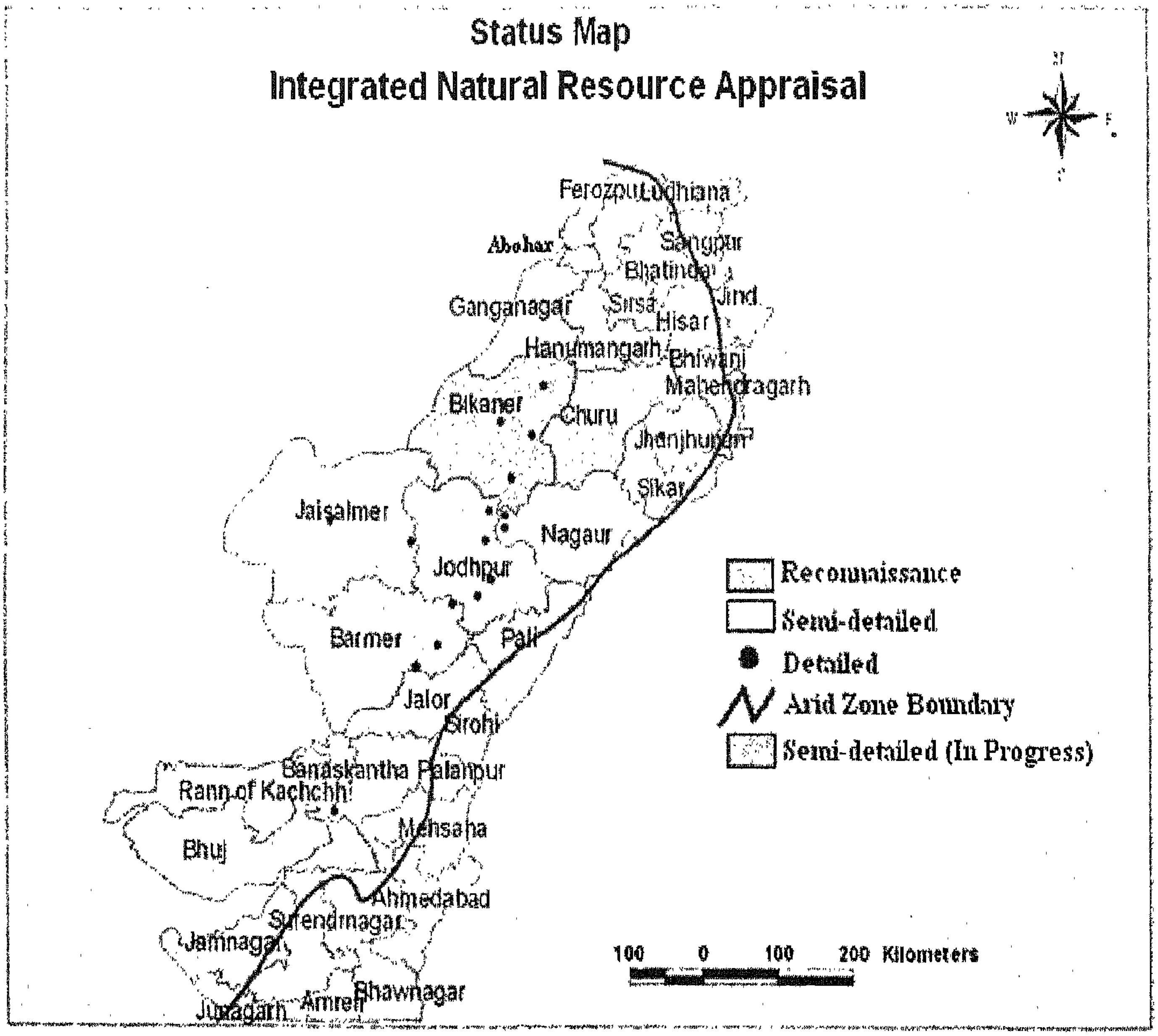

Fig. 6

Semi-detailed Survey

Survey and mapping of natural resources on semi-detailed scale (1:50,000) was found quite useful in delineating problematic and potential areas for taking up developmental activities at district level. Therefore to make planning survey oriented, the semi-detailed survey was simultaneously taken up in nine development blocks of Jalor, Pali, Barmer and Jodhpur districts during 1964-1966. This was followed in Santhalpur taluk of Banaskantha district in Gujarat state. The integrated survey by this time became so much popular that Second Audit Achievement Committee recommended that integrated survey of remaining part of arid zone of Rajasthan be completed within 10 years. Therefore it was felt to take up survey at district level starting with Jodhpur (1982) and later on in Nagaur district (Chatterjee and Kar, 1989). Meanwhile Govt. of Rajasthan requested CAZRI for integrated natural and human resources appraisal of Upper Luni Basin for development planning. The project was started in 1979 with the survey of Guhiya, Jojri, Bandi and Upper Luni catchments covering an area of 13,440 km^2 and completed in the year 1982. A detailed report on the status of resources, recommendations for development of land, water and vegetation resources of the four catchments and maps with earmarked sites for various development activities were submitted to the donor agency (Shankarnarayan and Kar, 1983).

The integrated survey of Barmer (Chatterjee and Joshi, 1989) and Jaisalmer (Chatterjee and Kar, 1992) districts were taken simultaneously from 1982. Thereafter, integrated survey of Kachchh district, Gujarat (Singh and Kar, 1996) and Jalor in Rajasthan (Singh et.al, 1995) were taken up together in 1986 and accomplished the task in 1990. Landsat FCC on 1:250,000 scale were used for survey and mapping work. This was followed by Jamnagar district in Gujarat (Joshi, 1999) and Sikar district in Rajasthan (Singh et.al, 1996). In the meantime President ICAR instructed CAZRI to prepare integrated natural resources appraisal report of Abohar tehsil of Ferozpur district in Punjab (Anonymous, 1992). This task was completed during 1991-1992. On the recommendation of Scientific Research Council of the Institute, the integrated survey of Hanumangarh (Khan and Balak Ram, 2003) and Ganganagar districts was taken up in 1996 and completed in 2001. IRS LISS-III data was used to identify and map various resources and spatial database has been created under GIS environment for these two districts.

Altogether an area of 2,19,478 km^2 has been surveyed on semi-detailed scale. This includes 1,57,207 km^2 area of Rajasthan, 61,093 km^2 area of Gujarat and 1178 km^2 area of Punjab states (Table 12). Integrated survey of Churu district (13,859 km^2) is in progress.

Detailed Survey

Anonymous Detailed characterization of biophysical resources is essential for micro level planning. Detailed survey of research farms, villages and watersheds covering total area of 1381.07 km^2 has been completed (Table 13). This includes survey of 14 Range Management and Soil Conservation areas and Central Research Farms of CAZRI. Village level detailed integrated survey of natural resources was taken up first in Kitnod, Nokha, Roda and Mahajan villages of Bikaner district (1965-1966) and Parasrampura village of Jhunjhunun and Rozu village of Banaskantha district (1967-1968). This was followed in five villages for Operational Research Project (ORP) around Daijar village and five villages for dryland agriculture project in Jodhpur district. Detailed survey was then taken up for ORP area in Doli and Jhanwar villages as also Jhanwar watershed (1985-1988). On the request of DRDA, Jodhpur, the detailed survey of Kailana watershed (Anonymous, 1991) was taken up for wasteland development programme in the year 1990-1991. Thereafter six villages of Bikaner district were surveyed for International Fund for Agricultural Development (IFAD) during 1989. A number of developmental activities were taken up on the basis of recommendations given in detailed survey reports. Again during 1994-1995 detailed survey of 11 villages, two each in Bikaner, Nagaur, Barmer, Jodhpur, Jaisalmer and one in Pali district under DDP/TOT project was carried out. Private agencies also recognized integrated

Table 12. Semi-detailed survey

S.No.	District/tehsil/catchment	Area (km^2)	Duration
Rajasthan State: Gross 1,76,860 km^2 , Net 1,57,207 km^2			
Development blocks			
1	Saila Development Block (Jalor)	1,455	1964-1966
2	Ahor Development Block (Jalor)	1,590	1964-1966
3	Jalor Development Block (Jalor)	943	1964-1966
4	Siwana Development Block (Barmer)	2,045	1964-1966
5	Balotra Development Block (Barmer)	2,459	1964-1966
6	Sumerpur Development Block (Pali)	1,797	1964-1966
7	Chohtan Development Block (Barmer)	2,161	1965-1966
8	Pali and Rohat Development Block (Pali)	2,994	1965-1966
9	Luni Development Block (Jodhpur)	2,000	1965-1966
Districts			
10	Jodhpur	22,515	1972-1975
11	Nagaur	17,667	1973-1976
12	Upper Luni Basin	13,440	1979-1982
13	Barmer	28,387	1982-1985
14	Jaisalmer	38,401	1982-1985
15	Jalor	10,640	1986-1990
16	Sikar	7,732	1991-1993
17	Hanumangarh	9,703	1996-2001
18	Ganganagar	10,931	1996-2001
Gujarat State: 61.093 km^2			
Taluk			
1	Santhalpur taluk (Banaskantha district)	1,356	1966
District			
2	Kachchh district	45,612	1986-1990
3	Jamnagar district	14,125	1991-1993
Punjab State: 1,178 km^2			
Tehsil			
1	Abohar (Ferozepur district)	1,178	1991-1992

survey approach. On the request of M/s Matang Irrigation Systems, detailed survey of Tulesar Charnan - Bawarli area (Khan et.al, 1997) completed during 1997. Now the use of PAN merged LISS-III data has greatly facilitated the micro level mapping of natural resources.

Special Surveys

A number of special surveys as per the objectives of the donor agency/ department have been carried out (Table 14). On the request of Town Planning Department, Govt. of Rajasthan, the land use survey and mapping of Churu (Sen et.al, 1980), Ganganagar (Sen and Gupta, 1980) and Jaisalmer (Sen and Gheesa Lal, 1980) districts was carried out during 1977-1980. A collaborative study with RRSSC, Department of Space, Jodhpur was carried out to evaluate feasibility of digital image analysis for integrated natural resources appraisal. Under Integrated Mission for Sustainable Development (IMSD) Project of Department of Space, Integrated survey of Pokaran tehsil, Jaisalmer district (Singh and Kar, 1997) and Bhinmal and Raniwara tehsils, Jalor district (Joshi and Singh, 1998) covering 12,997.4 km^2 (1995-1997) was completed. Similarly on the request of Govt. of Rajasthan, Integrated Natural Resources

Table 13. Detailed survey

Village/watershed	District	Area (km^2)	Duration
Research farms and 14 RM&SC areas	Barmer, Jaisalmer, Jodhpur, Pali, Nagaur, Sikar	25.97	1961-1964
Villages	Barmer	10.00	1965-1966
Kitnod	Bikaner	40.00	1965-1966
Nokha and Roda	Bikaner	10.00	1965-1966
Mahajan	Jhunjhunun	43.41	1967-1968
Parasrampura	Banaskantha	0.80	1967-1968
Rozu			
ORP area Daizar	Jodhpur	79.0	1974 -1975
Dryland agriculture Villages viz. Baori, Anwana, Danwara, Kelawa Kalan, Kelawa Khurd	Jodhpur	219.12	1971 -1974
Jhanwar watershed	Jodhpur	34.90	1985-1986
ORP area Doli and Jhanwar villages	Jodhpur	23.40	1987-1988
Wasteland development Kailana watershed	Jodhpur	54.26	1990-1991
IFAD Villages viz. Bambloo, Gusainsar, Panpalsar, Tejrasar, Naurangdesar, Pemasar	Bikaner	286.50	1989
DDP/TOT Project Villages			1994 -1995
Karnu,	Nagaur	41.29	
Pabusar,	Nagaur	63.95	
Champasar,	Jodhpur	49.31	
Pandit ji ki dhani,	Jodhpur	39.67	
Lakhusar,	Bikaner	61.96	
Barju,	Bikaner	45.13	
Lawan,	Jaisalmer	64.83	
Bharamsar,	Jaisalmer	89.05	
Korna,	Barmer	35.19	
Juna Mitha khera,	Barmer	20.39	
Rupawas,	Pali	33.75	
Consultancy Tulesar Charnan-Bawarli area	Jodhpur	9.19	1997

Table 14. Special surveys

S.No.	District/tehsil	Area (km²)	Duration
1	***Land Use Survey of Canal command area for town Planning Deptt., Govt. of Rajasthan:*** Churu Ganganagar Jaisalmer	79,581	1977-1980
2	***Feasibility of digital image analysis in integrated natural resources*** Pipar-Kaparda area	1,056	1988
3	***Integrated Mission for Sustainable Development (IMSD):*** Pokhran tehsil (Jaisalmer) Raniwara and Bhinmal tehsils (Jalor)	12,997.4 9,606.9 3,390.5	1995-1997
4	***Impact of Industrial Effluents along the Jojri, the Bandi and the Luni rivers***	345	1996
5	***Wasteland Mapping:*** Phase II: Jodhpur district Pali district Ajmer district Churu district Tonk district Phase III: Sikar district Phase V: Hanumangarh district Bikaner district Barmer district	1,40,808 22,850 12,387 8,481 16,830 7,194 7,732 9,703 27,244 28,387	1986-1988 1991-1992 1989-1999
6	**Land Use/land cover Mapping :** Barmer, Bikaner, Churu, Jaisalmer, Jodhpur, Nagaur, Sikar, Jhunjhunun and Jalor districts of Rajasthan	1,75,730	1989-1990
7	***Pilot Study on Sub Classification of Sandy areas :*** Osian tehsil, Jodhpur district	4399.56	2002

Appraisal study was carried out to assess the impact of effluents discharged by textile dyeing and printing industries of Jodhpur, Pali and Balotra towns along the Jojri, the Bandi and the Luni rivers (Singh and Balak Ram, 1997). Detailed study of biophysical resources of Salodi Watershed (Jodhpur district) and Kukma watershed (Kachchh district) has been completed under NATP Project on Land Use Planning.

Achievements

Integrated natural resources appraisal has been carried out over the past 40 years by the CAZRI. During this process improvements have evolved in methodology of survey, classification system, mapping and reproduction techniques and putting new attributes as per needs. Besides, remote sensing technology and developments in infrastructure facilities have provided qualitative improvements in output in terms of Major Land Resources Units.

Evolution, classification and analysis of landforms of hot arid zone of India has been accomplished and fourteen major landforms identified in arid Rajasthan, 13 in arid Gujarat and five in southern arid region. Extent of erosion, deposition and salinity hazards has been mapped. Saraswati-Drishadvati river system and other paleo-channels of arid zone have been identified and their courses mapped. Their control on ground water availability has been established and sites for exploration of ground water have been located. Origin and characteristics of ranns and sand dunes has been established. Eight major types of sand dunes with subclasses (Singh, 1977) have been identified and mapped and their morphological characteristics viz. age, type, grain size and slope aspects described. The intensity of sand movement has been quantified for desertification process.

The extensive soil surveys brought out variability in color, texture, calcareousness, salinity and nature of sub-strata in major soils of arid region. In western Rajasthan 85 soil series have been identified out of which 15 series have been recognized at national level. The morphological and chemical characteristics of these soils and their distribution have been documented. Similarly 39 soil series are identified in Kachchh district and six in Mahendragarh district. The nature and distribution of salt affected and sodic soils has been investigated. Morphogenetic peculiarities of arid soils have been characterized. Specific studies were undertaken on fine sand mineralogy, clay mineralogy and amorphous alumino-silicate. The ameliorative measures suggested for saline and sodic soils have helped thousands of farmers of Rajasthan. Fertility and micronutrient status of arid zone soils has also been established.

The plant communities under different habitat along with their density, phenology, growth analysis, root studies and ecological adoption parameters have been identified, characterized, grouped and mapped. Unconventional food plants during droughts, economic and medicinal plants as well as endangered species have been identified and documented. A very good herbarium has been developed through vegetation survey. It has also been possible to identify drought escaping plants, drought enduring shrubs, succulents and phreatophytes. Arid zone plants are also identified and grouped for edible and non-edible oil industries; gum and resin; fibre, sirki, mats and basket industries; dyes and tannin; fodder & top feed, soil binders and wind breaker. Studies have been carried out for identification and estimation of fodder production, biodiversity, biomass production, carrying capacity of 'Oran' and gochar lands and important tree and shrub species through remote sensing technologies.

In the field of hydrogeology, valuable information has been generated on the quality, depth to water, static water level, aquifer characteristics and status of ground water development. Resistivity survey was also done at different depths during Upper Luni Basin survey. Techniques are developed for ground water exploration, monitoring of ground water quality and assessment of potential zones. Safe yield and overdrafted zones have been identified. Prevention and control measure for sea water intrusion have been suggested. Measures for artificial recharge of ground water are laid down. Seismic study of certain areas was done to locate ground water potential points. Joint pattern system in granite rocks has been studied. Correlation of rock formation from Late Precambrian to Quaternary period has been done and six major basin in western Rajasthan have been identified and mapped.

Significant achievements have been made through characterization, quantification and assessment of potentialities of surface water resources in arid region. The status of surface water resources of 550 storage tanks of Luni Basin has been worked out. Annual runoff from the Luni and its tributaries has been estimated. Sites for hydrological structures have been suggested. Distribution of *nadis'* and their storage capacity in arid district of Rajasthan has been documented. The concept of Index catchment has been developed and index catchments have been delineated. Technologies for reclamation of waterlogged areas in IGNP command area are recommended. Significant technologies have been evolved for rainwater management through *'nadis'* roof water harvesting and water harvesting through constructed catchments, treated catchments and reducing exploration loss through artificial shading. Other water conservation measures viz. half moon terrace, vegetative barriers, sub surface barriers and runoff farming through micro- catchments, ridge furrow system and inter row water harvesting (IRWH) system designed and demonstrated. *'Tanka'* of different capacity have been designed and demonstrated in various parts of arid Rajasthan. Hydrological models were developed for estimation of run off, sediment transport and sustainable management of surface water resources.

In the field of Basic Resources Cartography and Present Land Use Survey, significant achievements include assessment of different land use systems and their dynamics in arid agro-ecosystems through application of remote sensing, GIS and automated cartography, development of land use classification system for hot arid zone (Sen, 1978), development of cartographic techniques for composite mapping or MLRU. With long experience and use of modern tools and technologies, land use mapping up to level-IV have been achieved as per the needs. Thus the agricultural lands and wastelands have been sub classified up to level-IV. Through present land use classification, the problem and potential areas and use and misuse of lands have been identified.

Mapping of degree and extent and of sands, expansion and contraction of 'Thar Desert', construction of three dimensional block diagrams, studies of Desert National Park and pictorial representation of desertification process are other notable works. Atlases have been prepared on important aspects viz. Agricultural Atlas of Rajasthan, Ground Water Atlas of Rajasthan, Agro-demographic Atlas of Rajasthan, Resource Atlas of Luni Basin and Sheeps in Rajasthan. Agro-ecological sub-zones of North-Western Arid Zone of India (Faroda et.al, 1999) and wind erosion map of Western Rajasthan (Pratap Narain et.al, 2000) are some of the recent achievements.

In the field of Agro-meteorology significant achievements have been made through delineation of extent of arid and semi-arid regions of India, documentation of historical weather data and monitoring of long-term climatic changes. Studies have been made on climatic water balance for moisture and aridity index, rainfall variability, probable maximum precipitation; return periods, dry and wet spells and their probabilities at tehsil level to work out agro-climatic potentials. Work has been done on drought and its impact on crop/forage productivity, evapo-transpiration and energy-use efficiency of crops, development and validation of soil-moisture/canopy physical/crop-weather models for drought, heat and water vapour fluxes and yield assessment. Agro-meteorological advisory services to the farming community have been taken up as a regular activity.

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Utilisation of Integrated Natural Resources Appraisal Data in Arid Region

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Introduction

The success of any resource appraisal effort lies in utilisation of the information generated through field and laboratory studies. The products of resource appraisal efforts are a report and a map. The Natural Resources and Environment Division of CAZRI has been carrying out resources appraisal of different areas of arid region for last 50 years and has developed a unique system of composite mapping called Major Land Resources Unit (MLRU). The Integrated natural resources appraisal for a district/block is carried out with respect to landform, soils, vegetation, surface and ground water resources, present land use and land degradation status and the information so generated are integrated to form a composite mapping unit called MLRU. The information related to socio-economics and livestock are super imposed on the MLRU. Thus, any specific MLRU is similar with respect to the land attributes and has unique potentials and constraints. The integrated resource appraisal report prepared for a particular district includes report on the status of natural resources, maps of all discipline and the MLRU map at 1:250,000 scales and recommendations for sustainable development. These data can be used for district level planning. In addition, the integrated resource appraisal has also been carried out at 1:50,000 & 1:10,000 scales for specific objectives, which provide more information for implementation purposes, like watershed development etc. The CAZRI has under taken different types of survey projects including integrated natural and human resources appraisal for development blocks/watershed/districts, and specific surveys requested by the sponsoring agencies.

Integrated natural and human Resources Appraisal

The Integrated natural and human resource appraisal report has following sections:

(A) Discipline-wise report and map (1: 250,000)

- Climate: Synoptic features, agrometeorology
- Landforms: Types, extent
- Soils: Soil series, land capability classification
- Vegetation: Types and extent of trees, shrubs and grasses
- Ground water: Depth and quality
- Surface water: Water bodies, runoff, drainage net work
- Present land use: Agricultural lands, wastelands, misc. land uses, land use changes
- Land degradation: Kind and degree of degradation
- Human resources: Demographic attributes, occupation, etc.
- Agro-economic status: Land holding, crop production, agro-economics
- Livestock resources

(B) Integrated Analysis of Resources and Map (1: 250,000)

- MLRUs: Characteristics, assessment and recommendations
- Sites recommended for surface water development, ground water recharge, regeneration of pastures and common property resources
- General recommendations for management of rain fed and irrigated agriculture.

(C) List of villages indicating MLRU

Specific surveys

Besides regular survey, the Institute was also requested to conduct specific surveys by the sponsoring agencies like Department of Space/ National Remote Sensing Agency, State Governments and Non-Government Organisations. Data collected during these different kinds of surveys have formed a part of database.

Utilisation of Resources Appraisal Data

The data available through these surveys have been used for Natural resource conservation and development, characterisation of Desertification processes, Ago-ecological classification and mapping of desertification and wind erosion. The information available with the CAZRI in the form of maps and reports have formed basis for developing policy by the Government of Rajasthan, for land allotment in arid region for agricultural purposes. The survey data have also helped to under take relief work during catastrophic events like flash floods in the river Luni (1979) and earth quack in Bhuj area (2001) of Gujarat. The reports and maps generated over the years have been used for different purposes which are described below.

Natural Resources Development

Land resources conservation and development in Upper Luni Basin (1979-81): Based on Integrated Analysis of Natural and Human resources report of upper Luni Basin (Shankarnarayan. and Kar, 1983) the Government of Rajasthan has taken up development of Guhiya catchment at the first instance. Various departments of the State Govt. have prepared development projects in consultation with CAZRI, which are being implemented. Realising the importance of the unique approach for development of land resources the ICAR team award was bestowed to all participating scientists.

Development of Abohar tehsil : The CAZRI was asked to suggest plan for development of the tehsil. The multidisciplinary team prepared a blue print of development for the area based on the MLRU and suggested recommendations for specific sites and cost were worked out (Anonymous, 1992). The recommendations were implemented by the Government of Punjab.

Jhanwar watershed development: The Jhanwar watershed was developed by the CAZRI in collaboration with the Rajasthan State Government soil conservation Department. The work was under taken under a National program of Dryland Farming on watershed basis and funds were made available by the State Government. The technologies for soil and water conservation measures were applied as per the integrated resources report. The Jhanwar watershed program was reviewed by the UNEP and was awarded "SAVING THE DRYLAND" appreciation certificate for contribution in combating desertification.

Integrated wasteland development at Kailana: The Micro-plan for Integrated waste land Development in 5000 ha near Kailana was prepared on the request of DRDA, Jodhpur (Anonymous, 1991). Amongst different wastelands, the rocky/ plateau/sheet rock area with shallow soil, and foothill zone with moderate slope and shallow soils constituted respectively 42.3 and 25.2% of total area. Both units have been recommended for regeneration of natural vegetation and ecological management. Valley fill region with deep soil and sandy hummocky units together constituted 19% of total area and recommended for agro-forestry and agro-horticulture. Cost of development was worked out to be Rs. 9757/- ha^{-1}. On the basis of this report the National Wasteland Development Board to the DRDA, Jodhpur sanctioned a sum of Rs. 3.20 crore for development of wastelands. Different departments of the Government of Rajasthan under DRDA, Jodhpur, executed the development work as proposed in the report. Two scientists associated in the project were honoured by the Collector, Jodhpur on 26th January 1992.

Selection of sites for watershed development: Integrated resources appraisal reports of Barmer (Chatterjee and Joshi, 1989), Jaisalmer (Chatterjee and Kar, 1989a), Jodhpur (Anonymous, 1982), Nagaur (Chatterjee and Kar, 1989b), Jalor (Singh et. al., 1995) and Sikar (Singh et. al., 1996) districts and IMSD report of Pokaran (Dist. Jaisalmer) (Singh & Kar, 1997) and Bhinmal and Raniwara tehsils (Dist. Jalor) (Joshi & Singh, 1998) have been used for selection of sites for watershed development.

Selection of sites for Index catchment: The concept of 'Index Catchment' as a geohydrological unit has been developed for the areas that are lacking integrated drainage system. The environmental problems associated with the Index catchment are almost similar those of watershed. Over 100 Index catchments were selected for integrated development in Jodhpur, Nagaur, Bikaner, Churu, Barmer and Jaisalmer districts where the development activities are being executed by the DRDA in 8th Five year plan period. Realising the practical significance of this concept the states of Rajasthan, Gujarat and Haryana have adopted it for integrated land use development.

Selection of sites for rainwater harvesting structures: About 11, 469 different capacity improved tankas with total storage capacity of 4, 75 and 200 cum were constructed in western Rajasthan to meet the drinking and cooking water requirement for a population of 1,32,000 through the year.

Wasteland Map for selection of sites for forest development: Wasteland reports and maps of Jodhpur, Pali, Churu, Ajmer, Tonk and Sikar districts are being adopted by the forest department, Government of Rajasthan

Town and country planning in IGNP command area: On the request of Rajasthan Government for planning land use during developing phase of the IGNP command the survey was carried at 1:50,000 scale in Ganganagar (Sen and Gupta, 1980), Jaisalmer (Sen and Gheesa Lal, 1980) and Churu (Sen et al. 1980) districts covering 76,37,000 ha area. The proposed land use was accepted for development and maps utilised for country planning.

Assessment of Damage of Natural Resources Due to Natural Hazards

Development of Luni Flood affected area (1979): In July 1979 there was an unusual flood in the river Luni, causing extensive damage of about Rs.100 crore. These included severe erosion and deposition of agricultural land and loss of infrastructure, along the Mithri-Jojari, Guhiya and the Luni proper. An assessment of the flood affected agricultural land in the form of sand casting, scouring etc. was carried out. Nature and magnitude of damage at randomly selected sites was quantified and translated in terms of efforts needed in land levelling, scraping and soil amelioration. The mean cost worked out was Rs. 3350 per ha. The information served basis for extending relief by Central / State Govt.

Water balance study in Luni Basin: In Luni basin, 250 raingauges, 30 stream and sediment gauging stations, 140 wells for GW recharge and 5 tanks for sedimentation study were selected over 33,000,00 ha to study the water balance study. The study was carried out for four years and very good information on peak discharge, total volume of flood storm and sediment transport were generated. The information were supplied to Central Water Commission, Flood commission, Railways, PWD and Irrigation Department which helped in planning relief measures to the flood victims and future planning of water management in the basin.

Impact assessment of Earthquake on natural resources in Kachchh region: Integrated resources appraisal was carried out to assess the loss/ damage of natural resources by earthquake of 26th January, 2001 and information was submitted to the concerned authorities in ICAR/State Government (Pratap Narain et al, 2002).

Input for Policy Formulation

Relaxation in Government policy for land Allotment for Agricultural purposes in DDP districts: In the year 1976, on recommendation of CAZRI, the Govt. of Rajasthan banned land allotment for agricultural purpose in eight DDP districts. Now after more than 20 years the State Government wanted to review the land allotment policy and for this purpose the view of CAZRI was sought. The CAZRI felt that in DDP district rainfall is low and erratic, vast area is under sand dunes and sandy plains, which upon cultivation is prone to wind erosion. Remaining area mainly consist of shallow, saline, calcareous and hard pan and gypsiferous soils. The region has very high pressure of human and animal population. Marginal lands when put to agriculture will accelerated wind / water erosion, salinization and water logging. In western Rajasthan already desertification in different proportion is operative by wind erosion (68.3%), water erosion (11.1%), and water logging and salinization (3.1%). In fact, there is a need for integrated development of these lands by adopting silvipasture.

The CAZRI suggested that however, with the changed scenario and increasing demand, those lands, which are, arable according to the land capability classification can only be allotted for agricultural purposes. However before taking final decision the requirement of area for development of village institutions and strategic considerations should also receive attention. The view point of CAZRI was deliberated at different levels including at Divisional commissioner, Revenue Secretary and Cabinet sub committee before final decision at Cabinet level. CAZRI was invited to participate at every level. The State Government directed the District Collectors of DDP districts to carry out land allotment in consultation with CAZRI. Several meetings were organized at CAZRI with the concerned officers of the respective districts. Land capability maps at 1: 2,50,000 scale, Integrated natural and human resource appraisal report and list of villages along with the land capability class were made available to them which were adopted for land allotment.

Assessment of land degradation status of India: Ministry of Agriculture, Government of India (1993) under the Chairmanship of Joint Secretary (SWC) & LRC, constituted a committee for assessment of present status of land degradation in the country. CAZRI was one of the members of this committee. Data on land degradation status of western Rajasthan were accepted and incorporated in final document (Table 15).

Table 15: Status of land degradation in Rajasthan (Total area 342.04 lakh ha)

Type of degradation	Present assessment (Area in lakh ha)	% of geographical area
Soil erosion due to water	59.03	17.3
Soil erosion due to wind	98.11	28.7
Ravines	2.9	0.8
Saline/sodic	11.83	3.5
Water logged/Marshy	1.46	0.4
Degraded forest	16.68	4.8
Total	190.01	55.5

Status of eco-degradation in Aravalli hills: The planning commission Government of India had constituted an expert Group on delineation of Hill areas in the country and CAZRI provided input concerning the extent of the hill area of Aravalli, major land uses, causes and extent of eco-degradation.

Spread of desert: There was hue and cry that desert is marching in the north-eastern direction. The study of multidisciplinary team of the Division concluded that Desert is not marching in any directions, however there was slight contraction/ spread at the desert fringe depending on the variation in rainfall. This study was accepted. There was an opinion that desert was marching through nine gaps in the Aravalli and it was proposed to construct a wall to arrest spread of desert. A high level committee was set up to consider this proposal but finally the view of CAZRI was accepted and idea of wall construction was dropped.

Causes of desertification in Pushkar valley and adjoining area: The human induced degradation had deteriorated biological productivity of fluvial and aeolian ecosystem in Pushkar valley. This has adversely affected the amount and quality of water in Pushkar and Budha Pushkar lakes. The CAZRI was invited by the Rajasthan State Govt. to investigate the causes and suggest measures to restore the ecology. The study revealed that rate of siltation varied from 66 to 5905 m^2 per year. The effluent discharged from the hotels, private guest houses through the nallah are polluting these lakes. Out of 462 km^2 45% and 28% area have been desertified by water erosion and wind erosion/deposition hazards respectively. Only 9%

area did not show any sigh of degradation. The report was adopted and suggested measures were carried out.

Assessment of Impact of Industrial effluents on natural resources in Jodhpur- Pali-Balotra area : In Jodhpur, Pali and Balotra towns, the industrial effluent discharged from a large dyeing and printing factories in the Jojri, the Bandi and the Luni rivers have deteriorated the ground water along the rivers and degraded the agricultural lands. The waste water emanating from these units has a high TDS (19000-21000 mg L^{-1}). Ground water along the rivers has become polluted due to mixing with the industrial effluent (EC 2.53-21.5 d Sm^{-1}). The area irrigated with the water has been severely affected. Nature and extent of the problems was characterized after conducting survey which was sponsored by the Rajasthan Government (Singh and Balak Ram 1997). The survey report is being consulted by the Rajasthan High court to decide law suite.

Resource Characterisation

Desertification and wind erosion mapping in western Rajasthan: Field information collected during the course of integrated survey of different districts and remote sensing appearances of the terrain and biota were used to map desertification status in western Rajasthan on 1 million scale. Dominant land use in different rainfall zones and associated processes of desertification and their severity were mapped (Singh et. al., 1992). Desertification processes identified were: wind erosion/deposition, water erosion, salinity/ alkalinity, waterlogging and vegetation degradation in the rangelands. The severity of each of the processes was categorized into: no apparent hazard, slight, moderate, severe and very severe. A sixth category, "naturally desertified", indicated desertification due to natural factors alone. Together, the information produced a "Desertification status" map indicating. 68.4% area affected by wind erosion/deposition, followed by water erosion (11.0%), salinity/alkalinity (2.4%) and water logging (0.7%0). Desertification of severe intensity has affected approximately 21% area of western Rajasthan, while that of moderate and slight intensities have affected 40 and 32% area, respectively. Wind erosion/deposition is the most dominant hazard (Pratap Narayan, et al., 2000).

Desertification map of arid region of Gujarat: Similarly the desertification status map of Gujarat has also been prepared.

Delineation of Agro-Ecological Zones for North Western Hot Arid Region of India: The data available from different reports and maps of arid zone district have been correlated, compiled and synthesised for the entire arid region. The north-western hot arid region of India covering 31.7 m ha area spread in Rajasthan, Punjab, Haryana and Gujarat has been classified in four sub regions, eleven zones and thirty four sub zones (Faroda et al., 1999) according to following criteria.

- *Agro-ecological sub regions*: Based on physiography, rainfall and water resource including surface/ground water and canal irrigation the arid region has been classified in four sub-regions.
- *Agro-ecological zones*: Landform- soil association and land use have resulted in eleven zones.
- *Agro-ecological sub-zones*: Thirty four sub zones have been created through an integrated approach involving terrain characteristics; parent material; soil texture, depth and salinity; surface and ground water potential and cropping pattern. The sub-zones are homogeneous with respect to potentials/ constraints for rainfed/irrigated cropping and silvipasture and will require specific technology for sustainable development.

Identification of Soil Series:

Total 85 soil series have been identified most of which have been correlated by the NBSS&LUP (Sohan Lal et al., 1994, Shyampura et al., 2002). These soil series are widely adopted by various agencies carrying out soil mapping in the arid region.

Taxonomic classification of soils of arid Rajasthan:

Soils of entire arid Rajasthan have been classified according to Key to Soil Taxonomy (1992) in orders Aridisols and Entisols, which constitutes, respectively, 41.05 and 51.84% of total area; in sub orders Psamments (51.72%), Cambids (30.83%), Calcids (9.34%), Gypsids (0.43%), Salids (0.45%) and Fluvents (0.12%). These have been further classified in 30 soil mapping units at family level amongst which the unit Torripsamments-dune, Torripsamments-plain, Psammentic Haplocambids, sandy/coarse loamy Typic Haplocalcids/Typic Calcigypsids is the dominant unit which cover 39.98% of total area (Dhir et al., 1997).

***Soil resources mapping of arid Rajasthan**: A Collaborative project with NBSS&LUP* : The NBSS&LUP launched a nation wide project "Soil Resource Mapping" and accordingly for arid part of Rajasthan work of soil resource mapping was assigned to CAZRI. The data collected for different desert districts were used to prepare soil maps up to family level at the scale of 1:250,000 as per the legend. These maps were reduced to 1:500,000 scale and published by the Bureau along with a bulletin entitled "Soils of Rajasthan for optimizing land use" (Shyampura, and Sehgal, 1996)

Resource Management: Advisory

Establishment of Gujarat Institute of Desert Ecology: The Government of Gujarat for establishment of Gujarat Institute of Desert Ecology has adopted the integrated resources reports and maps of Kachchh district (Singh and Kar, 1996). These data have formed basis for undertaking development programme by the Gujarat Institute of Desert Ecology.

Selection of site for Desert National Park: Based on the report of CAZRI, the site for Desert national park was selected near Miyajalar in Jaisalmer and adjoining part of Barmer district.

Management of soils irrigated with sodic ground water: (1984-86) Detailed soil and ground water Status carried out in Villages Samadari to Balotra (Dist. Barmer) was used by the District official for free distribution of gypsum to 265 farmer having problematic soils and irrigation water identified in CAZRI report and quantity of gypsum given to each farmer was based on the recommendations (Joshi and Dhir, 1991, 1994).

Sand dune maps: Sand dune maps are being utilised by the defence personnel for alignment of roads and locating areas for better trafficability.

Wind erosion control for Gas Authority of India (GAIL) pipeline in west of Jaisalmer: At the request of GAIL, New Delhi a number of recommendations were made to stabilize the land scape after construction of a gas pipeline from Gamnowala Tar to Ramgarh in north west of Jaisalmer district. The recommendations included activities like backfilling of excavated earth, levelling and compacting of the surface, spreading of heavier particles and gravels on the loose sandy surfaces to protect from faster movement, less disturbance to the natural vegetation during construction activities, including scrapping of plants to the extent possible. The recommendations were carried out.

Sand control for AIR building near Lanela (Jaisalmer): The premises of All India Radio (AIR) at Lanela (District Jaisalmer), during summer as the result of severe wind erosion used to be covered by 1 to 3 m high sand deposition. At the request of AIR, Jodhpur the study revealed that the sand is being blown from 2-4 km patch of highly degraded grazing land located between Meetha rann and the AIR building. The suggestions included revegetation of grazing land, plantation of 3 shelter belts at the spacing of 100 m each across the wind direction and plantation of *Lasiurus sindicus, C. colocynthis, crotolaria burhia , P. turgidum* and *Cynodon* wild variety in a specified way. The recommendations were carried out and the building was protected from sand deposition.

Prospecting for ground water: Maps showing former courses of Vedic Saraswati, Drishdawati, Sutlej and other buried channels in the surveyed area have been used for prospecting for ground potential by the Ground water Department. A number of tube wells have been drill by the ONGC and State Govt. in the north-western part of Jaisalmer district around Asota, Longewala, Ghotaru where prior drainage channel was demarcated by the scientist of the Division.

Locating hard pan in IGNP area: The methodology developed for interpretation of resistivity data for locating the kankar pan was adopted by the Ground Water Department of the Government of Rajasthan for locating kankar pan in IGNP command area.

Landscaping of RAU campus, Bikaner: The Vice Chancellor of the University invited a multidisciplinary team of scientists to suggest landscaping for the new RAU campus at Bikaner. Team consisting of Plant ecologist, soil scientist and hydrologist carried out appraisal of the natural resources and developed detailed plan for development of the campus. A detailed plan including list of species of tree, shrubs and flowering plants suitable for the area and techniques for their establishment; to improve water holding capacity and reduce percolation losses; practices for amelioration of sodic soils by use of gypsum, organic manure and phosphatic fertilizers. Location and design of a large water reservoir to maintain water supply to establish and maintain the plantations were suggested (Saxena et al., 1994). The University authorities have adopted the recommendations.

Lab to land programme: The Division carried out detailed integrated resources survey of five villages viz. Daijar, Basani Lachha, Parari Natha and Manaklao. The transfer of technology was carried out based on the recommendations.

ORP area: In villages Doli and Jhanwar the transfer of technology was carried out as per recommendation of in the integrated report. The soil and water conservation measures were carried out in the Jhanwar watershed as per the survey reports.

DDP-TOT villages: Detailed Integrated resources appraisal was carried out in 11 villages in Jodhpur (Champasar, Panditji ki Dhani), Barmer (Korna, Juna Mitha kheda), Bikaner (Barju, Lakhusar), Nagaur (Karnu, Pabusar), Jaisalmer (Lawan, Bharamsar) and Pali (Rupabas) districts. As per the reports technological requirement was identified for each village and transferred by the scientists of the Institute.

Selection of site and Development of master plan for KVK at Barmer :The KVK at Barmer was sanctioned to a NGO, 'SURE' (Society for uplift of Rural Economy). The SURE invited CAZRI to help in the development of lay out of KVK farm, office building, quarters and other instructional units. A team of scientist deputed for the purpose, helped in selection of the site and developed master plan which was also accepted by the ICAR and adopted for development.

Alternate land use and management for Sardar Samand and Sadari farms (District Pali): The CAZRI was requested to suggest measures to improve the productivity of Sardar Samand and Sadari farms which had deteriorated and running in loss. Based on our survey of these farms at Sardar Samand farm in place of agriculture the agro-horticulture was taken up and at Sadari farm the improved management for citrus plantation was adopted.

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Utilization of Natural Resource Information Using GIS and DSS

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Introduction

Land and water are basic natural resources for agricultural development. The efforts in the recent past have focused on intensification of agriculture and enhancing crop yield while ignoring implications of intensive agricultural practices on the state of natural resources. Environmental concerns such as loss of biodiversity, land degradation, damaging water quality, and sustainability have arisen as second generation issues of intensive agriculture. Development of a region, calls for the protection of natural resource, and their sustainable management in harmony with environment and utilization without diminishing quality and potentiality for future use.

Until recently, vast data collected on natural resource, have remained in the form of records, technical monographs, survey reports and maps. Integrated natural resource survey of Rajasthan and Gujarat carried out by CAZRI Jodhpur, is not an exception. Wealth of data collected by hard labour over five decades, have been utilized in preparing resource, interpretative maps and survey reports. However, these have a potentiality to be arranged in relational data base management system (RDBMS) format that is utilizable by decision support system (DSS) for land use planning. Prior to the advent of GIS, one had to rely on simple cartographic techniques for creation of out puts for planning. Strong computer based geoinformatics is needed to manage the wealth of information in arc, point and line with attribute data and manipulate them as per the requirement of user agencies. Mining of database by GIS and DSS opens further avenues for selecting appropriate land utilization types for optimization of land use on sustainable basis. This paper is to highlight this point for futuristic approach.

A case study dealing with the delineation of agroecounit in Jodhpur, using natural resource database is presented. The application of agroecounit for land suitability evaluation, optimization of existing land use, alternate land use options and soil health monitoring have been elaborated. The other potential avenues of research, using master database of agroecounit have been highlighted in terms of site specific precision farming, market driven land use planning, and watershed management. The potential utility of agroecounit database by linking DSS and simulation models in terms of sustainable use of canal water, temporal variation in yield and area of crops, is also discussed.

Earlier Approach

Natural resource survey provides basic data for planning, and their interpretation is of immense use for planner and decision makers. Identification of homogeneous zone with respect to land, water and other resources is essentially needed for proper planning. Several attempts have been made at international, national and regional levels. The Planning Commission, Govt. of India recognized 15 agroclimatic regions in the country by integrating physiography and climate (Basu & Guha, 1996). Indian Council of Agricultural Research (ICAR) identified 126 agro-climatic subzones in the country (Ghosh, 1991). The approach has neither given adequate consideration to the soils and environmental conditions nor had uniform criteria. Sehgal *et al.* (1989) based on physiography; bioclimate and length of growing season identified 54 agro-ecological zones. Sehgal *et al.* (1992) further prepared the agroecological region map of India based on FAO model (1978) for national planning. Agro-ecological region 2, representing arid ecosystem is further subdivided into 4 sub regions, 11 zones and 34 sub zones for visualizing the production, potentiality and constraints for agriculture (Faroda *et al.*, 1999). Agro-ecounit is the lowest category within sub zones ideally suited for district planning (Sehgal, 1996). It represents polygon/polygons homogeneous with respect to available moisture, drainage, effective depth, texture, soluble salts, organic matter, CEC and mineral reserves, and rainfall, LGP and ground water potentials. These are the crucial parameters for determining productivity potential of soils (Require *et al.*, 1970; Soil Survey Staff, 1995). Sehgal (1996) demonstrated utility of the agro-ecounit in Rajkot district of Gujarat, while Jain *et al.* (2000) has shown its importance for alternate land use planning in Pali district of Rajasthan. However, potentiality of agro-ecounit is yet to be explored fully with use of GIS and simulation models. Integrated resource survey conducted by CAZRI has resulted in Major Land Resource Unit (MLRU). Each MLRU is uniform with respect to potentials and constraints for development. Most of the data required for formation of agro-ecounit are available with CAZRI. Some of the required information not available can be extrapolated from the existing database by applying appropriate pedotransfer function without sacrificing accuracy of output. Eswaran (1992) introduced the concept of Sustainable Land Management (SLM) by adding socioeconomic and environmental module in soil and land database. The highly lauded revolutionary noble concept is still in the experimentation stage.

Database Structure in GIS

A database is needed i) to establish the potentials and limitations of different kinds of soils for agricultural production, ii) to keep tracks of different kinds of soil degradation with their extent and damage, iii) to establish the land management practices for sustainable productivity, iv) to serve as basis for transfer of technology, and v) to aid in decision making for multiple objectives. Conventional maps are too coarse to meet the outlined demand. However, GIS application can improve the soil and land information after being grafted on digital elevation model DEM (Robert et al., 1992). GIS application provides quantitative relationship between the landform and soil attributes for better understanding of regional pedology. GIS may act as bridge between land resource mapping and targeted production research on sustainable basis (Larson & Robert 1991; Peterson *et al.* 1993). Data Structure (Fig.7) has been proposed by Burrough (1986) to meet the demand for the future research in agriculture and in allied field. On the similar line, All India Soil

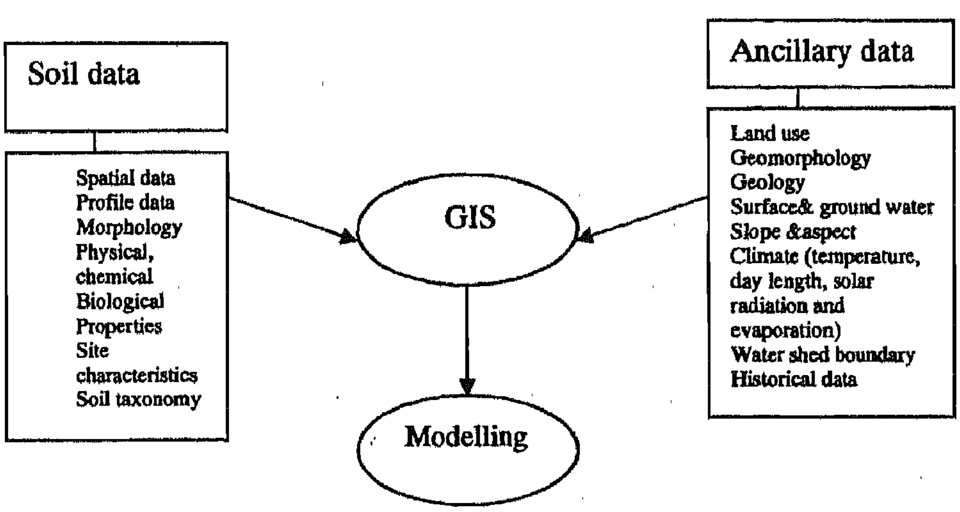

Fig. 7. Minimum data set for land use planning, after ISRIC (1993)

and land Use Survey has developed an Integrated Soil and Land Use Information System (ISLUIS) for soil health card and NBSS&LUP has been recognized as a sub center for collecting soil related information for Agricultural Research Information Center (ARIC) designated as ICAR *information system.*

Creation of Agro-ecounit for Jodhpur District

Integrated resource survey conducted by CAZRI has most of the information required for developing agroecounit. The required thematic information from abstracted data such as attribute maps on soil depth, particle size class, rainfall, LGP, kind and severity of erosion, surface and ground water potentials was generated in GIS, using master database of the district. However, thematic maps from point data can produce better information on integration and refinement. These thematic informations in the form of maps were superimposed over one another in GIS environment. Appropriate generalization without sacrificing the accuracy level of output Jodhpur district has been classified into 28 agroecounit (Fig 8) within the 8 broad frameworks of land-forms and rainfall zone. In the legend first digit (Table 1) indicates soil and terrain features, *second stands for* rainfall and LGP and third represents ground water recharge potential and its quality.

Application of Agroecounit Classification

Evaluation of different land utilization types of the region for optimization of existing land use, suitability of land for irrigation, evaluation of most crucial soil quality for management, yield forecasting and monitoring of soil health, are elaborated below.

Suitability evaluation

Among the fodder trees *A.tortilis, C. mopane, A. nilotica, D.nutan* and *sindicus are*

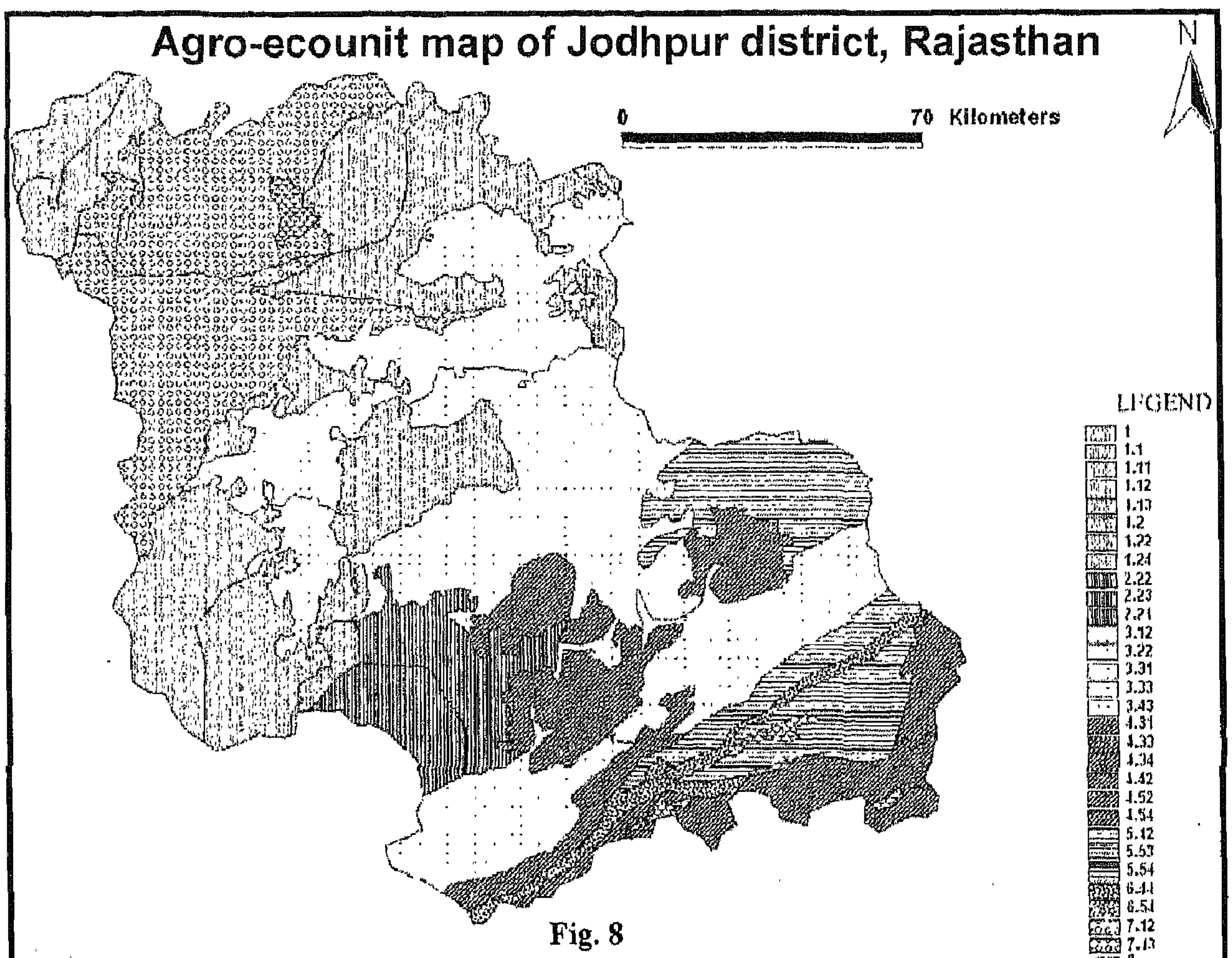

Fig. 8

For details of legend refer Table 16

Table 16. Agro ecological units for district planning- A case study for Jodhpur district.

S.No	Agroecounit	Area Km^2(%)
1.1 Sandy arid plain (high intensity of dunes, severely eroded, 200-250 mm rainfall and 60-75 days LGP)		
1.11	Deep, calcareous sandy soils, groundwater of <2 dS m^{-1} EC and 200-400 m^3/day recharge potential.	501 (2.2)
1.12	Deep, calcareous sandy soils, groundwater depth of 2-4 dS m^{-1} EC and 60-80 m^3/day recharge potential.	1733 (7.6)
1.13	Deep, calcareous sandy soils, groundwater of 6-8 dS m^{-1} EC and 60-80 m^3/day recharge potential.	1166 (5.1)
1.2 Sandy arid plain (high intensity of dunes, severely eroded 150-200 mm rainfall and 45-60days LGP)		
1.22	Deep, calcareous sandy soils, groundwater of 2-4 dS m^{-1} EC and 90-160 m^3/day recharge potentials.	897 (3.9)
1.24	Deep, calcareous sandy soils, severely eroded, groundwater of 6-8 dS m^{-1} EC.	1099 (4.8)
2.2 Sandy arid plain (low intensity of dunes, severely eroded, 150-200 mm rainfall and 45-60days LGP)		
2.22	Deep, calcareous sandy soils, groundwater of 2-4 dS m^{-1} EC and 90-160-m3/day recharge potential.	146 (0.6)
2.23	Deep, calcareous sandy soils, groundwater of 4-6 EC dS m^{-1} and 90-160 m^3/day recharge potential	840 (3.7)
2.3 Sandy arid plain (low intensity of dunes, severely eroded 250-300 mm rainfall and 60-75 days LGP)		
2.3 4	Deep, calcareous sandy soils, groundwater of 6-8 dS m^{-1} EC.	544(2.4)
3.1 Sandy arid plain (occasional dunes, moderately eroded 200-250 mm rainfall and 60-75 days LGP)		
3.12	Deep, calcareous coarse loamy soils, groundwater of 2-4 dS m^{-1} EC and 200-400 m^3/day recharge potential.	2234 (9.8)
3.2 Sandy arid plain (occasional dunes, moderately eroded 150-200 mm rainfall and 60-75 days LGP)		
3.22	Deep, calcareous coarse loamy soils, groundwater of 2-4 dS m^{-1} EC and 200-400 m^3/day recharge potential.	409 (1.8)
3.3 Sandy arid plain (occasional dunes, moderately eroded 250-300 mm rainfall and 60-75 days LGP)		
3.31	Deep, calcareous coarse loamy soils, groundwater of <2 dS m^{-1} EC and 200-400 m^3/day recharge potential	2883 (12.5)
3.33	Deep, calcareous coarse loamy soils, groundwater of 4-6 dS m^{-1} EC and 200-400 m^3/day recharge potential.	954 (4.2)
3.4 Sandy arid plain (occasional dunes, 300-350 mm rainfall and >90days LGP)		
3.43	Deep, calcareous coarse loamy soils, groundwater of 4-6 dS m^{-1} EC and 30-50 m^3/day recharge potential	1247 (5.5)

Cont...

S.No	Agroecounit	Area Km^2(%)
4.3 Pediments agroecounit (severely eroded, 250-300mm rainfall and 45-60 days LGP)		
4.31	Shallow, calcareous loamy soils, groundwater of <2 dS m^{-1} EC and 30-50 m^3/day recharge potential	1076 (4.7)
4.33	Shallow, calcareous loamy soils, groundwater of 4-6 dS m^{-1} EC and 30-50 m^3/day recharge potential	389 (1.7)
4.34	Shallow, calcareous loamy soils, groundwater of 6-8 dS m^{-1} EC.	253 (1.1)
4.4 Pediments agroecounit (severely eroded, 300-350 rainfall and 45-60 days LGP)		
4.42	Shallow, calcareous loamy soils, groundwater of 2-4 dS m^{-1} EC	374 (1.6)
4.5 Pediments agroecounit (severely eroded, >350 rainfall and 45-60 days LGP		
4.52	Shallow, calcareous loamy soils, groundwater of 2-4 dS m^{-1} EC and 30-50 m^3/day recharge potentials	89 (0.4)
4.54	Shallow, calcareous loamy soils, groundwater of 6-8 dS m^{-1} EC and 90-160 m^3/day recharge potentials	427 (1.9)
5.5 Pediplain agroecounit (moderately eroded, >350 mm rainfall and >90 days LGP)		
5.53	Moderately deep, calcareous fine loamy soils, groundwater of 4-6 dS m^{-1} EC and 30-50 m^3/day recharge potential	451 (2.0)
5.54	Moderately deep, calcareous fine loamy soils, groundwater of 6-8 dS m^{-1} EC and 30-50 m^3/day recharge potential	701 (3.1)
6.4 Alluvial plain agroecounit (moderately eroded, 300-350 mm rainfall and >90 days LGP		
6.44	Deep, calcareous coarse loamy soils, groundwater of 6-8dS m^{-1} EC and 30-50 m^3/day recharge potential	240 (1.0)
6.5 Alluvial plain agroecounit (moderately eroded, >350 mm rainfall, and >90 days LGP		
6.54	Deep, calcareous coarse loamy soils, groundwater of 6-8dS m^{-1} EC and 30-50 m^3/day recharge potential	172 (0.8)
7.1 Buried pediment agroecounit (severely eroded, 200-250 mm rainfall, and 45-60 days LGP		
7.12	Shallow, calcareous loamy soils on, groundwater of 2-4 dS m^{-1} EC	2021 (8.8)
7.13	Shallow, calcareous loamy soils, groundwater of 4-6 dS m^{-1} EC.	1798 (7.9)
8.00	Ranns	216 (0.9)

highly suitable for Pediplain and alluvial plain, moderately for sandy arid plain, pediment and buried pediment agroecounits (Table 16). The trees under discussion are marginally suitable for sandy arid plain (agroecounit 2), experiencing150-200 mm rainfall and 45 -60 days LGP (Table 16). Sandy arid plains (agroecounit1, 2 and 3.2) and buried pediments (agroecounit 7) are highly suitable for moth; moderately and marginally suitable for guar and pearl millet, respectively. Agroecounits 3.1, 3.3 and 3.4 are highly suitable for guar, moderately suitable for moong, pearl millet, cowpea and moth. Agroecounit 4 is marginally suitable for guar and moth. However, agroecounits 5 and 6 belonging to Pediplains and alluvial plains agroecounits respectively are highly suitable for pearl millet, guar, cowpea, sesame and moong. During Rabi season, the availability of ground water and its quality is the most crucial. Agroecounits 3, 5, 6 and 7 are moderately suitable for barley and mustard. However, the application of gypsum is recommended with optimum mixture of ground and surface water in agroecounits 5 and 6 to counter the impact of salinity. The remaining area is not suitable for Rabi crops on account of water non availability for irrigation. Agroecounits 3 and 7 are moderately suitable for gram on account of availability of good quality of water for irrigation. Agroecounit 8 is not suitable for arable cropping.

Optimization of existing land use

Based on the suitability evaluation, agroecounits 1, 2, 3.12, 7.12 and 4 are recommended for silvopasture, where *Lasiurus sindicus* may be one of the components. The area under interdunes and inter hilly terrain may be cultivated for moth or guar as a legume, with short duration pear millet. Combinations of grasses and trees enhance the soil fertility in way of fixing nitrogen, increasing microbial activity and restricting the aridity to some extent. Arable cropping on large scale may be restricted. Agroecounit 7.11 may be utilized for long duration pearl millet with the support of life saving irrigation. In view of high demand of fodder, pulses and food grains, agro forestry by planting one of the tree among *A.tortilis, C. mopane, A. nilotica, D.nutan* on the ridges for good quality fodder and one of the cereal / legume/oilseeds among pearl millet, moong, cow pea and sesame or their suitable combination as intercrop are recommended for agroecounits 3.1-3.4, 5 and 6. The planted grasses and trees are suggested to continue after Kharif season with mustard and barley crops in Rabi season. However, agroecounit 7.11 may be preferred for gram, for meeting the demand of pulses. Remaining area may be kept fallow during Rabi to restore fertility for the next season. The present double cropping with cotton, wheat, mustard and cumin are not sustainable in agroecounits 5 and 6 on account of poor quality of ground water and high build up of carbonate in the sub soils.

Yield forecasting

The four management groups, namely very low, low, medium and high have been designed in order to include social component in the land use plan. Yield and returns under each set of condition has been calculated according to the procedure out lined in FAO manual (FAO, 1984). The yield of dominant crops under Jodhpur condition is presented in Fig 9 under medium set of management practices.

Soil health monitoring

The status of soil quality indicators, namely soil depth, available water capacity, organic and inorganic carbon stock and erosion Eswaran, 1992) is presented in Table 2 during 1975 as a base year. The observation at any point of time may bring out the state of soils under the present set of conditions.

Suitability evaluation for irrigation

Agroecounits in Jodhpur have been evaluated for irrigation suitability. Agroecounits 1, 2, 4, 5 and 6 are not suitable for irrigation on account of sandy texture, poor quality of groundwater and carbonate build up in the substrata, while agro-ecounits 3 and a part of 7 are ranked moderately suitable for this purpose. Agroecounit 5 and 6 contained higher amount of soft powdery lime in the subsoil that may be responsible for genesis of salinity and sodicity in future, on the introduction of carbonate and bicarbonate rich ground water for irrigation.

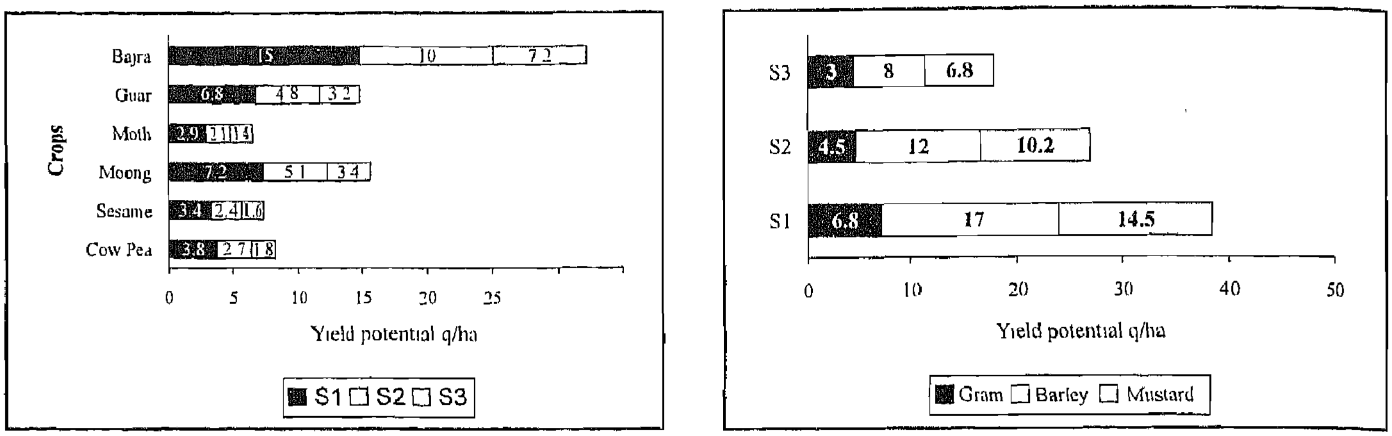

Fig. 9 Potential yield of different crops in Jodhpur conditions

Table 17. Soil quality indicators as a base line during 1975 in Jodhpur

Agro-ecounits	Depth class	AWC mm/M	#RCS kg/M^2 X*100	Erosion	Carbonate accumulation
1.0	>100	50-75	8.5	Very severe	Diffused
2.0	>100	50-75	8.5	Very severe	Diffused
3.0	>100	75-100	11.6	Moderate	Below 50 cm
4.0	<50	50-75	15.5	Severe	Non calcareous
5.0	50-75	100-125	28.6	Slight	Below 60 Cm
6.0	75-100	100-125	38.6	Slight	Below 75 Cm
7.0	<50	50-75	7.5	Severe	Below 40 Cm
8.0	Ranns				

Representative carbon stock for the 100 cm soil profile

Assessment of crucial land quality

According to Eswarn (1992) key soil properties bearing on soil quality and response to management are i) available water capacity, ii) Cation exchange capacity, iii) pH and base saturation, iv) hydraulic conductivity, permeability, bulk density and crusting, v) effective soil volume, vi) surface tilth, vii) erodibility, and viii) water logging. These parameters could be derived from the existing CAZRI database for agroecounit. Pedogenic carbonate and soil texture are the two important characteristics that can be used as pedotransfer function to determine the AWC and hydraulic conductivity which are significant under Jodhpur condition for sustainable agriculture.

Development of soil quality and crop yield model

The relationship between the most crucial soil quality viz. available water capacity (AWC) and crop yield was a linear function under Jodhpur conditions. A threshold value of soil quality could be calculated on the integration of regression equation between AWC and yield. Threshold value provides basis to evaluate changes in soils due to management.

Other potential use of Agroecounits

Future use of agro-ecounit link database for integrated nutrient management, alternate land use planning, validation of yield influencing factor, market driven land use planning, precision farming, watershed research, challenges in local soil management, agro technology transfer, estimation of water demand in large canal area, spatial and temporal dynamics in crop productivity and area, yield gap analysis and variation in yield at farm level are highlighted.

Efficient nutrient management

The soil fertility map of agoecounits containing the information on nutrient dynamics, clay minerals, soil buffering capacity, soil reaction and calcareousness formulate the basis for specific fertilizer use practices. Quantitative information obtained from carefully monitored medium term and long term soil fertility studies on well-defined agroecounit extended to similar sites and forms a basis for site specific fertilizer recommendations.

Introduction of new land utilization types

Based on the land evaluation results on the matching of land utilization types requirement and attributes of agroecounit, the feasibility of introducing new crops in the area is possible. Challa (1999) suggested new land use options in Buldana district of Maharastra on evaluation of units obtained on amalgamation of information related to bench mark soils and growing period.

Validation of yield influencing factors

The relationship between thematic maps namely soil series, texture, land capability, soil irrigability and soil management from agroecounit database and crop growth in terms of normalized difference vegetation index (NDVI) pave the way for working the most crucial land quality identification, using Spearman rank order and Pearson product moment correlation test and multiple regression analysis. Soil characteristics e.g. EC, $CaCO_3$, drainage class, organic carbon and CEC appear to be the most important parameters controlling soil productivity and vegetation growth.

Market driven land use planning

Land use planning is dynamic, changes with market demand and supply. Based on the land evaluation, expected yield and quality, fertilizer and irrigation availability, prevailing socio economic constraints and priority of farmers, alternate land use plan could be developed with the help of linear/ goal programming by using master database of agroecounit in GIS. For example, export of wheat from India having a certain quality specifications can be produced on specific areas that can be identified from the available database and land evaluation.

Concept of precision farming

We must look to the new approach for local soil management called precision farming which has captured interests of farmers in western countries. Use of GPS linked to a computer and yieldometer as well as sensor on farm machinery are the state of art to adopt soil specific crop management practices such as applying fertilizers, pesticides irrigation and estimation of yield.

Natural resource database for watershed management

Under the Integrated Mission for Sustainable Development (IMSD) programme of Department of Space, studies are being carried out using remote sensing and other conventional data for generation of action plan package on watershed/ tehsil/ block basis in 175 districts all over India. In this programme a natural resource data base such as hydrogeomophology, water quality, soil, land use, land cover, drainage and watershed slope, transport and settlement are made using remote sensing and other conventional methods. Then integration of natural resource database and contemporary technology is carried out in GIS and action plans are generated for development of land and water resources. This information could easily be traced from the database of agroecounit for the desired information.

Local Challenges of soil management

This type of studies are essentially needed to answer the very specific question, such as behavior of soil under irrigation. In this connection the studies have been carried out in the Pipar area of Jodhpur district, using master database of agroecounit. By comparing the three layers such as carbonate content, quality of ground water and level of salinity in soils simultaneously, it was concluded that the extent of sodicity was function of depth and form of lime accumulation. The study warranted that the carbonate and bicarbonate rich water should be avoided for irrigation in the soils, having calcic, petrocalcic and gypsic horizon.

Agro technology transfer

The decision support system for agrotechnology transfer (DSSAT) is a series of computer programme consisting of three components, namely database management, crop simulation models and technology transfer. DSSAT becomes a powerful and accurate tool for making predictions of crop performance or management requirements in association with the database of agroecounits. This is as good as or better than those made by any other means.

Estimation of water demand in large canal area

Models dealing with current season information on weather forecasts and local information on crops in association with the master database of agroecounit can assess the spatial availability of water demands in real time scale. This allows visualizing the spatial variations in irrigation requirements in different distributaries of canal network. Such visualizations can have a powerful impact on overall water management strategy to be adopted, particularly in the event of shortfall in water supply.

Spatial and temporal dynamics analysis in area and crop productivity

Interfacing crop simulation models to GIS database of agroecounit will help to simulate crop yields and related variables and their changes under different climatic and management conditions. Scientist, administrators, regional planners and policy makers in formulating future strategies can use thematic maps reflecting those results. However, simulation models need to be properly validated and suitably modified, if necessary, before their application to diverse rainfed conditions.

Characterizing yield gap

In an agro-ecounit the difference between the potentials of crop production and what farmers realize is termed as yield gap. It is the popular way of characterizing the untapped potentials and defining the opportunity that can be exploited, if all constraints are removed. By application of CERES millet model potential yields can be estimated for pearl millet growing areas of Rajasthan.

Studying variability in yield at farm level

After identifying the potential zone for a particular crop through GIS link database of agroecounit and simulation model, one could digitize the soil map to provide the basic map layer and develop an attribute database for soil type, soil family association, pH, slope and other physical and chemical characteristics at farm level. Each layer can be overlaid to create polygons each with unique characteristics based on classification of each layer. GIS crop model system can then be used to simulate the crop growth and development of each polygon or field with different characteristics.

Future strategies

- Building up a desert information system
- Evaluation and interpretations of existing database.
- Standardization of evaluation procedures
- More research on linking digital soil maps and database to simulation models
- Generation of natural resource thematic map to meet the needs of stakeholders under todays demand driven intensive farming.

Conclusion

Natural resource information collected by integrated resource survey of CAZRI, through remote sensing and supplemented ground truthing can be explored, for land use planning, judicious management of natural resource, conservation and sustainable use of soils, land and crop resources, using GIS and DSS. Further application of simulation models with GIS and DSS could enhance the utility and understandability of natural resource information. GIS based database opens the new vistas for utilizing natural resource information for multifarious purposes viz. reproduction of utility maps, suitability and other interpretative maps, easy linkage with other georferenced coverage to generate new composite overlay, cost effective and time saving, periodic updating of maps/ information and capabilities of quick monitoring and impact assessment of development measures makes it a useful tool for generating action plans and its implementation for land resource management of a region, district and watershed.

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