ICAR- Indian Institute of Soil and Water Conservation (IISWC)
Research Centre, Kota - 324 002 (Rajasthan)

60 YEARS OF RESEARCH ON SOIL AND WATER CONSERVATION IN CHAMBAL RAVINE REGION

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डॉ. सुरेश कुमार चौधरी
उपमहानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resources Management)

In India, land degradation covers 120.4 million ha area, out of which nearly 4 million hectares land along several river systems in the alluvial zones is affected by ravines as reported by National Remote Sensing Agency. The aerial survey carried out for Chambal Development Scheme has shown that the area covered by ravines upto 4.5-6.0 m depth is about 50,600 hectares. Ravines pose a considerable challenge to poverty reduction and social equality besides lowering land productivity. The ravines contribute to huge sediment load to river systems as these sites are major sediment producing hot spot.

The ICAR-IISWC, Research centre at Kota has developed effective gully control and ravine rehabilitation strategies based on hydrological behaviour, climatic and edaphic limitations and Indigenous Technical Knowledge (ITK) to deal with the problems of ravine lands on the bank of Chambal river. The centre has been contributing to research for tackling the problems related to soil and water conservation and agriculture and tree based production systems in the ravine region of Yamuna river system for past six decades. The current publication *'60 Years of Research on Soil and Water Conservation in Chambal Ravine Region'* is the outcome of compilation of the research achievements of the centre. The last three chapters analyze current challenges and prioritize future action plant to ensure sustainable management of Natural Resource in this region.

I hope this publication will serve as a much-needed source of information related to problems and their remedial measures related to ravines. I hope that this document will be useful for policy makers, government agencies and non government organizations and other agencies for reclamation and management of ravine land. The contributors deserve a word of appreciation for this timely and sincere effort.

12th November, 2021
New Delhi

(S. K. Chaudhari)

PREFACE

Dr M. Madhu
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Restoration and conservation of diverse ecosystems is a primary concern for achieving sustainable development goals (SDGs). Rapid demographic growth associated with imprudent exploitation of land, water, forest, minerals, and other non-renewable natural resources in India has taxed heavily on its rich natural wealth. High-value riparian ecosystems are hot-spots of land degradation due to severe gully erosion along with major river systems of India with stern onsite and offsite implications. Rapid loss of land quality in gullied and inter-gullied areas due to accelerated erosion rates and terrain deformation leads to a severe reduction in land productivity and biodiversity, increased sediment discharge to river systems, and disruption of livelihood support of native inhabitants. Nonetheless, these lands have very high developmental potential as they are spread along with perennial water sources.

Three regional centers of ICAR-Indian Institute of Soil and Water Conservation (IISWC) located at Agra, Kota, and Vasad have been working for over sixty years to develop technological options for restoration and sustainable management of ravine lands along with Yamuna, Chambal, and Mahi river systems. This publication documents research work carried out by the ICAR-Indian Institute of Soil and Water Conservation, Research Centre on different aspects of gully erosion control and restoration and sustainable management of ravine lands of the Chambal river system. This publication also reports a comprehensive overview of the current status of land degradation due to water or wind erosion in Rajasthan, and research recommendations from ICAR and state institutions for the management of these lands. Effective technology dissemination and capacity building of stakeholders of natural resource management projects are equally important activities for achieving sustainable impacts of developmental programs. The book also highlights some major efforts by ICAR-IISWC and other line departments. I am confident that this attempt of bringing the information into one handy publication will be of immense help to planners, researchers, academicians, students, and policymakers engaged in research, training, and extension work in the field of soil and water conservation in general and ravine gullied system in particular. I compliment the authors and editors for their invaluable contributions and for doing an excellent job.

(M. Madhu)

November, 2021
Dehradun

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The authors are extremely grateful to Dr V. N. Sharda for motivating Regional Centre to bring out this publication and extending continuous support, encouragement and guidance through the process of compilation of information and structuring the manuscript. Authors owe special gratitude to Dr Pradeep Dogra, Principal Scientist for editing the first manuscript and our Institute Director Dr M. Madhu to review and final editing for improving the final manuscript of the book.

Over a period of fifty years several scientific and technical personnel have contributed to the research programmes conducted at Kota Centre, which is duly acknowledged. The scientists who steered the research, demonstration and training activities during this period as Head of the Centre were Dr N. Patnaik, Dr H.D. Bhaumik, Sh. R. Dayal, Sh. M. L. Khybri, Sh. Balvir Verma, Dr S. Chinnamani, Dr K.D. Singh and Dr S. N. Prasad.

The authors are also indebted to Department of Soil and Water Conservation and Watershed Development, Dept. of Forest, Govt. of Rajasthan and College of Technology and Engineering, MPUAT, Udaipur for providing valuable information for this publication. Cartographical assistance by Sh. P. R. Raibole and typographical services rendered by Shri V. K. Jain, ACTO and Sh. Ghanshyam Amer, PA, are thankfully acknowledged.

Authors

EXECUTIVE SUMMARY

A balanced and judicious management of our natural resources is a key to sustainable agriculture production and environmental security. To develop management strategies and to provide research and training support required for soil and water conservation programmes a chain of Soil Conservation Research, Demonstration and Training Centres was established during 1954-57. The Research Centre Kota was established in 1954 to take up the research and training programme especially on the problem of gully erosion along the river Chambal and its tributaries. Over a period of sixty years this Centre has developed and field tested technological packages for sustainable and productive utilization of ravine and marginal lands. The accomplishments and salient achievements of the Centre during the 60 years period of its existence are being summarized in this publication. The relevant information from other ICAR Institutions, Agricultural Universities and State Agencies located in Rajasthan has also been included to give an integrated view of natural resources management status at regional scale.

Rajasthan is the state with largest geographical area in the country (34.25 M ha), which is divided in two distinct physiographic regions by Aravali hills extending diagonally from North-East to South-West. Western semi-arid to arid sandy plains and Eastern semi-arid uplands occupy the area in 60:40 ratio. Wind erosion is the dominant soil degradation process in the Western arid plains while water erosion is major land degradation process in Eastern uplands. About 8.96 M ha in Eastern Rajasthan is estimated to be eroding soil @ more than 10 t/ha/yr, out of this about 2 M ha is facing erosion rate higher than 40 t/ha/yr. Gully erosion is an advance stage of sheet and rill erosion which is prevalent in the vicinity of rivers and their tributaries. Rajasthan is estimated to have 2.79 lakh ha gullied land mostly along the Chambal river system. In spite of various land reclamation activities carried out under different programmes the average annual ravine ingress rate is estimated as 0.556% on compound scale. Hot arid and sandy landscape of Western Rajasthan is exposed to strong winds during summers. The shifting sand dunes cause severe damage as crops roots get exposed at eroded sites and fertile lands and crop get buried under sand dunes where deposition takes place. Also the moving sand damages tender stems and leaves of the crop through sand blasting. Central Arid Zone Research Institute (CAZRI), Jodhpur has prepared a wind erosion map of Western Rajasthan and estimated 3.36, 7.43 and 7.77 M ha under severe, moderate and low categories of wind erosion classes, respectively. Other form of degraded lands in the state include barren rocky (0.48 M ha), saline soils (0.272 M ha), water logged (0.029 M ha), mine spoils (0.0129 M ha) and degraded forest (1.226 M ha). Water scarcity is the major concern associated with natural resources management in the state. Low and erratic rainfall, high evapo-transpiration and frequent droughts have resulted in rapid depletion of ground water table. Heavy biotic pressure has severely degraded natural vegetation especially due to prevalent open grazing system and nomadic tribes. Inadequate vegetation canopy cover induces excessive runoff and poor ground water recharge. Lack of education and resource-constrained communities add to the complexities of the problem.

Over a period of sixty years activities of the Centre have mainly focused on seven priorities areas which are: 1) Resource appraisal, 2) Technology for arable and non-arable rainfed production systems, 3) Watershed hydrology, 4) Rehabilitation of areas under influence of mass erosion, 5) Integrated watershed management, 6) Socio-economic analysis and policy for watershed and 7) Human resource development and technology transfer. In the priority area of resource appraisal parameters of Universal Soil Loss Equation (USLE) such as rainfall erosivity (R), soil erodibility (K), topography (LS), soil cover (C) and management practices (P) were evaluated. The USLE was then used to develop erosion map on the basis of 10 km^2 grid soil survey data provided by NBSSLUP, Regional Centre, Udaipur. This map depicted severity and extent of water induced sheet and rill erosion in the Eastern Rajasthan. The assessment of the problem of gully erosion or any other form of mass erosion was based on survey reports of forest department. Centre has also developed a comprehensive gully reclaimability classification system based on depth and width of gully, soil characteristics, water availability and climate.

Various mechanical and agronomical conservation measures were evaluated for arable lands. Graded bunds of 1.00 - 1.25 m^2 cross-section with 0.5 to 1.0 m VI and 0.2 to 0.3% grade were found suitable for the region. Mini bunds or furrows (0.02 m^2) spaced at 0.055 to 0.073 m VI also effectively reduced runoff and improved crop yields. Maintenance of bunds and furrow is a problem in cracking soils and therefore various grass barriers were also evaluated to be used in replacement of graded bunds. The four species tested and found suitable are *Vetiver zizanioides*, *Saccharum munja*, *Cenchrusciliaris* and *Dichanthium annulatum*. Masonry gully control structures are recommended to check gully head extension into adjoining table lands. To promote *in-situ* utilization of rainfall conservation bench terracing (CBT) with 1:2 ratio of contributing to receiving area is recommended.

Recommended agronomic measures are contour cultivation, deep tillage (20 cm), crop residue recycling (5 t/ha) and mulching with crop residue, dry grass or dust. Crops, their varieties and cropping systems have been evaluated for the region. Intercropping has great potential in bringing stability to crop production in rainfed areas. Great deals of efforts were made to identify suitable intercropping systems for the region. Under normal monsoon conditions sorghum and pigeonpea intercropping in alternate rows 30 cm apart has been found most promising system. For delayed or abnormal monsoon situations castor + green gram (1:2 rows) has proved to be a superior cropping system. For the Rabi season chickpea + linseed (2:1 rows) has been found more remunerative than mono cropping systems. Integration of trees on farm land also helps in drought mitigating. Several agroforestry systems were evaluated and it was found that sorghum and Taramira are relatively more compatible crops for agroforestry systems than pulses or safflower crops during *Kharif* and *Rabi* seasons, respectively. Lemon and guava based agri-horti system were also evaluated and compatible intercrops have been identified.

Several studies were conducted in the Chambal ravines to develop technologies for productive utilization of non-arable lands. Tree and grass species are identified for hump top, side slopes and ravine beds under normal, water logged and saline conditions and their growth potential have been assessed. Site-specific soil working techniques, post planting management of tree and grass species have also been investigated and package of practices for ravine rehabilitation has been recommended. Ecological studies were also conducted to monitor changes in floristic composition and vegetation soil-interaction under protected and open grazing situations.

In the priority area of watershed hydrology rainfall characteristics were analyzed, stochastic rainfall models and rainfall intensity-duration-return period relationship were developed for the region. Long term monitoring of runoff and soil loss from micro-watershed under agriculture land uses showed that depending on crop about 10-16.4% of rainfall is lost through surface runoff. Effect of mechanical and vegetative measures on runoff was evaluated for five years in farmers' field. It was observed that mechanical measures alone and in combination with vegetative measures reduced runoff by 47.4 and 78.5%, respectively. Natural vegetation under protected condition can almost completely check the runoff and soil loss from ravine watersheds. Depending on the topographic condition average runoff ranged from 1.8 to 3.4%. Water budget of prominent crops were estimated using weighing type lysimeter. Techniques for efficient utilization of harvested rainwater were investigated for different crops.

Rehabilitation of ravine lands has been the main focus of research at Kota Centre. Shallow ravines (<3m) are recommended to be reclaimed for cultivation with the help of appropriate land shaping, earthen embankment and masonry check dams. Ravines deeper than 3 m needs a careful and systematic step-wise rehabilitation programme which consist of a) gully head stabilization through marginal bunds at the periphery of table lands with a provision of drop spill way for safe disposal of diverted runoff, b) stabilization of side slopes by slope easement and establishment of grasses and trees, c) gully bed stabilization with a series of check dams which could be of live hedges, rubble with brush wood or masonry.

Three integrated watershed development projects were implemented by the Centre at Chhajawa, and Dhoti watersheds in Baran District and Badakhera watershed in Bundi District. These watersheds were monitored for project impact on ecological and socio-economic parameters. All watershed projects demonstrated suitability of conservation technology recommended by the Centre for this region. Runoff and soil loss reduced to safe limits, water availability and irrigated area increased and there was conspicuous improvement in cropping intensity, crop and animal productivity, employment generation and house hold income and other socio-economic parameters. Ecological influences of watershed interventions on soil quality and plant biodiversity were also quantified through studies taken up under controlled conditions at research farm.

The Centre conducted variety of training programmes under the priorities area of human resource development. A five and half month duration comprehensive training on soil conservation and watershed management has been a major and regular training activity at the Centre. In all 1546 graduate Assistants in 78 batches and 89 gazetted officers in 7 batches have been trained up to 31st March, 2018. A total of 59 B.Tech.students were trained under one month duration summer placement training. The Centre has also organized about 190 short courses and trained 5617 trainees of different levels on various aspects of watershed management. The technology dissemination was initiated at the Centre in 1959 with "Borkhandi Soil Conservation Project" and continued with "National Demonstrations", "Lab to Land Programme", ORP Chhajawa and IWDP Badakhera and NWDPRA, Dhoti watershed projects. Impact studies were taken up subsequently for quantitative assessment of success of these technology dissemination programmes in improving agriculture production, protecting natural resources and other socio-economic indicators.

Among the other non-ICAR research and development institutions in the State only MPUAT, Udaipur has contributed in evaluating conservation technologies and has recommended Puerotrican terraces and contour bunding for Southern Rajasthan.

Rajasthan is rich in indigenous traditional wisdom for efficient rainwater conservation which has also been documented in this report. Traditional *in-situ* moisture conservation techniques are summer ploughing, *Kulying*, *Kulphying*, *Criss-cross* ploughing, *Bandhi* and *Bandha*. Water harvesting and recycling techniques are *Talai*, *Johad*, *Sagar*, *Khadin*, *Tanka*, *Kund* and *Baorie*. These age old traditional water harvesting methods have maintained self-sufficiency of water in the state until recently, whereas increased access to ground water and installation of canal network have disturbed ecological water balance of the region.

In the post-independence period soil and water conservation works started in 1959 under River Valley Project in the state. Subsequently various programmes namely NWDPRA, DPAP, DDP, IWDP and EAS were launched. By the end of XII Plan 59.68 lakh ha area was treated under these programmes which is about 24.33% of the total treatable area of the State.

Critical natural resources management issues in Rajasthan that need to be addressed by research institutions are technology for drought management, depleting ground water table, waste land utilization, low cost conservation technology, management of CPRs and monitoring status of natural resources. Accordingly, a vision statement for next 50 years for the Kota Centre has been prepared.

1.0 INTRODUCTION

1.1 Background

Land and water resources are core constituents of terrestrial life support systems. Degradation of these two resources has emerged as a global concern linked with increasing fragility and instability of human security. Anthropogenic land degradation drivers such as deforestation, overgrazing and unscientific exploitation of land and water have led to a rapid depletion and degradation of our natural capital. The degradation process is manifested through decline of soil quality, vegetation, water resource and bio-diversity, and has serious ecological, economic and socio-cultural implications. It effect several land based ecosystem services and rural livelihood resulting socio-economic damage to society as a whole. In the Indian sub-continent ever increasing biotic pressure on natural resources poses a very serious threat to regional socio-ecological balance. The per capita land area in India shrank from 0.36 ha in 1960 to 0.20 ha in 1990 and is expected to further reduce to 0.12 ha in 2028 if there is no additional loss of arable land due to degradation or urbanization. Similarly, annual per capita availability of fresh water resources in India was 5227 m^3 in 1955, 2464 m^3 in 1990 and is projected to be 1496 m^3 in 2025 against minimum per capita requirement of 1700 m^3. The annual global cost of land degradation due to land use change and reduced crop land and range land productivity has been estimated at roughly USD 300 billion; which is primarily borne by those benefiting from ecosystem services, *i.e.,* the farmers (Nkonya *et. al.*, 2015). Realizing the importance and urgency to protect soil and water, Government of India established a chain of Soil Conservation Research, Demonstration and Training Centres during first and second five year plans (1954-57). These Centres were later transferred to the Indian Council of Agricultural Research on 30th September, 1967, and subsequently became the constituents of Central Soil and Water Conservation Research and Training Institute (CSWCRTI) as its regional research Centres. The CSWCRTI was renamed as Indian Institute of Soil and Water Conservation (ICAR-IISWC) in 2014. Targeting some of the most vulnerable agro-ecosystems, the ICAR-IISWC regional Centres focused on addressing various aspects associated with water erosion induces land degradation. Over a period of about sixty years these research Centres have monitored and documented degradation and depletion of land and water resources, and their impact on agriculture production and rural livelihood. These Centres have pioneered in developing and disseminating remedial measure through research, training and outreach activities for reversing the degradation processes and sustainable management of land and water resources.

1.2 Resource Base of Chambal Ravine Region

1.2.1 Climate

The ICAR-IISWC, Research Centre, Kota represents the upper Chambal catchment. The region falls in hot semi-arid climatic zone with water surplus in month of July, August and September. The climate can be divided into three distinct seasons namely hot and dry summer (April - June), monsoon (July - October) and cool and dry winter (November - March). The annual rainfall is 740 mm with inconsistent and highly erratic patterns. More than 90% of total precipitation is received during June to September. May is the hottest month with 41.9°C mean maximum temperature and January is the coldest with 6.5 °C mean minimum temperature.

1.2.2 Geology and Soils

South-Eastern Rajasthan comprising the districts Jhalawar, Kota, Baran, Bundi, Tonk, Sawai Madhopur and Karoli, is characterized by hills of Aravali and Vindhyan ranges, rocky outcrop uplands and almost flat alluvial plains. The river Chambal and its tributaries, traversing the region, drain the entire area. The physiography comprises of two diverse geology. It consists mainly sand stone quartzite, silicaceous limestone and dolomite on the one hand, while a vast area is formed from the alluvium brought down by Chambal and its tributaries.

The soils are very deep to deep, dark grayish brown, well drained, calcareous, fine soils with weakly expressed slickensides on nearly level plains constitute the dominant soil scape and are classified as fine, Typic Chromusterts. These soils occur in association with deep to very deep, very dark greyish brown, moderately well drained calcareous fine soils, which are placed under fine Typic Pellusterts. A significant portion of this physiography is severely affected by ravine formation. The soils of this area are classified as coarse loamy/fine loamy, highly calcareous Typic Ustochrepts.

1.2.3 Land Use

Out of 4.16 M ha area of the region about 0.88 M ha (21.2%) is under forest vegetation and 2.08 M ha (49.9%) is under agriculture. Barren and uncultivable lands, pasture and other grazing lands, cultivable waste lands and fallow lands occupy 0.99 M ha (23.8%) area. Of 2.08 M ha arable lands, nearly 1.20 M ha (57.7%) is under irrigation and remaining 0.88 M ha is under rainfed agriculture.

The forest vegetation in the region falls under Northern Tropical Ravine Thorn Forests. The ravine region is characterized by dominance of thorny vegetation. Extremes of climatic and edaphic conditions result in low productivity in adjoining marginal lands also. Champion and Seth (1968) have classified the natural vegetation of ravines under type 6BC2: Northern tropical ravine thorn forests. Parandiyal *et. al.* (2000) also studied the floristic diversity of Chambal ravines. The typical vegetation consists of low growing type of coarse grasses like *Aristida royleana, Aristida adscensionis, Eremopogon faveolatus, Heteropogon contortus, Themeda quadrivalvis, Hevlendra letberosa, Eragrostis spp., Eleusinespp., Desmostachya bipinnata, Iseilema prostratum* and rarely occurring *Dicanthium annulatum* among grasses; bushy shrubs of *Zizyphus nummularia, Capparis zeylanica, Capparis decidua, Crotalaria burhia, Cassia tora, Calatropis procera, Clerodendron phlomoides, Grewia pilosa, Grewia tenax, Lantana camara* etc.; under growth of *Abutilon theophrasti, Achyranthes aspera, Argemone mexicana, Cassia tora, Blumea lacera, Indigofera linifolia, Rhynchosia minima, Tephrosia purpurea, Xanthium strumarium, Solanum spp. etc.* and xerophytic trees like *Dichrostachys cinerea, Acacia senegal, Acacia leucophloea, Acacia nilotica, Prosopis juliflora, Balanites aegyptiaca* and other trees like *Cordia dichotoma, Azadirachta indica, Feronia elephantum, Holoptelea integrifolia, Soymida febrifuga, Salmalia malabarica, Salvadora oleoides, Tamarix dioica* etc.

1.3 Problems

Out of 2.08 M ha arable lands more than 42.3% is under rainfed farming where land degradation due to soil erosion has become a matter of serious concern. Apart from sheet, rill and gully erosion the arable lands are also threatened by ravines. The ravine areas are very fragile and highly vulnerable ecosystems. Severe terrain deformation with unstable slopes and highly erodible soils with very low fertility levels, occurrence of back flow and excessive biotic pressure add to the complexity of the problem. The upstream area of ravine region is characterized with rocky land forms with shallow depth of soil resulting scarce vegetation, excessive soil erosion, poor permeability, while downstream areas exhibit cracks and pot holes formation, salinity and water logging in associated command area and deep gullies. Low and erratic rainfall and hot summers results in huge evapotranspiration deficit. The potential ET is more than double of the annual precipitation. More than 90% of annual rainfall is received during June to September in intense storms which results in excess runoff due to poor permeability of soils and lack of conservation measures. Exploitation of ground water for irrigation has been greater than annual recuperation through recharge of rainfall, which has resulted in very fast depletion of ground water level. The major problems of the region are water scarcity, moderate to severe soil erosion (>10 t/ha/yr), poor ground water recharge (<20% of rainfall) due to excessive runoff, subsistence farming, overgrazed wastelands and poor socio-economic condition of the farmers.

The productivity of rainfed arable lands is less 1 t/ha due to frequent weather aberrations.

Slow recovery and growth of natural vegetation due to excessive biotic pressure and water limited ecosystem further aggravate degradation process. Despite severe unemployment and underutilized manpower, resource constrained local communities are unwilling and incapable of taking up cost intensive and complex ravine reclamation initiatives without external support. The ravine lands have been low priority areas for developmental projects due to inadequate political and policy support.

1.4 About ICAR-IISWC, RC, Kota

During First Five Year Plan period (1951-56) a chain of Soil Conservation Research, Demonstration and Training Centers were established under the Ministry of Agriculture and Co-operation (Government of India) in different agro-climatic zones of India to tackle the eco-zone specific soil erosion problems. The Soil Conservation Research and Training Centre at Kota was established during 1954 to appraise erosion problems in ravines of the Chambal river system, conduct research in hydrological, edaphic, crop and vegetation aspects and to suggest measures for control of gullies and their productive utilization, considering the runoff contributing area to gully system as a management unit. Demonstration of the technology in farmers' lands and imparting training in Soil and Water Conservation to line department officials and other stakeholders of land and water management programmes have been other important activities of the Centre.

1.4.1 The Specific Objectives of the Centre

i. To devise suitable methods for control of soil erosion in the agricultural, forest and grasslands.

ii. To evolve specifications for mechanical measures of erosion control.

iii. To work out suitable techniques of crop husbandry which contribute to the conservation of soil and water and better management of the land.

iv. To study and recommend suitable species of grasses and legumes and methods for stabilization of earthen structures and improvement of grasslands.

v. To study and recommend various forest species and methods of reforestation of the denuded and highly eroded lands.

vi. To set up demonstration projects for popularizing soil and water conservation measures in the region of the Centre.

vii. To impart specialized training in soil and water conservation to the non-gazetted officers of the various state governments.

The administrative control of the Centre was subsequently transferred to the Indian Council of Agricultural Research on 30th September, 1967. With re-organization of the Soil Conservation Research Centers, it became a Regional Research Center under the Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun with effect from 1st April, 1975; and the Centre's objective were redefined to be more specific to a ravine Research Centre.

1.4.2 Revised Mandate and Objectives of the Centre under CSWCRTI

i. Appraisal of ravine problems and conservation of land and water resource along the Chambal river system.

ii. Evaluation of hydrological behavior and management of watersheds for reducing sediment discharge and improving water regime and productivity in ravine lands.

iii. Evaluation and identification of suitable plant materials for different land uses in ravine lands according to land capability.

iv. Development of suitable technology for increasing production from ravine lands.

v. Monitoring of changes in environment as affected by land use and management practices in ravine lands.

vi. Development of techniques for (a) rain fed farming and (b) efficient water management in ravine lands.

vii. Development of techniques for stabilizing ravine lands.

viii. To impart specialized training of Gazetted Officers, Graduate Assistants and other personnel, deputed by the various state Governments in Soil and Water Conservation.

ix. Demonstration of soil and water conservation practices for improving production on farmers' fields.

1.4.3 Revised Mandate and Objectives of the Centre under ICAR-IISWC

The CSWCRTI was further renamed as Indian Institute of Soil and Water Conservation (ICAR-IISWC) in April, 2014. Over the years focus of research, training, extension and consultancy programmes at Kota Centre expanded to accommodate following Institute mandates:

i. Undertake research and develop strategies for controlling land degradation under all primary production systems and rehabilitation of degraded lands in different agro-ecological zones of the country.

ii. Act as a repository of information on the status of soil degradation / soil and water conservation.

iii. Provide leadership and co-ordinate research network with State Agricultural Universities / Institutions / NGOs / State Departments for developing location specific technologies in the area of soil and water conservation.

iv. Act as the national and international Centre for training in research methodologies and updated technology in soil and water conservation, watershed development and its management.

v. Provide consultancy and collaborate with national and international Institutions in the field of soil and water conservation.

The Centre is equipped with a 61.89 ha research farm representing Chambal ravine landscape situated along right bank of Chambal river, a research laboratory, meteorological observatory, runoff and soil loss monitoring systems and other modern field equipment's required for soil and water conservation research. The Centre's mandate is pursued through a well-planned research, training and outreach programmes which are periodically reviewed in the background of changing needs of target area.

1.4.4 Research

The multidisciplinary team of scientists operated in following four research units at the Centre to address issues demanding specialized skills.

1.4.4.1 Hydrology and Engineering

This includes gauging of watersheds for determination of amount of runoff, loss and peak rate of discharge from small watersheds representing Chambal ravine landscapes and to identify important hydrological indicators useful in evaluation of effectiveness of vegetative and structural measures for erosion control, and surface and sub-surface flows from the watersheds.

1.4.4.2 Plant Science

Studies are conducted on identification and evaluation of different tree and grass species for rehabilitation of denuded ravines, maximization of productivity of severely eroded terrain through multilayered vegetative systems and monitoring runoff and soil loss under different vegetative covers.

1.4.4.3 Soil Science and Agronomy

Research is conducted to restore productivity of degraded ravine land through soil and water conservation measures, fertility management, agronomic practices and suitable cropping systems. Research programmes also focused on optimizing resource use efficiency through efficient use of inputs and soil amendments, rainwater harvesting, and developing understanding of water budget components under different systems of crop management including studies on different agroforestry, agro-horticulture and other alternative land use systems.

1.4.4.4 Economics and Social Sciences

Investigations on economic viability and social acceptability of recommended ravine reclamation practices and packages using standard economic and statistical tools. Monitoring and evaluation of watershed management programmes and constraints associated with dissemination of soil and water conservation technologies is also carried out.

1.4.5 Human Resource Development

The Centre organizes 5½ months regular training courses on watershed management and related activities for the field staff of state soil and water conservation departments. In all 1546 graduate assistants in 78 batches and 89 gazetted officers in 6 batches have been trained during about 65 years of its existence. Need based specially tailored 2–21 days short courses on various aspects watershed management were organized for a range of watershed functionaries including Watershed Development Teams (WDT), Panchayati Raj Institution (PRI) members, Watershed Committees (WC) and officers and field staff of the state watershed departments and NGOs etc. In 190 short courses 5617 watershed stakeholders were trained.

1.4.6 Outreach Activities

The technologies developed at the Centre, particularly of rainwater harvesting, participatory watershed management, ravine land restoration and increasing agricultural production, both under rainfed condition and with supplemental irrigation were transferred to the farmers' fields through Lab to Land Programme (1979-83), Farmers Participatory Action Research Programme (FPA RP 2008-11), field evaluation of technologies under transfer of technology programme (2012-17) in Kota Bundi, Baran and Jhalawar district of South-Eastern Rajasthan.

2.0 EXTENT OF LAND DEGRADATION

Rajasthan is a state which faces the extremes of both wind and water induced soil erosion. Rajasthan is the state with the largest area (342476.13 sq km) in the country, which is divided in to two distinct physiographic regions by Aravalli hills extending diagonally from North-East to South-West. The Western semi-arid to arid sandy plains, and Eastern semiarid uplands, occupy the area of state in 60:40 ratios. Wind erosion is the principal soil degradation process in western plains with vast stretches of aeolin sand deposits. Although water induced soil erosion is also a significant phenomenon occurring in the region, it's largely inconsequential in the presence of shifting sand dunes. Water erosion is dominant land degradation process in the Eastern uplands and therefore it has been prime area of concern for ICAR-IISWC, Research Centre, Kota.

Periodical assessments of wasteland distribution across the state have been made by National Remote Sensing Centers (NRSC) of India. District wise status of different forms of wastelands in the year 2015 is presented in Table 2.1. These assessments are based on remote sensing techniques and therefore have procedural limitations as indicated by gross under assessment of total area under ravine lands. The NRSC data report 1.299 lakh ha as against 2.79 lakh ha area delineated by ICAR-IISWC (2014) for the same period. Nevertheless the NRSC data gives an overview of the relative extent of various types land degradation in the state which occupies about 23% of total area geographical area of Rajasthan. Scrub vegetation, degraded forest and grazing lands cover 61% of wastelands of the state. About 30% of wastelands are Western sandy landscape (dunes) which are mostly stabilized. Other wastelands in the state include barren rocky (5.76%), saline/alkali soils (1.01%), waterlogged soils (0.12%) and mine spoils (0.04%). There is a general trend of reduction in the area of all forms of wastelands in the state except saline/alkali and mine spoils. While overall 5.7% reduction in total wasteland area of Rajasthan over six years (2008-15) has been reported by NRSC (2019), there was an increase in mine spoils and saline/alkali area by 93% and 3% (Table 2.2).

Table 2.1: Wastelands (sq. km) in different districts of Rajasthan in the year 2015 (NRSC, 2019)

District	Ravine land	Scrub land	Water-logged land	Saline /Alkaline area	Degraded forest land	Degraded grazing land	Sands	Sand stabilized	Mining wastelands	Barren rockey area	Total wastelands	TGA	% TGA
Ajmer	31.6	1538.08	0.63	28.77	213.91	79.86	-	9.11	1.11	167.91	2071.39	8481	24.42
Alwar	91.61	530.58	-	2.09	191.85	6.09	0.05	-	0.08	223.68	1046.05	8380	12.48
Barmer	21.54	1696.68	19.79	172.95	90.19	187.67	1.93	2280.61	0.38	391.18	4862.90	28387	17.13
Banswara	9.10	318.68	-	-	634.41	17.42	-	-	0.33	90.29	1070.23	5037	0.21
Baran	57.61	286.36	-	-	1153.3	73.46	37.15	-	-	29.01	1636.89	6955	23.53
Bharatpur	3.55	376.6	8.58	3.07	44.07	2.02	-	0.59	-	89.78	528.27	5092	10.37
Bhilwara	11.07	2000.68	-	-	346.07	309.03	-	-	0.18	206.33	2854.51	10455	27.30
Bikaner	82.78	525.86	28.53	-	68.37	440.07	-	6213.11	5.44	20.18	7384.31	27244	27.10
Bundi	160.74	281.24	-	-	693.84	10.90	-	0.35	-	56.83	1203.89	5550	21.69
Chittaurgarh	-	1001.01	-	2.60	845.97	46.69	-	-	0.01	89.10	1985.39	10856	18.28
Churu	3.97	369.31	1.36	18.91	17.98	103.82	-	27.25	0.12	3.32	546.28	16830	3.24
Dausa	11.34	254.17	-	0.37	57.01	32.14	0.25	0.16	0.05	14.74	370.23	3432	10.78
Dhaulpur	97.81	306.02	-	-	302.95	2.32	-	-	0.18	21.67	823.40	3008	27.37
Dungarpur	-	452.31	-	-	596.17	23.14	0.22	-	42.47	46.22	1477.48	3770	39.19
Sri Ganganagar	-	116.63	16.35	-	-	0.28	-	944.68	2.41	-	1089.89	10978	9.92
Hanumangarh	-	102.23	11.39	-	23.21	9.44	-	145.95	0.31	-	251.99	9656	2.60
Jaipur	190.25	282.81	-	68.82	361.83	31.89	10.76	5.02	0.14	66.64	1559.87	10636	14.66
Jaisalmer	-	11040	7.62	130.42	107.94	122.61	-	12093.8	2.4	1219.4	24724.29	38401	64.38
Jalore	55.25	317.84	-	76.08	133.15	241.10	0.63	124.66	0.65	173.35	1122.70	10640	10.55

Jhalawar	5.01	909.6	-	-	521.76	12.21	-	-	3.38	9.92	1461.89	6219	23.50
Jhunjhunu	58.19	349.45	-	-	128.83	36.87	7.75	12.98	1.92	26.50	623.31	5928	10.51
Jodhpur	6.43	1357.63	-	63.47	59.82	586.03	0.24	1536.95	0.60	495.06	4106.23	22850	17.97
Karauli	6.51	425.65	-	-	1185.57	6.65	-	-	-	45.37	1709.84	5524	30.95
Kota	16.07	392.63	-	-	525.35	5.09	0.31	-	0.08	5.25	944.77	5481	17.23
Nagaur	29.72	682.12	0.99	119.34	0.08	373.89	-	96.81	2.27	58.82	1475.62	17718	8.32
Pali	9.11	1471.01	-	92.22	155.78	284.96	34.26	3.06	1.35	262.73	2314.47	12387	18.68
Rajsamand	-	1407.14	-	-	22.5	26.67	26.67	-	0.77	357.25	1814.38	4689	38.69
Sikar	82.26	412.26	0.09	10.62	273.72	44.46	1.57	20.76	0.11	26.0	871.84	7732	11.27
Sirohi	45.25	778.69	-	9.16	481.78	34.85	3.73	18.58	2.21	104.25	1478.51	5136	28.78
Sawai Madhopur	117.26	242.25	-	-	347.89	8.37	11.18	4.67	-	9.18	731.65	5003	14.62
Tonk	55.36	543.75	-	-	99.3	2.69	1.82	0.16	-	13.86	716.94	7194	9.96
Udaipur	-	2405.23	-	-	1325.79	37.58	0.54	-	2.26	220.52	3991.91	12590	31.70
Total	**1299.36**	**34137.26**	**95.34**	**799.01**	**11122.01**	**3181.41**	**103.16**	**23539.35**	**28.99**	**4544.40**	**78851.33**	**342239**	**23.03**

Table 2.2: Change in the land degradation status (lakh ha) over time (NRSC, 2019)

Type of Degradation	2008-09	2015
Ravine Lands	1.340	1.299
Saline/Sodic Lands	0.772	0.800
Water logged/Marshy	0.103	0.100
Degraded Forest	11.370	11.120
Degraded Grazing Lands	3.524	3.180
With or Without Scrub	36.400	34.137
Shifting Sands	0.108	0.103
Stabilized Sand	25.474	23.530
Mines spoil	0.015	0.029
Barren Rocky	4.547	4.540
Total	**83.654**	**78.85**

2.1 Water Erosion

Earlier work documenting water induced erosion in Rajasthan were focused on ravine lands (Anonymous, 1972 and 1982). Based on ocular observations taken at 10 km grid point Shyampura and Sehgal (1995) estimated 31365 sq. km (3.13 M ha) under the influence of water induced erosion, which was 9.16% of total area of the state. Apparently it was a gross under estimation of the problem and subsequently more detailed careful assessment of severity and extent of land degradation due to water erosion were taken up in due course.

2.1.1 Sheet and Rill Erosion

Sheet erosion is the uniform removal of soil in thin layers by the forces of raindrops and overland flow. This is an initial stage of erosion processes which cover large areas of sloping land and remain un-noticed until substantial part of top soil is washed away or rills grow into small gullies. For making an assessment of soil loss through sheet and rill erosion Narayana and Rambabu (1983) derived soil loss rates for 20 land resource regions from sediment data from 36 river systems along with some additional data on rainfall and discharge rate of different catchments. Later, Singh *et. al*. (1992) presented an iso-erosion map of India based on 21 observed and 64 estimated soil loss data points spread over different land resource regions of India. The iso-erosion lines were drawn by super imposing soil map, rainfall erosivity, slope, land use, forest vegetation and irrigation. These works summarized the problem of soil erosion at National scale and presented somewhat reliable estimates for annual soil loss at regional level. Nevertheless, more detailed mapping (larger than 1:250,000) was desirable for prioritizing watersheds and using the erosion maps as planning tools. The ICAR-IISWC and ICAR-NBSSLUP jointly initiated the preparation of state wise detailed erosion maps using soil survey data available at 10 km grid. The soil erosion map of the Eastern Rajasthan was prepared using Universal Soil Loss Equation (USLE) depicting severity and extent of sheet and rill erosion (Singh *et. al.*, 2005). Based on primary data extracted from soil survey data sheets and soil resource maps (Shyampura and Sehgal, 1995) this map elucidates the severity of water induced erosion in Eastern Rajasthan (Fig. 2.1 and Table 2.3). About 66.7% of total geographical area (1, 34,627 sq km) of Eastern Rajasthan show annual soil loss rates exceeding 10 t/ha. This may be little surprising as average annual rainfall in the region is relatively low and ranges from 400 to 1000 mm. Much higher erosion rates per unit of rain energy in Rajasthan are primarily due to very poor soil cover and high soil erodibility. Erosion permitting crops such as sorghum and maize are cultivated during monsoon season. Higher soil erodibility due to low soil organic matter and erosive rainfall pattern are also contributing factors for such differences. Under these conditions steeper slopes with topographic factor exceeding the value of 2.0 trigger soil loss rates to >40 t/ha. About 14.8% area of this region located predominantly in Dungarpur, Udaipur, Rajsmand, Alwar, Jaipur and Sawai Madhopur districts show severely higher erosion rates more than 40 t/ha/year. About one third of the area has soil loss rates less than 10 t/ha/year which is well within the soil loss tolerance limits. These are mostly the flat areas in central high lands spread over Jaipur, Ajmer and Bhilwara districts with loamy textured soils. Despite a methodological limitation of this erosion map for its inability to delineate and highlight advance stages of erosion such as gully erosion, which is one of the major concerns in the 33.3% area of the region, the erosion map highlights the high risk erosion prone areas and major causative factors responsible alarming erosion rates, and therefore it is a valuable planning tool to state developmental agencies.

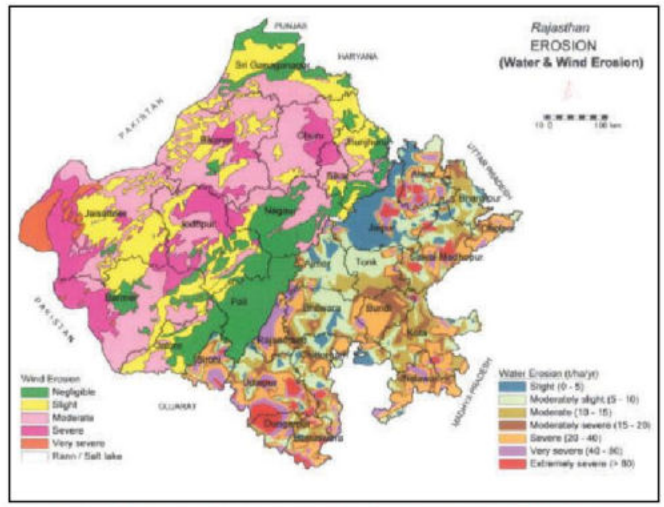

Fig. 2.1: Wind and water erosion status in Rajasthan

Table 2.3: Area distribution under different erosion classes

Erosion class	Range of soil loss (t/ha/year)	Area (000'ha)	Area of Rajasthan (%)
Very slight	<5	1341.5	3.92
Slight	5-10	3128.7	9.14
Moderate	10-15	2600.0	7.59
Moderately severe	15-20	1578.4	4.61
Severe	20-40	2786.9	8.14
Very severe	40-80	1323.0	3.86
Total		**13437.1**	**39.24**

Source: Singh *et. al.* (2005)

2.1.2 Gully Erosion

Gully erosion is an advanced stage of rill erosion where surface channels have been eroded to the point where they cannot be smoothened over by normal tillage operations. Generally gully formation is prevalent in the vicinity of river and their tributaries. Steep elevation difference between drainage line and adjoining table lands, cracking clay or erosion prone deep alluvial soils, absence of adequate vegetation due to excessive grazing and tree felling and uncontrolled runoff concentration into cart wheel grooves and natural drainage channels are the contributing factors to gully formation which eventually leads to severe terrain deformation restricting land use options.

There are hardly any pre-independence historic records documenting extent or distribution of ravine lands in India. Based on detailed ground survey the National Commission on Agriculture of India provided first authentic report on state wise ravine area distribution and reported a total of 3.67 M ha and 0.452 M ha of ravine lands in India and Rajasthan, respectively (NCA, 1976). During the period of 1985-2000, NBBSLUP and NRSA developed soil degradation and wasteland maps of India using two different approaches. Following process-based degradation mapping derived from 10 km grid soil profile studies supported with satellite data, NBSSLUP estimated 10.37 M ha ravine land in the country which was classified as *Terrain Deformation* due to water erosion (Sehgal and Abrol, 1994). The NRSA followed remote sensing technology for identifying land use and physical features for mapping non-agricultural areas and reported 2.06 M ha of gullied and ravine land. The gross underestimation of ravine area by NRSA was primarily due to exclusion of agricultural land and difference in mapping approach. To tackle the issue of conflicting figures reported by different organizations, National Academy of Agricultural Sciences (NAAS) took an initiative to harmonize and normalize the area statistics with scientific and logical reasoning through inter-institutional meetings (ICAR-NAAS 2010). The harmonized statistics suggested a total of 10.37 M ha area under influence of gully erosion, which included 2.06 M ha ravine waste-lands. Nevertheless, these estimates emerged from land degradation data previously reported by different organizations without any further ground verification the harmonized data carried forward the inherent limitations of data collection procedures use previously. In the year 2014 ICAR-IISWC delineated ravine lands in four states of Rajasthan, Madhya Pradesh, Utter Pradesh and Gujarat using remote sensing imageries with visual delineation approach supported with intensive ground truthing. Total ravine area delineated in four states was 10.36 lakh ha. In Rajasthan 18 districts had significant presence of ravine lands with a total spread of ravine land in the state of 2.79 lakh ha. Sawai Madhopur, Kota, Dhaulpur, Jaipur, Bundi are major ravine districts. There was about 38% reduction in the total ravine area in the state with reference to ravine area statistics reported by NCA for the period of 1976 (Table 2.4).

Table 2.4: District wise changes in ravine land over time in Rajasthan

District	Ravine land (area in ha)	
	1972 (Verma *et. al.*, 1985)	2014 (ICAR-IISWC, 2014)
Ajmer	3000	2999
Alwar	10000	10064
Banswara	500	228
Barmer	-	1320
Bharatpur	53300	2907
Bhilwara	3300	3983
Bundi	86000	25482
Chittorgarh	-	566

Dholpur	-	35762
Dungarpur	800	813
Jaipur (+ Dausa)	20000	34960
Jalore	-	43
Jhalawar	690	5474
Jhunjhunu	-	6413
Kota (+ Baran)	132600	41885
Nagaur	-	1495
Pali	-	1871
Sawai Madhopur (+ Karauli)	130000	81987
Sikar	-	7866
Sirohi	1200	118
Tonk	4400	7478
Udaipur	-	352
Total	**452000**	**279261**

2.1.2.1 Rate of Gully Extension

The ravine extension rates of over a period of 15 to 20 years were estimated for Chambal ravines region by extracting topographic data from village revenue maps, Survey of India topo sheets and Google earth maps for different dates (Table 2.5). Data obtained from secondary sources were verified with actual ground surveys feedback from local inhabitants. The ravine ingress rate was computed using following equation.

$A_n = A_0 (1 + \frac{r}{100})^n$	*Where A_n is ravine area after n years, A_0 is initial ravine area, r is compound rate of ravine ingress (%) and n is number of year.*

The estimated annual ingress rate for untreated Chambal catchments ranged from 0.133 to 1.264 % with an overall average of 0.556%. This implies that 100 ha of ravine area would extend to 102.8, 105.7 and 111.73 ha after 5, 10 and 20 years, respectively in the absence of adequate conservation measures. The average ingress rate increased from 0.43% to 1.26% over a period of 60 years under unprotected conditions. Partially or fully treated ravine clusters have shown negative ingress rates indicating reduction in ravine area and initiation of restoration of ravine lands.

Table 2.5: Ravine ingress rates in Chambal catchment of South-Eastern Rajasthan

Time segment	Location	Land treatment	Study period	Observed changes in ravine area spread (ha)			Ingress rate (%)	Data source / Reference
				Initial	Final	Difference		
I	Kachnavada cluster, Dist. Kota	Unprotected	1951-1970	165.80	182.50	16.70	0.481	Village revenue maps & Survey of India topo-sheets for respective years (Katiyar 1992, Katiyar *et. al.* 1994, 1995)
	Badakhera cluster, Dist. Bundi	Unprotected	1951-1970	730.40	831.00	100.60	0.647	
	Pipalda cluster, Dist. Kota	Unprotected	1955-1971	360.00	395.99	35.99	0.597	
	Khunetia cluster, Dist. Kota	Unprotected	1955-1971	58.23	62.80	04.57	0.473	
	Baldeopura cluster, Dist. Kota	Unprotected	1955-1971	25.10	27.30	02.20	0.526	
	Biraj cluster, Dist. Bundi	Unprotected	1952-1971	2313.00	2375.00	62.00	0.133	

	Ajinda-Kapren cluster, Dist. Bundi	Unprotected	1952-1971	2055.00	2185.00	132.00	0.312	
	Domgraja cluster (Sultanpur), Dist. Kota	Unprotected	1952-1971	1606.00	1692.00	88.00	0.267	
II	Gokulpura cluster, Dist. Kota	Untreated	1962-1982	2016.00	2395.00	379.00	0.865	
	Bagli Village, K. Patan, Dist. Bundi	Unprotected	2003-2016	90.46	106.51	16.05	1.264	Google earth maps for respective years supported by field survey
III	Lohli-Bagli cluster, Khatkar, Dist. Bundi	Partially treated	2001-2018	317.62	229.53	- 88.09	-1.449	
	Badakhera, Lakheri, Dist. Bundi	Treated ravine cluster	2006-2018	400.31	345.76	- 45.55	- 0.902	

2.2 Wind Erosion

The Western part of Rajasthan, covering an area of 207849 sq. km is under arid climate. During hot summer months sandy landscape is exposed to strong winds. In the absence of any vegetative cover loose sand and other fine particles are blown miles away and get deposited at distant places. This process of soil movement is called wind erosion. The process often leads to fertility depletion of eroded fields. Considerable damage occurs to the sites where deposition takes place as the productive soil gets buried under coarse grained sands. Another form of threat to agriculture from wind erosion is sand blasting which is the injury caused to tender stem and leaves during the sand storm. Also exposure of shallow root leads to death of crop plants.

Based on field criteria such as depth of removal or deposition of fresh sand sheets, size and distribution of sandy hummocks (Nebkhas), and drifting of sand dunes, severity of wind erosion and deposition has been mapped by Narain *et. al.* (2000) and presented here in Fig. 2.2 and Table 2.6. The map shows that about 61% area of the state is under the influence of wind erosion and more than half of it is under moderate to very severe categories. Broadly the extreme Western part of Jaisalmer district is under very severe class, where large, elliptical fields of high megabarchanoids occur amidst linear dune fields. Here the wind erosivity index is greater than 480. Human settlement is almost absent in this area. This zone is flanked to the East by severe and moderate wind erosion classes extending up to Sanchar - Balotra - Jodhpur - Osian - Nagaur - Sihor - Jhunjhunu - Nohar - Suratgarh line. Large variations occur in the North-East, especially in Ratangarh - Churu - Sikar area where the erosivity index is low, but high cultivation and grazing pressures on the highly erodible dune and inter dune land scape has resulted in moderate to severe wind erosion. In between above zones the shallow sandy and rocky tracts of Barmer - Jaisalmer - Ramgarh - Pokran severity of wind erosion is very low, because of paucity of sediment and hardness of the surface. Roughly to the East of Bhinmal – Jalore – Bilara – Merta - Nagaur the terrain consists mainly of sandy alluvial plains, with scattered hillocks and rocky pediments. These areas are without appreciable sand sheet cover, have negligible wind erosion problem. The deep alluvial plain in the North, especially along the Ghaggar valley and around Sri Ganganagar, as well as the hilly areas of the Aravalies in the North-East are also under negligible wind erosion class.

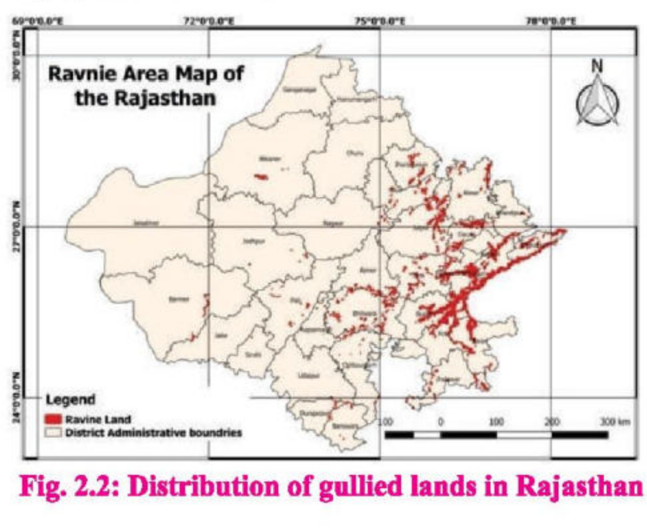

Fig. 2.2: Distribution of gullied lands in Rajasthan

Table 2.6: Wind erosion / deposition classes in Western Rajasthan

Erosion / deposition	Area (000' ha)	Area of Rajasthan (%)
Very severe	592.3	1.73
Severe	3016.8	8.81
Moderate	7430.0	21.69
Slight	5242.0	15.31
Negligible	2529.6	13.23
Total	**18810.7**	**60.77**

Source: Narain *et. al*. (2000)

3.0 TECHNOLOGICAL ACHIEVEMENTS

The Centre has taken up various research programmes on appraisal of the resources, their conservation and productive utilization. The research activities were focused on the seven priority areas as listed below:

3.1 Water erosion appraisal in different agro-ecological regions
3.2 Conservation measures for sustainable production systems
3.3 Hydrological behaviour of watershed for conservation planning
3.4 Rehabilitation of areas affected by mass erosion
3.5 Participatory integrated watershed management
3.6 Socio-economic analysis and policy development for watershed management
3.7 Human resource development and technology transfer

The research accomplishment of Research Centre, Kota in above listed seven priority areas are classified as theoretical and applied. The theoretical accomplishments refer to the contribution towards understanding of processes and developing research tools, which are primarily for the researchers. The applied section refers to the technologies developed for field applications.

The technological achievements are presented in two section where, technologies developed and refinement by the research centre, Kota and secondly by the other R&D organization in the region.

3.1 Technologies Developed and Refinement at Research Centre, Kota - Theoretical

3.1.1 Water Erosion Appraisal in Different Agro-ecological Regions

3.1.1.1 Inventory and Database of Erosion Status Using Modern Tools and Procedure

3.1.1.1.1 Erosion map of Rajasthan

The ICAR-IISWC and ICAR-NBSSLUP jointly initiated the preparation of state-wise detailed erosion maps using soil survey data available at 10 km grid. The soil erosion map of the Eastern Rajasthan was prepared using Universal Soil Loss Equation (USLE) depicting severity and extent of sheet and rill erosion (Singh *et. al*., 2005). Based on primary data extracted from soil survey data sheets and soil resource maps (Shyampura and Sehgal, 1995) this map elucidates the severity of water induced erosion in Eastern Rajasthan (Fig.3.1 and Table 3.1). About 66.7% of total geographical area (1,34,627 km^2) of Eastern Rajasthan show annual soil loss rates exceeding 10 t/ha. This may be little surprising as average annual rainfall in the region is relatively low and ranges from 400 to 1000 mm. Much higher erosion rates per unit of rain energy in Rajasthan are primarily due to very poor soil cover and high soil erodibility. Erosion permitting crops such as sorghum and maize are cultivated during monsoon season. Higher soil erodibility due to low soil organic matter and erosive rainfall pattern are also contributing factors for such differences. Under these conditions steeper slopes with topographic factor exceeding the value of 2.0 trigger soil loss

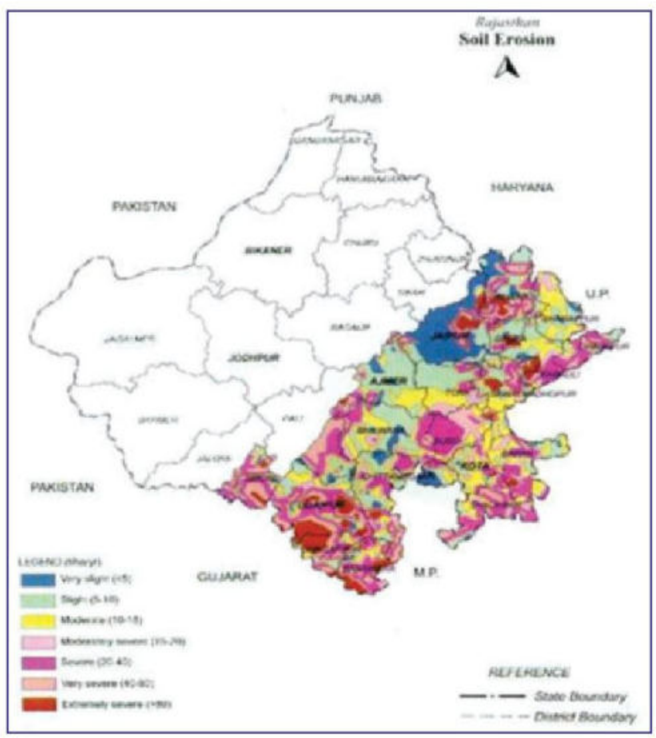

Fig. 3.1: Erosion map of Eastern Rajasthan

rates to >40 t/ha. About 14.8% area of this region located predominantly in Dungarpur, Udaipur, Rajsmand, Alwar, Jaipur and Sawai Madhopur districts show severely higher erosion rates more than 40 t/ha/year. About one third of the area has soil loss rates less than 10 t/ha/year which is well within the soil loss tolerance limits. These are mostly the flat areas in central high lands spread over Jaipur, Ajmer and Bhilwara districts with loamy textured soils. Despite a methodological limitation of this erosion map for its inability to delineate and highlight advance stages of erosion such as gully erosion, which is one of the major concerns in the 33.3% area of the region, the erosion map highlights the high risk erosion prone areas and major causative factors responsible alarming erosion rates, and therefore, it's a valuable planning tool to state developmental agencies.

Table 3.1: Area distribution under different erosion classes

Erosion class	Range of soil loss (t/ha/year)	Area (000'ha)	Area of Rajasthan (%)
Very slight	<5	1341.5	3.92
Slight	5-10	3128.7	9.14
Moderate	10-15	2600.0	7.59
Moderately severe	15-20	1578.4	4.61
Severe	20-40	2786.9	8.14
Very severe	40-80	1323.0	3.86
Extremely severe	>80	678.6	1.98
Total		**13437.1**	**39.24**

Source: Singh *et. al.* (2005)

3.1.1.1.2 Gully erosion assessment in Chambal ravine region

Gully erosion, an advanced stage of water erosion induced land degradation, is a serious problem in Chambal ravine region. There have been periodical assessments of the problem through direct and indirect methods. In the year 2014 initiative was taken to delineate ravine lands in Rajasthan using remote sensing imageries with visual delineation approach supported with intensive ground truthing. In Rajasthan 18 districts had significant presence of ravine lands with a total spread of ravine land is 2.79 lakh ha. Sawai Madhopur, Kota, Dhaulpur, Jaipur, Bundi are the major ravine affected districts. There were about 38% reductions in the total ravine area in the state with reference to ravine area statistics reported by NCA for the period of 1976 (Table 3.2).

Table 3.2 District-wise changes in ravine land over time in Rajasthan

District	Ravine land (area in ha)	
	1972 (Verma *et. al.*, 1985)	2014 (ICAR-IISWC, 2014)
Ajmer	3000	2999
Alwar	10000	10064
Banswara	500	228
Barmer	-	1320
Bharatpur	53300	2907

Bhilwara	3300	3983
Bundi	86000	25482
Chittorgarh	-	566
Dholpur	-	35762
Dungarpur	800	813
Jaipur (+ Dausa)	20000	34960
Jalore	-	43
Jhalawar	690	5474
Jhunjhunu	-	6413
Kota(+ Baran)	132600	41885
Nagaur	-	1495
Pali	-	1871
S. Madhopur (+ Karauli)	130000	81987
Sikar	-	7866
Sirohi	1200	118
Tonk	4400	7478
Udaipur	-	352
Total	**452000**	**279261**

Rate of gully extension: The ravine extension rates of over a period of 15 to 20 years were estimated for Chambal ravines region by extracting topographic data from village revenue maps, Survey of India topo-sheets and Google earth maps for different dates (Table 3.3). Data obtained from secondary sources were verified with actual ground surveys feedback from local inhabitants. The ravine ingress rate was computed using following equation

$A_n = A_0 (1 + \frac{r}{100})^n$	*Where A_n is ravine area after n years, A_0 is initial ravine area, r is compound rate of ravine ingress (%) and n is number of year.*

Table 3.3: Ravine ingress rates in Chambal catchment of South-Eastern Rajasthan

Time segment	Location	Land treatment	Study period	Observed changes in ravine area spread (ha)			Ingress rate (%)	Data source / Reference
				Initial	Final	Difference		
I	Kachnavada cluster, Dist. Kota	Unprotected	1951-1970	165.80	182.50	16.70	0.481	Village revenue maps & Survey of India toposheets for respective years (Katiyar 1992, Katiyar *et. al.* 1994, 1995)
	Badakhera cluster Dist. Bundi	Unprotected	1951-1970	730.40	831.00	100.60	0.647	
	Pipalda cluster, Dist. Kota	Unprotected	1955-1971	360.00	395.99	35.99	0.597	
	Khunetia cluster, Dist. Kota	Unprotected	1955-1971	58.23	62.80	04.57	0.473	
	Baldeopura cluster, Dist. Kota	Unprotected	1955-1971	25.10	27.30	02.20	0.526	

	Biraj cluster, Dist. Bundi	Unprotected	1952-1971	2313.00	2375.00	62.00	0.133	
	Ajinda-Kapren cluster, Dist. Bundi	Unprotected	1952-1971	2055.00	2185.00	132.00	0.312	
	Domgraja cluster (Sultanpur) , Dist. Kota	Unprotected	1952-1971	1606.00	1692.00	88.00	0.267	
II	Gokulpura cluster, Dist. Kota	Untreated	1962-1982	2016.00	2395.00	379.00	0.865	
	Bagli Village, K. Patan, Dist. Bundi	Unprotected	2003-2016	90.46	106.51	16.05	1.264	
III	Lohli-Bagli cluster, Khatkar, Dist. Bundi	Partially treated	2001-2018	317.62	229.53	- 88.09	-1.449	Google earth maps for respective years supported by field survey
	Badakhera, Lakheri, Dist. Bundi	Treated ravine cluster	2006-2018	400.31	345.76	- 45.55	- 0.902	

The estimated annual ingress rate for untreated Chambal catchments ranged from 0.13 to 1.3% with an overall average of 0.56%. This implies that 100 ha of ravine area would extend to 102.8, 105.7 and 111.73 ha after 5, 10 and 20 years, respectively in the absence of adequate conservation measures. The average ingress rate increased from 0.43% to 1.26% over a period of 60 years under unprotected conditions. Partially or fully treated ravine clusters have shown negative ingress rates indicating reduction in ravine area and initiation of restoration of ravine lands.

3.1.1.2 Soil Erosion Processes and Models

3.1.1.2.1 USLE parameters

Soil erosion is a major factor contributing to land degradation and impairing environmental quality. It is often triggered and accelerated by land use changes and faulty management practices. To effectively control soil erosion and efficiently manage the land resources for sustained productivity on agricultural lands, it is imperative to properly understand the dominant erosion mechanism in a given area. Among the several erosion assessment models, the USLE is the simplest and most widely used model for predicting soil erosion for conservation planning and evaluation of best management practices (BMPs). The USLE is expressed as:

$$A = RKLSCP$$

Where,

A = Average annual soil loss per unit area above a measuring point (t/ha/yr),

R = Rainfall erosivity factor or rainfall and runoff factor, equal to the sum of the annual or seasonal energy-intensity (EI) interaction factors for all storms (MJ mm/ha/h/yr),

K= Soil erodibility factor (t/ha/R unit) of a specific soil type and horizon,

L = Slope length factor which is ratio of soil loss from the actual land slope to that from a standard plot (22.13 m) (dimensionless),

S = Slope steepness factor which is ratio of soil loss from the actual land slope to that from a standard plot slope (9%) (Dimensionless),

C=Cropping management factor (dimensionless),

P= Erosion control or support practice factor (dimensionless).

The research carried out at Kota Centre to determine appropriate values of the USLE parameters is summarized here under:

Rainfall erosivity factor (R): Rainfall erosivity (R) is the most dynamic factor in the erosion process. The R-factor was calculated from 43 years (1956 to 1998) rainfall data available for the Kota region (Narain, *et. al*., 1982 and Ali *et. al*., 2001). On annual basis, values varied from 83 to 1034 MJ-mm/ha-hr, with an average of 354 MJ-mm/ha-hr. Monthly distribution of rainfall erosivity is given in the Fig.3.3. A major part of the R-factor amounting to 87% of the annual values occurred during the rainy period (June to September) in the Kota region. The month of August registered the maximum rainfall erosivity followed by July and September. The rainfall erosivity factor for the 2, 5 and 10 year return period was 255, 550 and 900 MJ-mm/ha-hr, respectively.

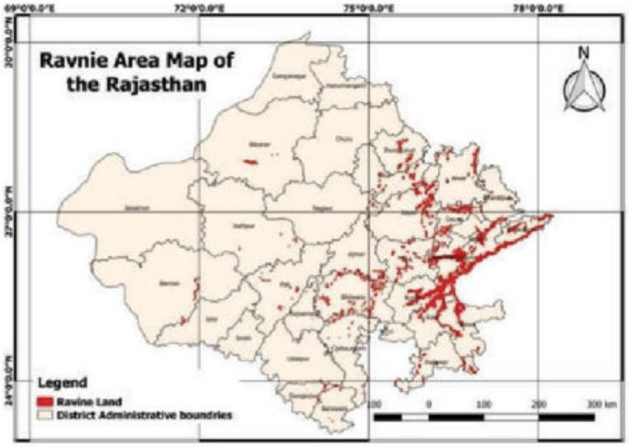

Fig. 3.2: Distribution of gullied lands in Rajasthan

Fig. 3.3: Cumulative monthly EI_{30}

The existing procedure for estimating the erosion index (EI_{30}) is quite laborious and time consuming. In order to simplify the complex procedure for estimating the erosion index (EI_{30}), a relationship between EI_{30} and precipitation index 'PI' (defined as the product of the total daily rainfall and rainfall intensity of specified period) has been developed (Verma *et. al*., 1986) for various durations and are presented in Table 3.4.

Table 3.4: Relationship between EI_{30} and PI

Duration (minutes)	Equation	Correlation coefficient (r)
5	$EI_5 = 2.691\, PI_5 - 2.9504$	0.9793
10	$EI_{10} = 2.681\, PI_{10} - 1.8909$	0.9653
15	$EI_{15} = 2.3391\, PI_{15} - 1.5094$	0.9114
30	$EI_5 = 2.5325\, PI_{30} - 0.5432$	0.9804
60	$EI_{60} = 2.6785\, PI_{60} - 0.8768$	0.9904
1440	$EI_5 = 2.2636\, PI_{1440} - 0.0070$	0.9644

P and I have the unit of cm and cm/h, respectively.

Soil erodibility factor (K): The soil erodibility factor K for the clay loam soils of region was determined using soil loss data obtained from fallow runoff plots at 1% slope (Narain *et. al*., 1982; Ali *et. al*., 2001) and adjusted for slope gradient factor. The cropping season (July-September) K-values varied between 28.5 and 208.5 kg/ha/unit R-factor with an average annual value of 114.5 kg/ha/unit R- factor for the silty clay soil of the Kota region. While the annual K-values ranged from 41.3 to 226.9 kg/ha/unit R-factor with an average annual value of 102.9 kg/ha/unit R-factor.

Topographic factor (LS): In Kota region, all the cultivated plots as well as fallow plots were of standard size (22.13 m x 1.86 m) and 1% slope for the different cropping systems. The length and degree of slope factor were jointly computed as a topographic factor (LS) following the procedure outlined by Wischmeier and Smith (1978). For the standard size runoff plots, the LS factor was calculated as 0.116 for the 1% slope for the Kota region (Ali and Sharda, 2005).

Cropping management factor (C): This factor for different crops has been estimated for successive growth stages (Narain *et. al.,* 1982; Ali *et. al*., 2001) as presented in table 3.5. The crop growth period varied between 60-70 days for leguminous crops (cowpea, black gram, green gram and groundnut) and between 90-120 days for the cereal crops (sorghum and maize). The C-values for leguminous crops varied between 0.3511 and 0.6058, small range of Cdue to the quick establishment of legume crops, which provides a good soil cover to minimize soil erosion. Among the legumes, cowpea was least susceptible crop to erosion (0.3511) and cluster bean was the most erosive leguminous crop. C-value of intercropping ranged between 0.3084 and 0.3718 while maize crop registered highest C-value (0.5236), which was attributed to wider plant to plant and inter row spacing. Thus, a proper vegetative cover (C-factor) plays a crucial role in minimizing the soil erosion at a given location.

Support practice factor (P): The support practice factor (P) defines the effect of a conservation practice on soil erosion which may include agronomic and land configuration measures for reducing the length and/or degree of slope. Ali *et. al.* (2001) estimated 'P' factor for contouring, dead furrow and compartmental bunding (Table 3.6). The values estimated for contouring was 0.77 for dead furrow at 5.5 or 7.3 m horizontal interval (HI) these values were 0.21 and 0.29 and for compartmental bunding at 5.5 m and 7.3 m HI, the P values were 0.02 and 0.03. The compartment bunding with 0.02 m^2 cross sectional area almost completely conserves the runoff.

Table 3.5: Soil Cover 'C' values estimated from runoff plots data for different crops

Crop	Year of record	Crop stages				Value of 'C'
		1st stage (0-30 days)	2nd stage (30-60 days)	3rd stage (60-90) days	4th stage (> 90 days)	
Natural cover	9	0.0109	0.1132	0.0271	0.0000	0.1512
Sorghum	9	0.2461	0.2529	0.1175	0.0000	0.6165
Maize	3	0.1294	0.3201	0.0741	0.0000	0.5236
Castor	5	0.2151	0.2006	0.1137	0.0000	0.5294
Greengram	5	0.1160	0.2510	0.0408	0.0000	0.4078
Blackgram	3	0.3287	0.1211	0.0617	0.0000	0.5115
Groundnut	3	0.1275	0.1920	0.0914	0.0000	0.4109
Soybean	3	0.2499	0.1409	0.0184	0.0000	0.4092
Cowpea	3	0.3236	0.0243	0.0032	0.0000	0.3511
Clusterbean	3	0.2610	0.3337	0.0111	0.0000	0.6058
Sorghum+ Pigeonpea (1:1)	4	0.2913	0.0685	0.0051	0.0069	0.3718
Castor + Greengram (1:2)	5	0.1567	0.1180	0.0293	0.0044	0.3084
Dichanthium annulatum	6	0.0014	0.0029	0.0045	0.0000	0.0088

Table 3.6: Erosion control practices factor (P) for various measures

Treatment/ Crop	Erosion control practices factor (P)					
	Contouring	Dead furrow	Compartmental bunding			
	Row crop	Row crop + legumes	5.5 m HI	7.3 m HI	5.5 m HI	7.3 m HI
Sorghum	0.82	-	0.21	0.29	0.02	0.03
Castor	0.71	-	-	-	-	-
Sorghum + Pigeonpea (1:1)	-	0.71	-	-	-	-
Castor + Greengram (1:2)	-	0.83	-	-	-	-
Average	**0.77**	**0.77**	**0.21**	**0.29**	**0.02**	**0.03**

3.1.1.2.2 Application of USLE for Kota region

The performance of Universal Soil Loss Equation (USLE) was evaluated for various crops in the Kota region based on the average annual, annual and crop growth stages soil loss values (Ali and Sharda, 2005; Sharda and Ali, 2008). The Nash and Sutcliffe model efficiency ^{2} was 0.95 for the average annual prediction and 0.90 for the annual prediction. Model efficiency based on annual data series was found to be relatively poor (0.46). However, on an annual average basis, the model efficiency improved significantly to 0.81. The soil loss predicted by the USLE for both types of data sets was found to be in a reasonably good agreement with the observed data. The soil loss prediction by USLE for crop growth stages-I and II was better while it was poor for crop growth stage-III. Nash Sutcliffe model efficiency ^{2} for all values of crop growth stages ranged from -0.25 to -5.64. This implies that USLE can be used for prediction of average annual and annual soil loss under varied climatic situations of Kota region.

3.1.1.2.3 USLE parameters mapping for Eastern Rajasthan

On the basis of available agro-climatological and land use data thematic layers were developed on GIS platform and maps were developed for highlighting severity of erosion contributing factors such as rainfall erosivity, soil erodibility, land slope, soil cover and protective measures adopted (Fig.3.4).The research carried out at Kota Centre to determine appropriate values for the six USLE parameters is summarized here:

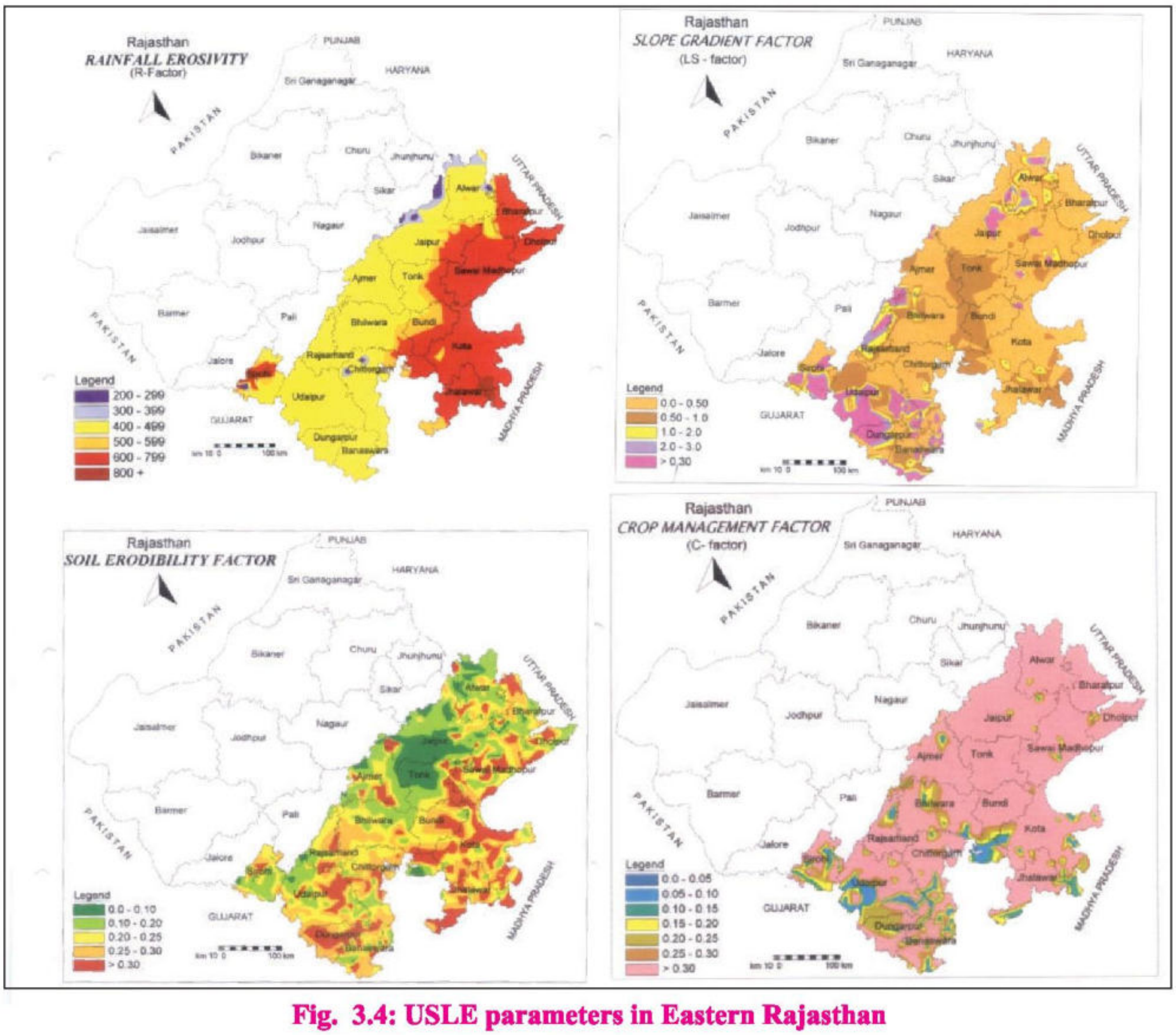

Fig. 3.4: USLE parameters in Eastern Rajasthan

Rainfall erosivity (R) map: Rainfall is the most dynamic factor in the erosion process. To determine erosion index (EI 30) values event wise rainfall data from self-recording rain gauge for several years period are required. Monthly, seasonal and annual EI30 values have been worked out for the region using rainfall data of 48 years period (1956-03). Monthly distribution of rainfall erosivity is given in previous section under theoretical portion. However, due to limited availability of rainfall data from self-recording rain gauges, Iso-erosion map as published by Ragunath *et. al.* (1982) has been referred for presenting the distribution of R values in Eastern Rajasthan.

Soil erodibility (K) map: The soil erodibility factor K for the clay loam soils of region was determined using soil loss data obtained from fallow runoff plots at 1% slope (Narain *et. al.*, 1982) and adjusted for slope gradient factor. The estimated K value ranged from 0.03 to 0.23 t/ha/unit of 'R' and averaged at 0.11 t/ha/yr. Another method to estimate K values is to use nomograph (Wishemeir *et. al.*, 1971). Soil erodibility values for 10 km grid point were estimated and mapped using nomograph with the soil survey data provided by NBSS &LUP

Crop management factor (C) map: This factor for different crops have been estimated for successive growth stages (Narain *et. al.*, 1982) as presented in table 3.5. The values for C factor ranged from 0.31 to 0.62 for various crops and crop combinations and 0.101 to 0.13 for grass cover. Using these values for dominant land uses C values were estimated for 10 km grid point.

Erosion control practices (P): This factor for contouring, dead furrow and compartmental bunding has been estimated by Ali *et. al.* (2001). The values estimated for contouring was 0.77, for dead furrow at 5.5 or 7.3 m horizontal interval these values were 0.21 and 0.29 and for compartmental bunding at 5.5 m and 7.3 m HI, P values were 0.02 and 0.03(Table 3.6). The compartment bunding with 0.02 m^2 cross sectional area almost completely conserved the runoff.

Based on research carried out at Kota and other IISWC, Research Centres on USLE parameters of the 10 km grid point using soil survey data provided by NBSS & LUP soil erosion map has been prepared by Singh *et. al.* (2004) and presented in previous section.

3.1.1.2.4 Soil loss estimation model

A simple soil loss estimation equation has been proposed by Ali *et. al.* (2002) for estimating the soil loss from agricultural land under various crop management practices. The annual soil loss values measured from 1956 to 1998 for 15 different covers *viz.* cultivated fallow (28 years), natural cover (3 years), *Dichanthium annulatum* (16 years), *Cynodon dactylon* (3 years), sorghum (9 years), blackgram (3 years), groundnut (3 years), maize (3 years), cowpea (3 years), cluster bean (3 years), greengram (3 years), sorghum + pegionpea (4 years), castor (5 years), castor + green gram (5 years) and *Cenchrus ciliaris* (3 years) were utilized for model development. The equation required rainfall erosivity (R), soil erodibility (K) and cover management factor (C) of universal soil loss equation (USLE) as the independent variables. Mathematical model is expressed as:

$$Y = 0.000845(RKC)^{0.82}$$

Where, Y is soil loss (t/ha), R is rainfall erosivity factor (EI unit per unit time which is usually seasonal/annual), K is soil erodibility factor (kg/ha/unit of R), C is cover management factor (dimensionless)

3.1.1.3 Soil Carbon Dynamics and Erosion–Productivity

3.1.1.3.1 Carbon sequestration potential of tree based land use systems

A study was undertaken to evaluate the carbon sequestration potential of different tree based production systems located at Kota Research farm and three natural forest sites in the Shahbad range of Baran division namely, Shahpur, Mamoni and Kaloni; which represent natural dry deciduous forests of the region. The dominant species in these plantations were *Terminalia bellirica, Boswelia serrata, Buchanania cochinchinensis, Diospyros melanoxylon, Butea monosperma, Anogeissus pendula, Lannea coromandelica*. The forest floor had good amount of undecomposed litter. The peak litter fall in most spp. was observed in

April month. In natural forest highest litter production has been observed in *Boswelia serrata* (9.02 Mg/ha) followed by *Lannea coromandelica* (8.83 Mg/ha), while the lowest litter production has been observed in *Acacia catechu* (1.62 Mg/ha). Under tree based land use systems highest litter production has been observed in *Acacia nilotica* (6.23 Mg/ha) followed by *Aegle marmelos* (5.66 Mg/ha). *Acacia nilotica* followed by *Aegle marmelos* based land use system has proved higher carbon sequestrations in terms of biomass production, litter accumulation and soil fertility build up under tree based systems in Chambal ravines (Table 3.7). Under natural forest condition total biomass production, carbon stock and CO_2 sequestration was substantially higher in Mamoni natural forest followed by Shahpur natural forest (Fig. 3.5). Total CO_2 sequestration in *Acacia nilotica* having estimated value of 2827.90 t/ha, was found higher compared to *Azadirachta indica* having estimated value of 1707.68 t/ha (Fig. 3.6). Over all carbon sequestration potential was less in natural forest areas compare to managed plantation in South-Eastern Rajasthan. The *Acacia nilotica* and *Aegle marmelos* species are highly suitable and provides a substantial role in carbon sequestration under Chambal ravines.

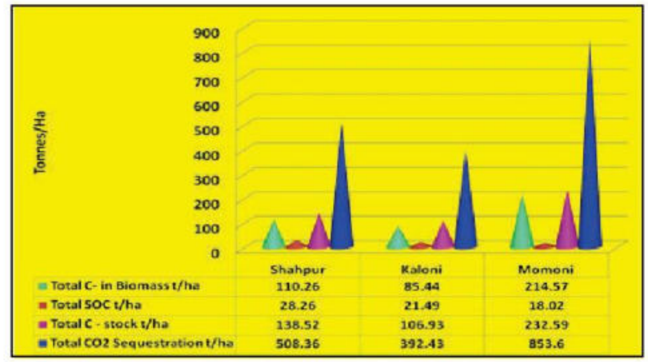

Fig. 3.5: Total cabon stock (t/ha) and CO_2 sequestration potential of natural forest under different locations at Shabad (Baran divivsion)

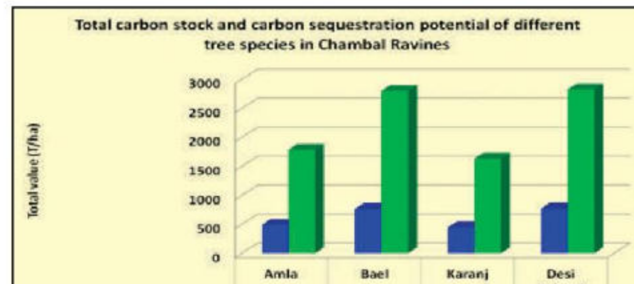

Fig. 3.6: Total carbon stock (t/ha) and CO_2 sequestration potential of different tree based systems in chambal ravines

Table 3.7: Assessment of Litter accumilation and decomposition dynamics under different tree based in Chambal ravines and Shahbad natural forests

Land uses	Tree species	Age in years	Litter production (Mg/ha/year)	Leaves as % of total litter	Litter decomposition rate as 99 % decay loss (months)
Silvipastoral	*Acacia nilotica*	09	6.23	70.03	7
Silvipastoral	*Pongamia pinnata*	09	3.98	72.40	9
Hortipastoral	*Aegle marmelos*	09	5.66	76.62	9
Hortipastoral	*Emblica officinalis*	09	2.39	69.12	7
Natural forest -Shabad	*Lagestromia parviflora*	35	4.56	75.23	10
Natural forest -Shabad	*Thespesia populnea*	35	5.12	78.46	9
Natural forest -Shabad	*Terminalia belerica*	35	7.14	83.40	11
Natural forest -Shabad	*Butea monosperma*	35	3.66	55.34	10
Natural forest -Shabad	*Lannea coramendalica*	35	8.83	88.14	8

Natural forest -Shabad	*Anogeisus pendula*	35	5.65	82.36	8
Natural forest -Shabad	*Diospyros melanaxylon*	35	5.01	75.87	11
Natural forest -Shabad	*Acacia catechu*	35	1.62	59.12	7
Natural forest -Shabad	*Buchanania cochinchinensis*	35	5.45	63.08	11
Natural forest -Shabad	*Boswelia serrata*	35	9.02	82.46	9

3.1.1.3.2 Soil quality assessment

Soil quality is one of the several factors contributing to crop productivity. For assessing the effect of soil and water conservation measures on soil quality of medium - deep black soils of South-Eastern Rajasthan an experiment at farmers' field was carried out at model watershed of Dhoti in Baran district. The project was initiated in January 2011with a field experiment set up at Dhoti watershed in Baran district (Rajasthan). Four land use treatments were imposed to compare effect of conservation measure with or without improved crop management. Contour furrows in the inter-bunded area with c/s 0.067 and 6 m HI were laid out after *kharif* sowing each year and crop were cultivated along the contours. Predominant cropping systems selected as test crops were i) soybean–coriander, ii) soybean–mustard, iii) soybean–wheat and iv) fallow–mustard. Soil profiles down to 150 cm depth were opened at all farmers' fields and profile study was conducted in the first year of project. Subsequently each experimental plot was sampled for surface (0-15 cm) and sub-surface (15-30 cm) changes in soil properties at sowing and crop harvest. The minimum data set was identified by using Principal Components Analysis (PCA). Identified indicators in MDS were converted to non-linear scores and integrated into indices through additional and weighted additive indexing method. The soil quality indices were intended to compare their ability to capture variability in soil chemical and physical parameters and in their relationship with systems productivity. Variability in soil properties observed in a watershed scale and its relationships with crop yields permitted to identify soil quality indices for Typic Chromusterts soils of South-Eastern Rajasthan. The scree plot (Fig. 3.7) and summary statistics (Table 3.8) identified seven soil quality variables which had Eigen value more than one and are responsible for about 72.7% of cumulative variability of soil data. These variables were OC, sand % bulk density, CEC, pH, available N and available P. The OC is an identified as a key soil quality indicator universally and has shown significant relationship with grain yield in this study. The level of available N is also a widely accepted soil indicator. However, sand %, bulk density, CEC, pH and available P did not show significant direct relationship with crop yield. Still PCA picked these parameters as these soil properties control variability of other soil properties which may have a more direct impact as soil quality. Introduction of improve crop management practices was more effective for soybean compared to mustard as the respective crop yields increased by 25% and 19% over prevailing farmers' practices. Application of suitable conservation measures alone improved soybean yield by about 18%. Improved crop management complemented the effect of conservation measures and resulted in about 44% and 28% increase in soybean and mustard crops compared to farmers practice.

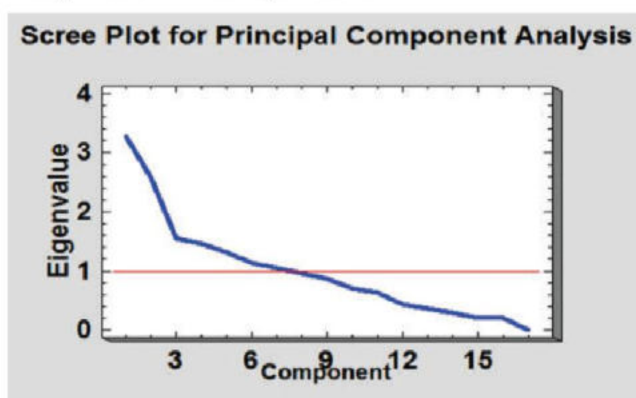

Fig. 3.7: Scree plot for principal component analysis

Table 3.8: Summary statistics of PCA for soil parameters.

Component	Eigen value	(%) Var	Cum (%)
Organic Carbon (OC)	3.27	19.26	19.26
Sand	2.58	15.15	34.42
Bulk Density (BD)	1.54	9.09	43.50
Cation Exchange Capacity (CEC)	1.45	8.54	52.04
pH	1.31	7.73	59.77
Available Nitrogen (Av. N)	1.14	6.73	66.50
Available Phosphorus (Av. P)	1.05	6.21	72.70
Calcium (Ca)	0.96	5.63	78.33
Zinc (Zn)	0.87	5.13	83.46
Copper (Cu)	0.71	4.17	87.63
Ferrous (Fe)	0.62	3.67	91.30
Manganese (Mn)	0.43	2.53	93.82
Calcium Carbonate ($CaCO_3$)	0.36	2.10	95.92
Magnesium Carbonate ($Mg\ Co_3$)	0.29	1.69	97.61
Sodium Adsorption Ratio (SAR)	0.21	1.22	98.83
Active Carbon (AC)	0.20	1.17	100.00
Magnesium (Mg)	0.00	0.00	100.00

3.1.1.3.3 Impact of land use systems on soil sustainability

Soil characteristics and erodibility indices of soils under five different land uses *viz.* *Leucaena*, *Prosopis*, rainfed agriculture, grass and open gullied lands were determined from three soil depth *i.e.*, 0-5, 5-15 and 15-30 cm. in South-Eastern Rajasthan at Kota (Singh *et. al*. 2006). Soil organic carbon and clay content was lowest in the open gullied lands followed by rainfed agriculture and grass land. Lands under *Prosopis* and *Leucaena* recorded higher organic carbon and clay content. Considering the erosion ratio and dispension ratio, the erodibility of soil followed the order of open gullied land > rainfed agriculture >*Prosopis*> *Leucaena*> grasslands. The erosion ratio had high significant positive correlation with dispersion ratio ($r = +0.87$), percolation ratio ($r = +0.95$), clay ratio ($r = +0.86$) and suspension percentage ($r = +0.69$) thus indicating the important role of these parameters influencing the soil erodibility. The dispersion ratio of soils ranged from 12.88 to 28.06 and it was lowest under grassland and highest under open gullied land and decreased with increasing soil depth.

3.1.1.3.4 Erosion-productivity relationship studies

Deterioration of soil by erosion often results in decreasing crop productivity. The extent to which crop yields respond to soil erosion depends on several variables such as crop type, soil properties, management practices and climate characteristics. Understanding the response of crop yields to soil erosion is of vital importance in assessing adequately the vulnerability of agriculture to erosion. Correct understanding of the effect of erosion on crop productivity is not yet established in semi-arid Vertisol region of India. A core project has been initiated at Kota Centre to develop a framework for evaluating vulnerability and resilience of various soil map units of different regions and to assess impact of erosion on crop productivity for principal crops of rainfed areas of South-Eastern Rajasthan. For developing erosion-productivity relationships for medium-deep black soils of South-Eastern Rajasthan erosion status and crop productivity levels are being monitored with two different approaches. Firstly field experiments with 12 standard size runoff plots having 0.5, 1.0, 2.0, and 4.0% slopes were constructed at research farm.

Relationship between soil loss and yield versus land slope was developed from the mean data of 2012 to 2017. Land slope had near about linear relationship with soil loss (Fig.3.8). It was observed that yield enhancement was recorded up to 2% land slope and thereafter 4% slope resulted in reduction of the mean yield of soybean. In a relationship between fertility level versus runoff and yield it was observed that increase in fertility level from 0% RDF to 150% RDF enhanced yield and reduced soil loss. This may be due to better growth of the crop in well fertilized treatment and better cover of the soil.

3.1.2 Hydrological Behavior of Watersheds for Conservation Planning

3.1.2.1 Hydrological Behavior of Land Uses and Management Practices

Agricultural watershed: Erosion studies were conducted at Research Centre, Kota for 14 years (1978 to 1991) under a field size 0.4 ha agricultural watershed having 1% slope. The crops studied during the period in different sets were sorghum (*Ashpuri*) + pigeonpea (1:1) for eight years (1978-85), castor (*Aruna*) + greengram (K 851) intercrops (1:2) for three years (1986-88) and soybean (Gaurav) for three years (1989-91). The data presented in Table 3.9 reveal that runoff from agricultural micro watershed ranged from 10.0 % under soybean to 16.4 % under sorghum (CSH-5) + pigeonpea with intermediate value of 15.5 % under blackgram + pigeonpea. Soil loss followed the trend of runoff. Though runoff and soil loss were within permissible limits but it could be inferred that soybean was most effective in reducing erosion hazards.

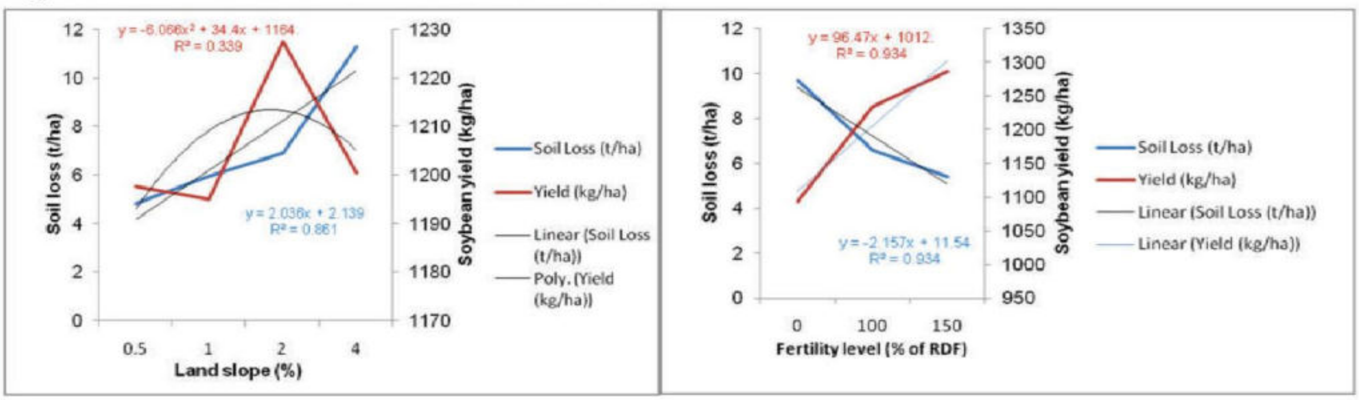

Fig. 3.8: Crop response and soil loss at variable land slopes and fertility levels

Table 3.9: Average annual rainfall, runoff and soil loss from a small agricultural watershed (0.4 ha) under different cropping systems

Cropping system	Rainfall (mm)	Runoff		Soil loss (t/ha)
		mm	% of rainfall	
Sorghum + pigeonpea	695.8	114.0	16.4	2.2
Castor + greengram	708.6	110.5	15.6	1.7
Soybean	588.6	58.8	10.0	1.3

Chhajawa watershed: The hydrological behaviour of micro-watershed of 15.4 ha under Chhajawa agricultural watershed, treated with graded bunds, masonry waste weirs, summer ploughing and contour cultivation was investigated during 1990-93 (Prasad *et. al.*, 1997). The data in Table 3.10 shows about 30% average reduction in runoff in response to watershed treatments. The watershed development treatments retained more rainfall within the watershed facilitating higher ground water recharge.

Table 3.10: Runoff from treated and untreated watershed

Year	Runoff as % of rainfall	
	Untreated watershed Diara (16.9 ha)	Treated watershed Chhajawa (15.4 ha)
1990	31.9	5.4
1991	20.0	10.1
1993	22.1	7.7
Average	**24.7**	**7.7**

Ravine watershed: In a study conducted for 12 years (1981 to 1992) at Research Centre Kota in Chambal ravines, two ravine watersheds of 0.85 ha having 37.5 % slope (W1) and 1.45 ha having 24.5% slope (W2) were studied. Watershed W1 was managed by planting *Acacia nilotica* in 1977 with five soil working techniques *viz*. continuous contour trenches on hump top and ravine beds, contour furrows on ravine slopes, half slanting pits on irregularly broken and sloping lands and saucer shape pits on ridge lines and hump. *Dichanthium annulatum* was planted at 50 cm x 50 cm in continuous furrows of 10 cm^2 at 1 m interval with three water spreaders and small check dams, and one chute spillway. The average runoff and soil loss data indicated that the watershed W2 produced lowest runoff (1.8 %) and soil loss (0.4 t/ha) as compared to 3.4% runoff and 0.84 t/ha soil loss under W1 watershed. This shows that permanent vegetative covers are very effective in reducing erosion losses under rugged terrain of ravines.

Another study was conducted at IWDP, Badakhera in Bundi district of Rajasthan to monitor the impact of soil and water conservation measures on surface runoff by Singh *et. al.* (2004). Three micro-ravine watersheds compared were, W1(44.5 ha) treated with mechanical and vegetative measures; W2 (11.27 ha) treated with mechanical measures of soil and water conservation and W3 (29.29 ha) without soil and water conservation treatments. Four years average data indicated that W1 and W2 recorded 78.5 and 47.4% less runoff, respectively than W3 (Table 3.11). This indicates that mechanical as well as vegetative measures were most effective in reducing surface runoff and promoting *in-situ* moisture conservation. In order to assess the effectiveness of check dams in silt retention in Badakhera watershed a survey was conducted by Singh *et. al.* (2004). The data presented in Table 3.12 show that 13533 tons of top soil retained in upstream sides of 12 check dams along with plant nutrients. It was further observed that structures constructed in upper reaches retained greater volume of sediment than middle and lower reaches.

Table 3.11: Runoff and soil soil loss from three micro-watersheds in Badakhera watershed in response to mechanical and vegetative treatments (W1), mechanical measures alone (W2) as compare to untreated control (W3)

Year	Rainfall (mm)	Runoff % of rainfall			Soil loss (t/ha)		
		W1	W2	W3	W1	W2	W3
1999	180.5	10.5	16.2	32.4	20.8	26.0	46.5
2000	150.8	3.5	14.6	14.7	12.9	23.2	36.4
2001	209.8	4.9	16.9	40.8	10.6	13.1	56.6
2002	78.0	6.1	11.8	20.4	NR	NR	NR
Average	**154.8**	**6.3**	**15.5**	**29.4**	**14.8**	**20.8**	**46.5**

Table 3.12: Silt and nutrient retention along the structures

Location of structures	Silt retention (tons)	Nutrient retained (kg)		
		N	P	K
		Upper reach		
WUR1	1500.2	112.7	4.2	274.9
WUR2	1243.2	92.3	3.1	251.7
WUR3	1981.2	148.0	4.8	3698.0
WUR4	673.3	50.6	1.9	123.3
WUR5	611.9	38.2	1.6	115.3
WUR6	2668.9	197.8	6.6	514.4
WUR7	668.4	45.9	1.9	140.8
		Middle reach		
WUR1	583.7	43.9	1.4	112.4
WUR2	1200.5	85.5	2.7	211.6
WUR3	807.5	55.3	1.7	155.6
		Lower reach		
WUR1	739.5	49.0	1.8	147.9
WUR2	855.1	54.1	1.9	161.8
Total	**13533.1**	**973.6**	**33.6**	**5907.7**

3.1.2.2 Water Harvesting, Groundwater Recharge and Management

3.1.2.2.1 Studies on rainfall characteristics

The climate of South-Eastern Rajasthan is dry semi-arid with average annual rainfall of 738.7 mm which is quite uncertain and erratic in nature. Summers are hot with 42.04^{0}C of mean maximum temperature in May. The mean minimum temperature is 6.91^{0}C recorded in January. Monthly variation in the meteorological parameters such as rainfall, potential evapotranspiration, mean maximum and minimum temperature are presented in Fig.3.9. Ever increasing population thrust on natural resources like land and water necessitated the estimation of the hydrological parameters for efficient management of the natural resources to bring them under mainstream of sustained production system.

Behavior of monsoon is highly erratic in this region. Forty eight years period (1956-03) rainfall data recorded at Meteorological observatory of Research Centre, Kota has been analyzed for various rainfall characteristics. Event-wise frequency distribution analysis plays a key role to estimate or predict the amount of rainfall expected to occur at desired return period and duration which is very much essential for design and planning of engineering and bio-engineering measures and selection of crop. The normal date of onset of monsoon was estimated as 2nd July ±15 days with early and late onset of monsoon as 17th June and 17th July, respectively. The highest frequency of occurrence of onset of monsoon was observed between 1-5th July (19%) followed by 26-30th June (15%). The normal date of withdrawal was 14th September ±14 days, and 31st August and 28th September was estimated as the early and late withdrawal of monsoon, respectively. The withdrawal of monsoon was observed at 9 occasions (19%) out of 48 years in between 6-10th September followed by 16-20th September (15%). Average length of monsoon season (LMS) was found to be 73 days with standard deviation of 21 days. The mean number of rainy days (NRDs) was recorded 33 days with standard deviation of 9 days.

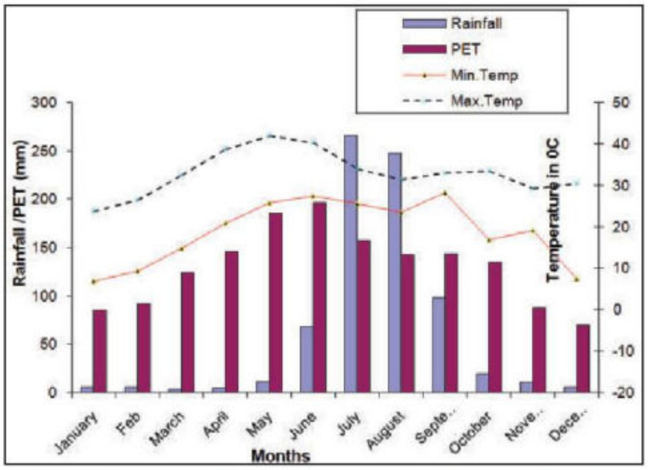

Fig. 3.9: Monthly averages of meteorological parameters in South-EasternRajasthan

Onset and withdrawal of monsoon: Daily rainfall data of 48 years (1956-2003) of Kota district of the South-Eastern Rajasthan was analyzed to assess the normal, early and late onset as well as withdrawal of monsoon (Ali *et. al.*, 2007). The study revealed that normal date of onset of monsoon was as 2nd July ±15 days, and the early and late onset of monsoon was estimated as 17th June and 17th July of the region, respectively (Table 3.13). The highest frequency of occurrence of onset of monsoon was observed between 1-5th July (19%) followed by 26-30th June (15%). The normal date of withdrawal was 14th September ±14 days, and 31st August and 28th September was estimated as the early and late withdrawal of monsoon, respectively. The withdrawal of monsoon was observed at 9 occasions (19%) out of 48 years in between 6-10th September followed by 16-20th September (15%). Average length of monsoon season (LMS) was found to be 73 days with standard deviation of 21 days. The mean number of rainy days (NRDs) was recorded 33 days with standard deviation of 9 days. Two parameter gamma, normal, Pearson type-III, and extreme value type-I distributions were found to be the best probability distribution function (pdf) for the onset, the withdrawal, the LMS and the NRDs, respectively in the Kota region. The 23th July to 2nd October, 103 days and 45 days was found to be the onset, withdrawal, the LMS and the NRDs at 90% probability level, respectively (Table 3.14). The rainfall pattern was observed to be highly erratic with average annual and seasonal (June to September) rainfall of 741 and 675 mm, respectively.

Table 3.13: General characteristics of South-West monsoon in Kota district

Parameter	Monsoon characteristics					
	Onset of monsoon		Withdrawal of monsoon		Length of monsoon season	Number of rainy days
	Julian days	Date	Julian days	Date	Days	Days
Normal	183	2 July	257	14 September	73	33
Standard Deviation	15 days		14 days		21	9
Early	168	17 June	243	31 August	-	-
Late	199	17 July	271	28 September	-	-

Table 3.14: Estimated dates of the onset, withdrawal, length and rainy days using the best probability distribution of South-West monsoon in Kota district

Return period (years)	Prob-ability	Monsoon characteristics												LMS	NRDs
		Onset of monsoon						Withdrawal of monsoon							
		Mean		Early		Late		Mean		Early		Late			
		Julian days	Date	Julian days	Date	Julian days	Date	Julian days	Date	Julian days	Date	Julian days	Date	Days	Days
2	50	183	2 July	168	17 June	198	17 July	257	14 Sept.	243	31 Aug.	271	28 Sept.	70	31
5	80	197	16 July	182	1 July	212	31 July	268	25 Sept.	254	11 Sept.	282	8 Oct.	89	39
10	90	204	23 July	189	8 July	219	7 Aug.	275	2 Oct.	261	18 Sept.	289	16 Oct.	103	45

LMS- Length of monsoon season; NRDS-Number of rainy days

Rainfall amount and its distribution: The rainfall for the standard weeks, months, season (June- September) and annual has been analyzed statistically. The average annual rainfall of Kota district is 738.3 mm with standard deviation of 226.2 mm and coefficient of variation of 30.6%, whereas average seasonal rainfall (June-September) is 676.3 mm with standard deviation of 216.7 mm and coefficient of variation of 32.0% (Table 3.15). About 92% of total annual rainfall amount concentrates during June-September. The highest rainfall is received during month of July (35.16% of annual) and August (32.53%). The September and June receive only 13.36 and 10.49% of annual rainfall. The weekly rainfall during the monsoon season varies from 6.6 (23rd week) to 74.6 mm (30th week). The rainfall variation is lowest in month of August (45.7%) followed by July (53.1%), while highest in month of September (86.0%) followed by June (88.8%). The weekly rainfall amount also follows similar trend. The variation is very high (more than 100%) in majority of standard weeks during the monsoon period except week numbers 33 (86.8%), 32 (88.2%) and 31 (95.9%). This implies that rainfall amount during monsoon period is positively skewed. This significant variation in rainfall amount indicates that rainfall pattern is highly erratic with space and time.

Stochastic rainfall analysis was compared seven most commonly used probability distribution functions (pdf$_s$) namely; normal, log-normal, gamma, extreme value type-I, log-extreme value type-I, Pearson type–III and log-Pearson type–III at Research Centre, Kota. Of these, 2-parameter log-normal distribution was found to be the best pdf for estimating the probabilities of seasonal and annual rainfall, while 2-parameter gamma, log-normal and normal distribution were the best-fitted for the month of June & September, July, and August, respectively (Ali and Sethy, 2007). The weekly rainfall during the monsoon season followed the 2-parameter gamma distribution. The regression models depicting the dimensionless relationship between ratio of probable rainfall to mean rainfall and exceedance probability were also developed to estimate probable rainfall at given probability from mean rainfall.

Weekly model

$$\frac{Q_p}{Q_m} = -1.29\,Ln(P) - 0.24$$

Monthly model

$$\frac{Q_p}{Q_m} = -0.70\,Ln(P) + 0.31$$

Seasonal as well as annual model

$$\frac{Q_p}{Q_m} = -0.29\,Ln(P) + 0.72$$

Where Q_p is the rainfall (mm) at selected probability 'P' and Q_m is the mean rainfall (mm).The analysis of variance was significant at 1% significance level. This was further confirmed by low values of standard error of estimates

Sethy *et. al.* (2005) found that 2- parameters log-normal distribution function was the best for one day as well as 2 to 5 consecutive days maximum rainfall. A relationship between one day as well as 2 to 5 consecutive days maximum rainfall estimated by the their best fitted probability distribution and return period has been developed and presented in Table 3.16. Regression analysis was done to find out the relationship between one day and consecutive days maximum rainfall. The following model was developed to estimate/ predict consecutive days maximum rainfall from one day's maximum rainfall data.

$$R_{ci} = R_1 \exp(0.0189D + 0.4107) + \exp(0.1103D + 4.0698)$$

Where R_{ci} is the maximum rainfall in ith consecutive days and D is duration in days from 2 to 5. The model was tested by using Thein's U-statistic and was found to be best suited for the region.

Table 3.15: General characteristics of weekly, monthly, seasonal and annual rainfall during South-West monsoon season (1956-2017)

Period	Weeks (date)/ Months	Min. (mm)	Max. (mm)	Mean (mm)	Standard deviation (mm)	Coefficient of variation (%)	Skewness
Weekly	23 (4-10 June)	0.0	54.3	6.6	12.3	185.7	2.2
	24 (11-17 June)	0.0	64.8	10.7	14.2	132.7	2.0
	25 (18-24 June)	0.0	96.0	21.0	25.7	122.7	1.2
	26 (25 June-1 July)	0.0	163.0	32.5	46.8	144.3	1.8
	27 (2-8 July)	0.0	464.9	50.1	75.4	150.3	3.9
	28 (9-15 July)	0.0	207.7	54.2	52.4	96.7	1.2
	29 (16-22 July)	0.0	293.6	59.4	65.3	109.9	1.9
	30 (23-29 July)	0.0	391.4	74.6	78.9	105.7	2.1
	31 (30 July-5 Aug.)	0.0	221.9	63.3	55.4	88.2	0.9
	32 (6-12Aug.)	0.0	176.5	53.3	45.3	85.0	1.1
	33 (13-19Aug.)	0.0	181.6	58.3	49.1	84.2	0.7
	34 (20-26Aug.)	0.0	302.3	53.5	63.7	118.9	1.8
	35 (27Aug.-2Sept.)	0.0	236.8	43.5	49.1	113.0	1.8
	36 (3-9Sept.)	0.0	399.7	48.9	69.8	142.8	3.2
	37 (10-16Sept.)	0.0	121.6	18.5	27.5	149.1	1.8
	38 (17-23Sept.)	0.0	67.5	7.8	14.8	188.5	2.7
	39 (24-30Sept.)	0.0	132.6	8.9	22.6	254.8	4.14
Monthly	June	2.4	418.3	77.1	73.7	95.7	2.0
	July	23.2	669.5	257.9	137.7	53.4	1.1
	Aug.	19.8	620.6	247.5	117.5	47.5	0.4
	Sept.	0.0	442.6	93.8	82.4	87.8	2.2
Seasonal	June to Sept.	295.9	1445.3	676.3	216.7	32.0	1.0
Annual	Jan. to Dec.	305.1	1504.8	738.3	226.2	30.6	0.9

Table 3.16: Regression models for 1 day as well as 2 to 5 consecutive days corresponding to 2 to 100 years return periods.

Duration (Days)	Relationship	Coefficient of determination (R^2)	Mean absolute error (%)
1	$R_1 = \exp\,[0.4232\, Ln\,(T) + 4.1037]$	0.9633	6.67
2	$R_2 = \exp\,[0.4440\, Ln\,(T) + 4.3891]$	0.9627	7.06
3	$R_3 = \exp\,[0.4872\, Ln\,(T) + 4.4237]$	0.9661	6.58
4	$R_4 = \exp\,[0.4872\, Ln\,(T) + 4.4744]$	0.9561	9.69
5	$R_5 = \exp\,[0.4960\, Ln\,(T) + 4.6126]$	0.9869	4.54

Where R_1 to R_5 Maximum rainfall amount in 1 to 5 consecutive days in mm, T-return periods in years.

3.1.2.2.2 Rainfall intensity-duration-return period relationship

Rainfall intensity duration return period equations and monographs are required for design of soil conservation and runoff disposal structures and planning flood control projects. Deviation in the rainfall intensity obtained by the two methods (equation and nomographs) has been observed to be less than $\pm$ 8%. Looking into simplicity in use, quickness and precision in results obtained, the nomograph appears to be very handy tool for field workers (Fig.3.10). Rainfall intensity-duration-return period relationships were developed as under:

$$I = \frac{5.7887T^{0.2347}}{(t+0.5)^{0.8332}}$$

Where I = Intensity of rainfall (cm/hr), T = Return period (years), t = Duration (hours)

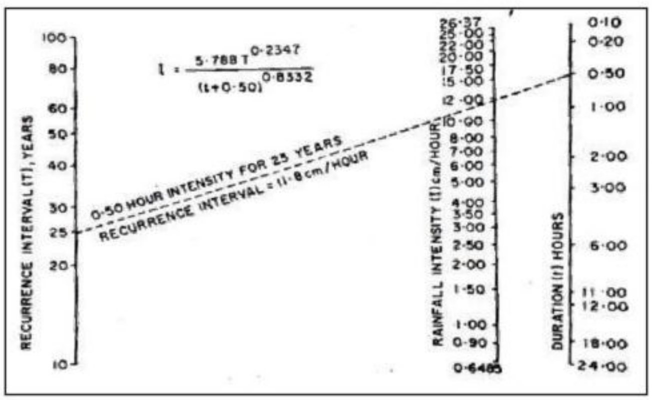

Fig 3.10: Nomograph for determining rainfall intensity from duration and frequency (Kota)

3.1.2.2.3 Rainfall-runoff model

Rainfall-runoff models play a vital role in agriculture in terms of hydrologic analysis and designing the best management practices for controlling soil erosion and land degradation, nutrients loss, estimating effective use of rainwater and extra water needs for irrigation, groundwater recharge and current water status at a given scale. A simple rainfall-runoff model based on normalized antecedent precipitation index (NAPI) for predicting runoff yields from small watersheds was developed (Ali *et. al.,* 2010; Ali, 2011).The developed RR model has three coefficients specific to a watershed, and requires two inputs, rainfall and derived parameter "NAPI". The developed RR model is defined as:

$$Q = \frac{P(bP + c\,NAPI + a)}{[(bP + c\,NAPI + a) - 1]} \quad \text{Valid for } P > 0$$

Where, Q is the rainfall corresponding the rainfall [unit of length, L], $NAPI$ is a dimensionless quantity; a,b and c are the model parameters specific to a watershed, b has inverse unit of the L, and a and c are dimensionless.

The 'NAPI' of a rainfall event for which runoff is to be predicted can be determined from its 5-antecedent days rainfall event and the parameters can be estimated from the historical time-series data of rainfall-runoff events of that watershed using the least squares optimization. The model was successfully tested with field data from three small watersheds located in Kota and Bundi district of Rajasthan. The results exhibited a good match to the field data by the developed model. Performance of the model has also been compared with Soil Conservation Service-Curve Number (SCS-CN) model. The performance of the derived model has resonance with the SCS-CN model.

3.1.2.2.4 Curve Number (CN) for small watersheds

The five curve number based methods used for estimation of runoff namely; National Engineering Handbook (NEH-4), storm event (SE), rank order (RO), lognormal frequency (LF) and s-probability (SP) were compared using the runoff data recorded from three small watersheds in Kota and Bundi districts of Rajasthan.

The area of the agricultural (AG), Badakhera (BK) and ravine (RV) watershed is 0.4, 29.2 and 1.4 ha, respectively. The most effective and the reliable curve number method was chosen based upon various tests of goodness-of-fit such as; coefficient of determination (R^2), index of agreement (D), root mean square error (RMSE) and relative bias (RB) for estimating runoff.

The LF method was found to be the most promising curve number method for estimating runoff from small watersheds in the Semi-Arid regions. The runoff predicted by LF method was in close agreement with the observed runoff for all the four tests of goodness-of-fit. However, the performance of SE, RO and NEH-4 methods was almost comparable to each other while the SP method registered higher deviation from observed runoff values.

It was concluded that LF method can be successfully employed for estimation of curve number based runoff from small watersheds. The curve number value for the AMC-II derived by the LF method was 79, 87 and 84 for agricultural AG, BK and RV watersheds, respectively (Table 3.17).

Table 3.17: Curve number values determined using different curve number estimation methods for selected watersheds

Watershed	Antecedent moisture condition (AMC)	Curve number estimation methods				
		NEH-4	SE	RO	LF	SP
AG	AMC-I	69	63	63	62	61
	AMC-II	84	80	80	79	90
	AMC-III	92	90	90	90	98
BK	AMC-I	72	75	72	73	74
	AMC-II	86	88	86	87	89
	AMC-III	93	94	93	94	96
RV	AMC-I	67	70	70	69	74
	AMC-II	83	84	84	84	85
	AMC-III	92	93	93	92	92

NEH-4 = the National Engineering Handbook; SE = the Storm Event; RO = the Rank Order; LF = the Lognormal Frequency and SP = the S-Probability methods

3.1.2.2.5 Evaporation from small ponds

Evaporation is the largest component of water loss from storage without any beneficial use to water resources development and management. Significance of its accurate estimation increases when the problems are associated with the water resources accounting of arid and Semi-Arid regions. Evaluating performances of four commonly used evaporation estimate methods, namely; Bowen Ratio Energy Balance (BREB), Mass Transfer (MT), Priestley-Taylor (PT) and Pan Evaporation (PE), based on four years field experimental data in BK watershed. The most effective and the reliable evaporation estimates model for the small ponds in the Semi-Arid region of India have been identified (Ali *et. al.,* 2008). Of these models, the PT model has been found most promising when the Bowen ratio, is known a *priori,* and based on its limited data requirement. The responses of the BREB, the PT, and the PE models were found comparable to each other, while the response of the MT model differed to match with the responses of the other three models. The coefficients, of the BREB, of the MT, of the PT and K_p of the PE model were estimated as 0.07, 2.35, 1.31 and 0.65, respectively. Estimated values of the evaporation rate by each method for different time scales such as; daily, monthly and seasonal are in Table 3.18.

Table 3.18: Evaporation rate by various evaporation methods for a pond in BK watershed for the study period 2002 to 2005

Time scale	Methods	Statistical parameters		
		Sample size	Range	Mean ±Std.
			mm/day	mm/day
Daily	EB	729	0.67-6.56	2.86 ±1.29
	MT		0.18-18.74	3.04 ±2.79
	PT		0.72-6.44	2.76 ±1.31
	PE		0.52-7.39	2.86 ±1.17
Monthly	BREB	24	1.61-4.94	2.85 ±0.87
	MT		0.39-8.84	3.01± 2.20
	PT		1.36-4.85	2.75 ±0.93
	PE		1.52-5.47	2.85 ±0.93
Seasonal	BREB	4	2.61-3.07	2.87 ±0.22
	MT		2.63-3.78	3.04 ±0.71
	PT		2.54-2.93	2.76 ±0.20
	PE		2.60-3.30	2.86 ±0.31

3.1.2.2.6 Models for estimating length of advancement of wetting front under water harvesting structures

Infiltration is an important hydrological process affecting the runoff, groundwater recharge and solute transport process. Determination of length of advancement of wetting front is prerequisite for estimation of potential recharge. The generalized explicit models for estimation of time varying length of advancement of wetting front (LAWF) from water harvesting structures under constant depth as well as variable depth of ponding has been developed by replacing the logarithmic term of the Green-Ampt (GA) model by sequential segmental second order polynomials and double exponential (Ali *et. al.*, 2013, 2016a).

For constant depth of ponding:

$$L_f(t) = (H+\psi_f)\left[\sqrt{\frac{F_1 K_s}{\eta_f (H+\psi_f)}\, t + F_2} + F_3\right]$$

where $L_f(t)$ is the wetting front advancement length at time *t* [L]; *H* is the constant depth of water [L]; $_f$ is suction head at the wetting front (negative pressure head), which is interface between the wetted and non-wetted zone in the soil profile at time *t* [L]; $_f$ is the fillable porosity of the water harvesting structures' bed material[-] and is equal to $\theta_s - \theta_i$; θ_i is the initial soil moisture [L^3L^{-3}]; θ_s is the total porosity (*i.e.* soil moisture at near or fully saturation) [L^3L^{-3}]; F_1, F_2 and F_3 are the model parameters whose values depend on the wetting front length [dimensionless] (Table 3.19).

Table 3.19: Universal values of the model parameters F_1, F_2, and F_3 (Ali *et. al.*, 2013)

Recharge separating segments ranges	F_1	F_2	F_3
$0 < \lvert L_f/(H+\psi_f)\rvert \le 1$	4.16	0.04	-0.15
$1 < \lvert L_f/(H+\psi_f)\rvert \le 5$	26.96	53.68	-6.85
$5 < \lvert L_f/(H+\psi_f)\rvert \le 15$	216.18	7906.76	-87.72
$15 < \lvert L_f/(H+\psi_f)\rvert \le 50$	1955.96	839845.55	-914.36
$50 < \lvert L_f/(H+\psi_f)\rvert \le 150$	18137.87	78804363.26	-8874.10

The model has also been tested with the published laboratory and field experimental data. The model has similar responses as that of the Green-Ampt model within accuracy of 0.5% and the corresponding percent bias of 0.2%. A simple and more accurate model was also developed using a two-step curve-fitting approach, which defined (Ali and Islam, 2018) as:

$$L_f(t^*) = (H + \psi_f)\left\{ t^* + 2.5009 \ln\left[1 + 0.5833\sqrt{t^*}\right] \begin{bmatrix} 0.9723 + 0.0117\left[1 - Exp\left(-27.36\,t^*\right)\right] \\ +0.0162\left[1 - \exp\left(-2.5168\,t^*\right)\right] \end{bmatrix} \right\}$$

In which dimensionless time, t^* is defined as:

$$t^* = \frac{K_s t}{\eta_f \left(H + \psi_f\right)}$$

This model is more accurate within 0.146% maximum absolute relative error and percent bias less than 0.070%, and modeling efficiency value approximately equal to 1.

For variable water depth:

$$L_f(t) = L_f(t-\Delta t) + \left[H(t-\Delta t) + \psi_f\right]\left\{\sqrt{\frac{F_1 K_s}{\eta_f\left[H(t-\Delta t)+\psi_f\right]}\,t + F_2} - \sqrt{\frac{F_1 K_s}{\eta_f\left[H(t-\Delta t)+\psi_f\right]}(t-\Delta t) + F_2}\right\};\ (t-\Delta t) \le t < (t+\Delta t)$$

Where $L_f(t\text{-}\Delta t)$ is the wetting front length at time $t\text{-}\Delta t$ [L]; Δt is the time interval[T] and other terms are defined earlier.

In another study, Ali and Ghosh (2016) have developed an infiltration model for estimation of cumulative and rate of infiltration under variable depth of water by modifying the GA equation. The derived models for infiltration rate and cumulative infiltration are defined:

$$F(t) = \eta\left\{L_f(t-\Delta t) + \left[H(t-\Delta t) + \psi\right]\left\{\sqrt{\frac{F_1 K_s}{\eta\left[H(t-\Delta t)+\psi\right]}\,t + F_2} - \sqrt{\frac{F_1 K_s}{\eta\left[H(t-\Delta t)+\psi\right]}(t-\Delta t) + F_2}\right\}\right\}$$

and (5)

$$f(t) = K_s\left[1 + \frac{H(t) + \psi_f}{L_f(t-\Delta t) + \left[H(t-\Delta t)+\psi\right]\left\{\sqrt{\frac{F_1 K_s}{\eta\left[H(t-\Delta t)+\psi\right]}\,t + F_2} - \sqrt{\frac{F_1 K_s}{\eta\left[H(t-\Delta t)+\psi\right]}(t-\Delta t) + F_2}\right\}}\right]$$

(6)

Where H (t) is the depth of water at time t [L]; Δt is the change in time from t to t-Δt [T]; and other terms are defined previously.

The models provide a solution for estimation of infiltration with no restrictions to infiltration time period, depth and nature of ponding and soil types unlike the rigorous solution of the Richards model. Performance of the model compared well with Richards (Richards, 1931) and Warrick *et. al.* (Warrick *et. al.*, 2005) models with published laboratory and field experimental data. Comparative studies of the model for variable water depth over variety of soils demonstrated its capability for their field uses to estimate potential infiltration/groundwater recharge, evaluate the performances of water harvesting structures, design of artificial groundwater recharging facilities, water harvesting structures, irrigation systems and resolving solute transport problems.

Ali *et. al*. (2016) and Ali and Islam (2018) also evaluated the performance of ten explicit GA models and reported that the Barry *et. al*. (2005) (BA) model is the most accurate infiltration model followed by the Parlange *et. al.* (2002) (PA), Ali and Islam (2018) (AI) and Vatankhah (2015) (VA) models based on overall performance index for variety of soil classes and infiltration periods. The models of Almedeij and Esen (2014) (AE), Swamee *et. al.* (2012) (SW), Salvucci and Entekhabi (1994) (SE) and Li *et. al*. (1976) (LI) also performed comparatively better. The (Stone *et. al*., (1994) (ST) and Ali *et. al.* (2013) (AL) models performed poorly. Based on the overall performance, all ten explicit models are ranked as BA > PA > AI > VA > LI > AE > SE > SW > ST >AL.

3.1.2.2.7 Integrated potential groundwater recharge simulation model for recharge ponds

Integrated models that simultaneously simulate potential recharge and time delay for wetting front to reach water table are necessary for comprehensive and coordinated planning of managed aquifer recharge. An integrated potential recharge simulation (IPGRS) models is developed to simulate potential groundwater recharge from the recharge ponds (Ali *et. al.,* 2015; Ali and Ghosh 2019). Mathematically, a model is defined:

$$R_p(t) = \frac{K_s}{\left[L_f(t)\,A_w(t) + K_s A_w\,\bar{(t)}\Delta t\right]}\left\{H(t-\Delta t)\,A_w(t-\Delta t) + \left[Q(t)A_c + P(t)\,A_i - E(t)\,\bar{A}_w(t) - Q_o(t)\right]\Delta t + \left[L_f(t) + \psi_f\right]A_w(t)\right\}$$

where $R_p(t)$ is the potential groundwater recharge rate from the recharge pond (RP) at time t [LT^{-1}]; $Q(t)$ is the runoff into RP at time t [LT^{-1}]; $P(t)$ is the rainfall over the RP at time t[LT^{-1}]; $E(t)$ is the evaporation from the RP at time t [LT^{-1}]; $Q_o(t)$ is the outflow of surplus runoff from the RP through outlet at time t [L^3T^{-1}]; $H(t-\Delta t)$ is the water depth at time, t-Δt [L]; A_{ws} is the area of the pond's catchment[L^2]; A_t is the top surface area of the RP [L^2]; A_{es} (t) is the average water surface area for evaporation between time t-1 and t [L^2]; A_{er} (t) is the average wetted planner area for recharge at time t [L^2]; and other terms are defined previously. The IPRS model is successfully applied with 3 years (2006-08) field data from two small recharge ponds located over BK watershed in Bundi district of Rajasthan (Table 3.20). Response of the IPGRS model is found promising for simulating potential recharge from small recharge ponds. Analyzed results showed that on an average 76.7 to 91.2 % of accumulated runoffs with overall mean of 76.7% in the selected ponds contributed to artificial recharge into aquifer underneath ponds. Evaporation losses varied from 7.7 to 9.2% of stored runoff with overall mean of 8.5%. Surplus flows from the ponds and stored runoffs in ponds at the end of simulation periods ranged, respectively from 0 to 8.3%; and 0.6 to 0.8%.

Table 3.20: Partition factors of the water balance components (%) for the ponds during the simulation period (2006-08)

Year	Pond 01				Pond 02			
	$\frac{R_t}{Q_t+P_t}$	$\frac{E_t}{Q_t+P_t}$	$\frac{Q_{ot}}{Q_t+P_t}$	$\frac{S_t}{Q_t+P_t}$	$\frac{R_t}{Q_t+P_t}$	$\frac{E_t}{Q_t+P_t}$	$\frac{Q_{ot}}{Q_t+P_t}$	$\frac{S_t}{Q_t+P_t}$
2006	90.6	8.5	0	0.5	90.0	9.9	0	1.1
2007	81.7	7.6	9.6	1.1	90.4	9.3	0	0.3
2008	76.7	7.1	15.4	0.9	91.2	8.4	0	0.4
Mean	**83.0**	**7.7**	**8.3**	**0.8**	**90.2**	**9.2**	**0**	**0.6**

3.1.2.2.8 Holistic water depth simulation model for ponds

Estimation of time varying water depth and time to empty of a pond is prerequisite for comprehensive and coordinated planning of water resource for its effective utilization. A holistic water depth simulation (HWDS) model for small, shallow ephemeral ponds have been derived by employing the generalized model based on the Green-Ampt equation in the basic water balance equation (Ali *et. al.*, 2015; Ali, 2016). The model is:

$$H(t) = \frac{1}{A_w(t)}\left[\begin{array}{l} H(t-\Delta t)A_w(t-\Delta t) + \left[Q(t)A_{ws} + P(t)A_t - E(t)\bar{A}_{es}(t) - Q_o(t)\right]\Delta t \\ -K_s\left[1 + \dfrac{H(t)+\psi_f}{L_f(t-\Delta t) + \left[H(t-\Delta t)+\psi_f\right]\left\{\sqrt{\dfrac{F_1 K_s}{\eta\left[H(t-\Delta t)+\psi_f\right]}}(t) + F_2 - \sqrt{\dfrac{F_1 K_s}{\eta\left[H(t-\Delta t)+\psi_f\right]}}(t-\Delta t) + F_2\right\}}\right]\bar{A}_w(t)\,\Delta t \end{array}\right]$$

All the terms are defined previously.

The HWDS model has successfully been evaluated with 3 years of field data from two small ponds located within BK watershed. The HWDS model simulated time varying water depth in the ponds with high accuracy as shown by correlation coefficient ($R^2 \geq 0.9765$), index of agreement ($d \geq 0.9878$), root mean square errors ($RMSE \leq 0.20$ m) and percent bias ($PB \leq 6.23$ %) for the pooled data sets of the measured and simulated water depth. The statistical F and t-test also confirmed the reliability of the HWDS model at probability level, $p \leq 0.0001$.

3.1.2.2.9 Air-water temperature model

Changes in temperature and precipitation patterns due to global warming are likely to affect the quantity and quality of water in different water bodies. Water temperature modeling techniques are usually employed to study the effects of global climate change on stream and river ecosystems. A simple linear regression (SLR) model depicting relationship between daily air and water temperature of water harvesting structures has been developed using the observed water temperatures and the corresponding air temperatures (Ali, 2013; Ali *et. al.,* 2016b). In mathematical notation, the linear regression model fitted to the measured water temperatures and the corresponding air temperatures is given by:

$$T_w = 1.04\ T_a + 0.22$$

Where T_w and T_a are the surface water temperature (^{0}C) and the air temperature (^{0}C), respectively.

The linear air-water temperature model showed the highest correlation factor; coefficient of determination, R^2 = 0.9618 and index of agreement, D = 0.9802, and the least root mean square error, RMSE = 1.621^{0}C and relative biasness, RB=-0.000031^{0}C value between the observed and simulated water temperature. This correlation was further confirmed by the statistical value of F-test and student t-test. Application of the SLR model for projecting changes in attributes of a small pond in BK watershed under the changing climate scenarios, revealed 1.3 to 3.7°C increase in pond water temperature with increase in air temperature from 1.5 to 4.3°C by the end of 2080.

This increase in water temperature resulted in an increase in water evaporation rate by 8.3 – 30.3% and reductions in hydro-period and saturated dissolved oxygen by 3 - 26 days and 2.2 – 6.5%, respectively.

3.1.2.2.10 Hantush's S function, S (α, β) estimation methods

Hantush's model is widely used for predicting rise in water table in response to groundwater recharge. Several approximate methods of the Hantush mound function, S (α, β) have been developed to overcome the limitation of Hantush's tabulated values of the S (α, β) function. These approximate methods have their own advantages and disadvantages, and difficult to identify the most accurate and computationally efficient S (α, β) estimation method. By evaluating the performance of four different Hantush's S function, S(α, β) estimation methods namely, Swamee and Ojha (SO), Singh (SI), Vatankhah (VA) and Gauss-Legendre quadrature (GL) method with various Gaussian points (GP), the GL method with 16-100 GPs is found to be the most accurate based on seven statistical accuracy and computation efficiency indicators (Ali and Islam, 2019). Based on overall performance index, the methods are ranked as GL with 100 to 16 GP > SO > GL with 14 to 12 GP >VA > GL with 10 GP >SI> GL with 9 to 3 GP. The findings of study will be helpful in modeling water table rise due to groundwater recharge, and optimum design and evaluating effectiveness of recharge basins.

3.1.2.2.11 Optimum design of recharge filter for artificial recharging of dug wells

Artificial recharging of functional and/or abandoned dug wells through recharge filter is an efficient and economical method for mitigating and maintaining depleting water table, preventing drying up and low yield of dug wells. Optimum sizing of recharge filter is necessary to avoid extra costs and low efficiency due to over-and under-designed recharge filters, respectively. A design procedure for the recharge filter based on the maximization of the hydrological water balance equation was developed to decide the optimum size and maximum filling time of the recharge filter. The time required to emptying the recharge filter was derived by the integration of the governing hydrological equation.

The maximum width of the recharge filter with rectangular/square shape is obtained:

$$W = \sqrt{\frac{10C\left(\frac{aT^k}{(t_m+b)^n}\right)A_{ws}t_m - 3600\,a_p\sqrt{\frac{2g\left[H-\left(d/2+e\right)\right]}{1.5+\frac{fl}{d}}}\;t_m}{r\left[\eta H - 0.001\left(\frac{aT^k}{(t_m+b)^n}\right)t_m\right]}}$$

Where W is the width of recharge filter [m]; r is ratio of the L and W of the recharge filter (*i.e.* $r = L/W$) [-]; L ($= rW$) is the length of recharge filter [m]; r = 1 for the squared shape recharge filter; H is the depth of recharge filter [m]; is the porosity of the filled material in recharge filter[-]; C is the runoff coefficient [-]; A_{ws} is the watershed area contributing to of ***a, b, k*** and ***n*** are parameters of the intensity-duration-frequency equation; T is the return period of designed rainfall intensity [years]; t_m is the designed rainfall duration [hr]; a_p is the cross sectional area of the outflow pipe [= $\pi d^2/4$,] [m^2]; d is the diameter of discharge pipe [m]; e is the distance from the filter's bed to the centre of pipe [m]; f is the friction loss factor of the pipe [-], and l is the length of pipe from recharge filter to the dug well [m]

The maximum diameter of the circular shaped recharge filter is:

$$d = \sqrt{\frac{10\,C\left(\frac{aT^k}{(t_m+b)^n}\right)A_{ws}\,t_m - 3600\,a_p\sqrt{\frac{2g\left[H-(d/2+e)\right]}{1.5+\frac{fl}{d}}}\;t_m}{(4/\pi)\left[\eta\,H - 0.001\left(\frac{aT^k}{(t_m+b)^n}\right)t_m\right]}}$$

Emptying time for recharge filter can be calculated as:

$$t_e = \frac{\eta\,A}{3600a_p}\sqrt{\frac{\left[H-(d/2+e)\right]\left[1.5+\frac{fl}{d}\right]}{2g}}$$

Where t_e is the emptying time [hr] and A is cross section area of recharge filter.

For demonstration of the applicability of design procedure, the recharge filter with different cross-sections was applied to the dug well in a hypothetical watershed through different numerical experiments. Sensitivity analyses indicated a wide variation in optimum sizing, and maximum filling and emptying times with the change in each input parameter of the recharge filter. The derived design procedure has successfully tested for optimum sizing of a recharge filter to artificially recharging a defunct dug well in Dhoti watershed in a semiarid region in western India. A field experiment showed that on an average 3559.4 m^3 surface runoff was artificially recharge annually to the aquifer through defunct dug well via an optimally designed recharge filter. The rise in depth to the water table in a observation well at 7.5 m away from the centre of the dug well was found to be ranged from 17.3 to 21.0 m with a mean of 19.8 m.

3.1.3 Rehabilitation of Areas affected by Mass Erosion

3.1.3.1 Development and Refinement of Technologies for Rehabilitation of Ravines

3.1.3.1.1 Floristic diversity of Chambal ravines under varying levels of protection

Natural vegetation of Chambal ravines at Kota was studied for assessing the impact of varying levels of biotic disturbances on the phyto-sociological characters of the flora (Parandiyal *et. al.,* 2000). Three different sites *viz*., protected, partially disturbed and unprotected ravine forests, were sampled from top, slope and bed by quadrat method. Species richness and overall plant density in the woody layer increased with decreasing biotic pressure. Species richness varied from 4 to 16 in less protected to protected sites in the woody layer. The overall plant density varied from 1780 to 11380/ha in the woody layer comprising of trees and shrubs. In the unprotected sites no tree above 3m height was recorded. The evenness of distribution of species increased with protection in the woody layer. *Prosopis juliflora* had highest importance value index (I.V.I.) which increased with declining protection and it was lower on the ravine top as compared to slopes and bottom (Table 3.21). *Prosopis juliflora, Balanites aegyptiaca, Dichrostachys cinerea, Lantana camara, Capparis zeylanica,* and *Grewia pilosa* dominated the woody layer at the ravine top of the protected forest, while *Grewia pilosa, Capparis zeylanica, Lantana camara* and *Capparis decidua* had higher I.V.I in woody layer of ravine top of the partially disturbed forest where *Prosopis juliflora* and *Dichrostachys cinerea* were the major tree species. At ravine top in the unprotected forest no shrub in the woody layer was observed. On the ravine slopes *Prosopis juliflora, Lantana camara, Capparis decidua, Grewia pilosa* and *Clerodendron phlomides* were dominant on protected and partially disturbed ravine forest sites while *Grewia pilosa* and *Clerodendron phlomidis* were absent on ravine slopes of unprotected forest (Table 3.22).

Table 3.21: Importance value index of plant species on Chambal ravines

S. No	Name of species	Ravine top			Ravine slope			Ravine bed		
	Woody species	PRF	PDRF	UPRF	PRF	PDRF	UPRF	PRF	PDRF	UPRF*
1	*Prosopis juliflora*	83	33	272	74	101	216	129	112	228
2	*Balanites aegyptiaca*	29	11	--	4	2	6	--	31	--
3	*Dicrostachys cinerea*	13	11	--	5	9	4	8	3	--
4	*Acacia nilotica*	--	--	19	--	--	--	--	--	--
5	*Acacia leucophloea*	15	--	--	4	--	8	6	--	--
6	*Azadirachta indica*	1	--	--	4	--	4	--	--	11
7	*Holoptelia integrifolia*	4	--	--	9	2	--	4	13	--
8	*Soymida febrifuga*	--	10	--	--	--	--	--	--	--
9	*Leucaena leucocephala*	1	--	--	2	--	--	6	--	--
10	*Lantana camara*	29	30	--	50	39	23	67	69	30
11	*Capparis zeylanica*	42	51	--	20	29	16	25	21	14
12	*Capparis decidua*	22	27	--	35	31	23	11	8	9
13	*Grewia pilosa*	49	83	--	64	72	--	32	22	--
14	*Clerodendrom phlomides*	4	13	--	18	6	--	7	19	11
15	*Mimosa hamata*	5	--	--	2	--	--	--	--	--
16	*Grewia tenax*	6	--	--	2	--	--	4	--	--
17	*Grewia spp*	12	4	--	--	--	--	--	--	--
18	Others					**Negligible**				
19	*Achyranthus aspera*	19.25	6.33	5.78	1.93	10.79	11.46	4.25	11.09	8.91
20	*Argemone mexicana*	--	--	3.19	--	--	0.62	1.8	--	--
21	*Abutilon racemosus*	0.79	--	--	--	0.69	--	--	--	--
22	*Corcoru stridens*	7.81	7.45	--	10.12	3.93	2.49	7.63	3.98	1.24
23	*Macroptelium atropurpureum*	--	0.56	2.64	4.47	--	--	2.36	--	--
24	*Rincosia minima*	2.38	2.34	2.13	–	1.45	0.62	1.55	2.22	1.90
25	*Ocimum amaricanum*	0.80	--	--	--	--	--	--	--	0.65
26	*Euphorbia prostrata*	–	--	0.96	--	--	--	--	--	--
27	*Parthenium hysterophorus*	0.79	1.15	1.29	--	--	5.06	--	--	11.83

S. No.	Name of species	Ravine top			Ravine slope			Ravine bed		
	Woody species	PRF	PDRF	UPRF	PRF	PDRF	UPRF	PRF	PDRF	UPRF*
28	*Justiciaprocumbens*	22.80	20.80	4.91	23.47	16.27	6.70	30.90	36.58	9.49
29	*Physalis minima*	--	--	1.06	--	--	1.24	--	--	--
30	*Abutilon bidentatum*	0.80	0.60	--	1.75	1.41	--	4.76	1.50	0.63
31	*Circium arvensis*	--	--	1.06	--	--	--	--	--	--
32	*Ruelliasimplex.*	8.17	6.11	--	10.20	7.31	2.48	11.14	8.96	1.88
	Grass species									
33	*Apludamutica*	6.67	7.23	--	9.69	6.91	1.56	--	--	1.92
34	*Aristidaadscensionis*	2.3	1.90	12.3	--	--	8.51	--	--	3.31
35	*Cenchrus ciliaris*	--	--	--	--	--	0.68	--	--	0.62
36	*Dicanthium annulatum*	2.49	0.58	3.37	--	--	--	--	--	1.26
37	*Desmostachyabipinnata*	--	--	--	6.20	7.10	0.63	--	0.81	--
38	*Digitariaadscendens*	--	--	--	--	--	0.715	--	--	0.87
39	*Eragrostis ciliaris*	2.04	2.92	16.35	--	--	19.20	--	1.76	13.59
40	*Cynodon dactylon*	--	--	--	--	--	1.32	--	--	3.30
41	*Heteropogon contortus*	0.82	--	--	--	--	--	--	--	--
42	*Panicum miliare*	6.07	11.77	30.7	--	1.48	29.85	--	0.78	32.01
43	*Panicum antidotale*	0.89	--	--	0.86	--	--	2.85	--	--
44	*Setariaglauca*	1.03	9.36	--	12.49	26.48	--	4.35	20.36	--
45	*Eremopogonfaveolatus*	--	--	1.83	--	--	--	--	--	--
46	*Themedaquadrivalivis*	--	--	--	--	--	0.67	--	--	--
47	*Dactyloctenium aegyptium*	--	--	--	--	--	0.67	--	--	--

*RF = Protected ravine forest, PDRF = Partially disturbed ravine forest, UPRF = Unprotected ravine forest

Table 3.22: Distribution of species in different frequency classes

Raunkier's frequency class	Character & range of species	Ravine top			Ravine slope			Ravine bed		
		PRF	PDRF	UPRF	PRF	PDRF	UPRF	PRF	PDRF	UPRF*
A	Rare (0-20%)	20	19	11	13	10	9	10	15	17
B	Seldom present (21-40%)	5	5	9	4	2	5	4	8	7
C	Often present (41-60 %)	1	4	2	1	6	3	4	1	0
D	Mostly present (61-80%)	6	0	2	9	1	3	2	2	2
E	Constantly present (81-100%)	4	7	5	5	7	5	6	5	5

* PRF = Protected ravine forest, PDRF= Partially disturbed ravine forest, UPRF = Unprotected ravine forest

In the herbaceous layer, the overall density and species richness increased with declining protection due to increased occurrence of unpalatable and obnoxious species. *Achyranthes aspera*, *Corchorus tridens* and *Justicia arvensis* were dominant on all subsites of the three sites in the herbaceous layer, among these also frequency of occurrence of species was higher on less protected sites. Among the grasses, *Aristida adscensionis*, *Eragrositis ciliaris* and *Panicum miliare* were dominant and their dominance increased with declining protection on all sub-sites. *Apluda mutica* and *Setaria glauca* recorded higher densities in the relatively protected sites. The study thus reveals that the quantitative and qualitative characteristics of vegetation were affected by the degree of protection provided to the site (Table 3.23).

Table 3.23: Diversity index, species richness and evenness of woody and herbaceous species in Chambal ravines.

Index	Ravine top			Ravine slope			Ravine bed		
	PRF	PDRF	UPRF	PRF	PDRF	UPRF	PRF	PDRF	UPRF*
A. Woody species									
Species richness (S)	14	11	3	16	11	8	11	9	6
Diversity index (H')	2.137	2.008	0.624	2.24	1.82	1.19	1.466	1.575	1.259
Evenness (E)	0.739	0.718	0.650	0.754	0.679	0.522	0.649	0.684	0.621
B. Herbaceous species									
Species richness (S)	23	21	33	18	15	29	21	16	40
Diversity index (H')	2.134	2.340	2.369	2.187	2.039	2.349	2.104	2.161	2.420
Evenness (E)	0.772	0.790	0.563	0.802	0.679	0.593	0.664	0.833	0.542

* PRF = Protected ravine forest, PDRF = Partially disturbed ravine forest, UPRF = Unprotected ravine forest.

3.1.3.1.2 Ecological studies

The natural vegetation in Chambal ravine area is classified as Northern Tropical Ravine Thorn Forest which occur under xerarch, hydrarch and hydrarch-halosere conditions. The ecological succession is given under Fig 3.11.The present ravine thorn forest is showing progression towards tropical dry deciduous forest which is the climatic climax vegetation of the region. The present status of thorn forest is due to severe biotic factor resulting in retrogression. The observed floristic composition of natural vegetation is as listed below:

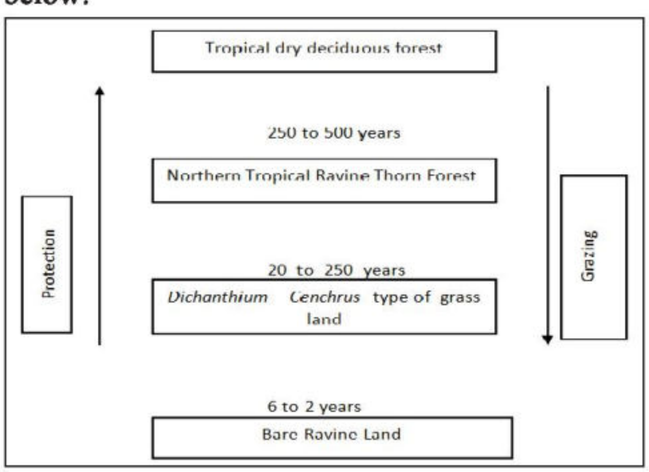

Fig. 3.11: Succession in forest under protected and unprotected conditions

Floristic composition:

Trees: *Acacia leucophloea, A. nilotica, A. catechu, Azadirachta indica, Balanites aegyptiaca, Cordia dichotoma, Dichrostachys cinerea, Dendrocalamus strictus, Feronia elephantum, Holoptelea integrifolia, Prosopis cineraria, P. juliflora, Pongamia pinnata, Soymida febrifuga, Salmalia malabarica, Salvadora oleoides, Tamarix dioica.*

Shrubs: *Asparagus racemosus, Capparis decidua, C. zeylanica, Cassia auriculata, Clerodendron phlomoides, Carissa opaca, Calotropis procera, Grewia pilosa, Lantana camara, Mimosa hamata, Zizyphus nummularia.*

Under growth: *Abutilon theophrasti, Achyranthes aspera, Argemone mexicana, Cassia tora, Blumea lacera, Indigofera linifolia, Rhynchosia minima, Tephrosia purpurea, Xanthium strumarium, Solanum sp.*

Grasses: *Dichanthium annulatum, Cenchrus ciliaris, Heteropogon contortus, Apluda mutica, Bothriochloa pertusa, Aristida adscenionis, Eremopogon faveolatus, Desmostachya bipinnata, Iseilema prostratum, Themeda quadrivalvis and Sorghum helepense.*

Wild life: Gullies of the Chambal River teem withwild life, when protected. Many mammals, reptiles, amphibians and aves are common. Near the river course fish life is abundant. Invertebrates are also common in the gullies and they consist of molluscs, earthworms, insects, centipedes, scorpions, spiders, honeybees, ants, crustaceae etc. Common animal found in the protected gullies are:

Carnivores: Indian jackal, rare visits of leopards has been reported in the gullies.

Herbivore: Wild hare, deer, porcupine, wild boar.

Reptiles : Snakes, tree lizard, ground lizard (Goha).

Amphibia: Frogs and toads

Fishes : Carp, Morrel, cat fish etc.

Aves : There are 84 species of birds belonging to 37 families and 14 orders, under 6 distinct habitats and 6 main food groups.

It has been observed that forest, water, orchard, and grassland sustained 80% of the bird population, while rest 20% found in cultivated lands. Among birds, insectivorous were 51.2% followed by carnivorous (27.3%) and herbivorous (14.3%) while remaining 7.2% depended on cultivated crops for their food. *Columboa livia* (Blue rock pigeon), *Streptopelia decaocto* (Ring dove), *S. senegalensis* (small brown dove), and *Psittacula krameri* (Rose ringed parakeet) are prominent birds of Chambal ravine region.

The gullies also have peacock in plenty and give an aesthetic appearance to the region.

3.1.3.2 Vegetation-Soil Interactions

Natural vegetation plays an important role in controlling soil erosion, reversing the land degradation process and restoring the productivity of degraded eco-system. The grass cover has been found very effective in reducing runoff and soil loss compared to agricultural crops (Table 3.24). These data are from mild slope (<2% slope) and as the slope or terrain roughness increases the relative efficiency of grasses would be even greater compared to other vegetation or land uses.

Table 3.24: Run-off and soil loss under agricultural crops and grasses

Treatment	Average rainfall (mm)	Run-off % of rainfall	Soil loss (kg/ha/yr)	Mean (years)
Dichanthium annulatum	480.5	5.6	178	2
Cynodon dactylon	656.8	7.7 to 10.7	300 to 400	4
Agricultural crops (sorghum, groundnut, black gram)	656.8	8.5 to 15.7	1100 to 2900	4

Under the grass cover increased root activity and fine root turn over results in addition of significantly large quantities of organic matter and organic acids (Table 3.25). This eventually leads to improved soil structure and infiltration rates. Evaluation of soil structure in terms of mean weight diameter (mwd) of water stable soil aggregates under different grass cover has been carried out (Nambiar *et. al.,* 1968). The mean weight diameter of soil aggregates in surface layers under grass cover was about five times higher than over-grazed area (Table 3.26). This has direct influence on pore size distribution of the soil which governs infiltration and water holding capacity of the soil.

Table 3.25: Mechanical composition, pH, organic matter and humic acid of soil under different grass covers

Grass species	Mechanical composition					Organic			
	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	pH	$CaCO_3$ (%)	Organic matter (%)	Humic acid (%)
Dichanthium annulatum	0 - 15	36.0	14.5	49.5	Clay	8.00	1.53	0.898	0.0176
	15 - 30	36.0	14.5	49.5	Clay	8.15	10.91	0.633	0.0072
	30 - 45	39.0	13.5	47.5	Clay	8.05	10.91	0.401	0.0016
	45 - 60	37.0	18.5	44.5	Clay	8.00	2.38	0.652	0.0048
Cenchrus ciliaris	0 - 15	36.5	15.0	48.5	Clay	7.90	0.69	0.891	0.0124
	15 - 30	36.5	15.0	48.5	Clay	8.05	10.91	0.652	0.0052
	30 - 45	39.5	16.0	44.5	Clay	7.90	2.38	0.408	0.0064
	45 - 60	39.5	16.0	44.5	Clay	7.90	1.53	0.586	0.0036
Aristida hystrix	0 - 15	36.0	15.5	48.5	Clay	7.70	1.53	1.094	0.0420
	15 - 30	42.0	21.5	36.5	Clay	7.80	10.91	0.814	0.0020
	30 - 45	44.0	21.5	34.5	Clay	7.95	4.10	0.662	0.0020
Over grazed area	0 -15	42.0	19.5	38.5	Clay	8.35	4.10	0.891	0.0068
	15 -30	46.0	21.5	32.5	Clay	7.90	1.53	0.560	0.0080

Table 3.26: Mean weight diameter (mm) of aggregate distribution in Kota clay soil under different grass covers

Grass	0-15 cm	15-30 cm	30-45 cm	45-60 cm
Dichanthium annulatum	1.407	0.504	0.252	0.370
Cenchrus ciliaris	1.400	0.550	0.330	0.264
Aristida hystrix	0.900	0.450	0.350	--
Over grazed area	0.270	0.255	--	--

3.2 Technologies Developed and Refinement at Research Centre, Kota-Applied

Over the last 60 years one of the major thrust areas for research has been to increase and stabilize the agricultural production from water stressed production systems in the vicinity of ravines. Various land uses and management strategies have been identified for arable and non-arable lands.

3.2.1 Resource Conservation Measures for Arable Lands

3.2.1.1 Agronomical Measures

3.2.1.1.1 Selection of crops and cropping systems

The loss of soil and nutrients is greater from bare land having no vegetative cover to dissipate the kinetic energy of rain drops responsible for detachment of soil particles but it is reduced considerably due to vegetative cover. The performance of green gram, black gram, sesame, soybean, sorghum, pigeonpea and castor was evaluated for canopy development and splash erosion by Prasad *et. al.* (2003) over a period of three years. The average canopy during rainy season was 56% in green gram and black gram followed by sesame and soybean (about 50%). Other three crops had less than 35% canopy cover (Table 3.27). The splash erosion was minimum in black gram and maximum in pigeonpea.

3.2.1.1.2 Sequential cropping

In rainfed medium black soils of the region farmers grow either a *Kharif* crop or a *Rabi* crop. To explore the possibility of double cropping system few studies were conducted with short duration pulses *i.e.,* green gram, black gram or cowpea in *kharif* followed by low water requiring oil seed crop such as safflower, *taramira* and mustard. The data in Table 3.28 compares the relative efficiency of 12 cropping sequences field-tested for four years. Green gram-safflower cropping was found most productive cropping sequence for the region.

Table 3.27: Canopy cover (%) and splash erosion under promising crops (three years average for the period from 1994 to 1996)

Crop	Canopy cover (%) at different age (DAS*)					Splash erosion (gm)
	15	30	45	60	Average	
Green gram	15.2	52.6	73.4	82.2	55.9	7.64
Black gram	14.3	50.8	74.5	83.6	55.8	7.07
Sesame	15.7	49.8	71.9	76.2	53.4	7.67
Soybean	14.6	43.8	67.8	77.6	51.0	7.80
Sorghum	9.3	27.5	47.4	58.0	35.6	10.48
Pigeon pea	6.7	21.0	37.3	56.3	30.3	11.78
Castor	8.8	24.1	44.1	58.1	33.8	11.28
Fallow	--	--	--	--	--	14.99

****DAS = Days after sowing***

Table 3.28: Grain yield and energy value of different pulse-oilseed crop sequences (mean data from 1978-79 to 1981-82)

Crop sequence	Grain yield (kg/ha)			Energy value (m k cal/ha)		
	Kharif	*Rabi*	Total	*Kharif*	*Rabi*	Total
Green gram - safflower	888	370	1258	3.09	1.31	4.40
Green gram - mustard	968	10	978	3.37	0.05	3.42
Green gram - *taramira*	918	110	1028	3.20	0.53	3.73

Green gram - chickpea	821	9	830	2.84	0.03	2.87
Black gram - safflower	795	157	952	2.68	0.56	3.24
Black gram – mustard	882	17	899	3.02	0.09	3.11
Black gram- *taramira*	792	51	843	2.74	0.25	2.99
Black gram- chickpea	576	6	582	2.00	0.02	2.02
Cowpea – safflower	484	268	752	1.56	0.95	2.51
Cowpea – mustard	457	12	459	1.48	0.06	1.54
Cowpea – *taramira*	476	87	563	1.54	0.42	1.96
Cowpea – chickpea	325	6	331	1.09	0.04	1.13
C.D. at 5%	--	--	--	--	--	1.12

3.2.1.1.3 Intercropping

Bringing stability in the crop production has been a major challenge in the rainfed areas. Intercropping provides biological insurance against crop failure brings stability in crop yields during weather aberrations and ensures higher crop yield and profit from unit area compared to sole cropping through efficient resources utilization. On the basis of annual rainfall and its distribution pattern and moisture retention capacity of soils, the region is best suited for intercropping system Accordingly, sorghum, pigeonpea, castor and soybean based inter cropping in the *Kharif* and chickpea based intercropping system during *Rabi* have been evaluated.

Sorghum based inter-cropping systems: Intercropping of sorghum and pigeon pea under rainfed conditions is commendable practice to ensure against total failure of mono-cropping of rainfed sorghum in South-Eastern Rajasthan. Studies conducted at Kota (Singhal *et. al.,* 1977) to find out the compatibility of different legumes *e.g.,* black gram, cowpea and pigeonpea for intercropping with sorghum, revealed that raising sorghum and pigeon pea in alternate lines 30 cm apart was more remunerative as compared to pure crop and other systems. Intercropping provided 36% and 120% higher income compared to mono-cropping of sorghum and pigeon pea, respectively (Table 3.29 & Fig.3.12).

Fig. 3.12: Intercropping sorghum with pigeon pea

Table 3.29: Yield land equivalent ratio (LER) and grass income under sorghum based intercropping systems (mean data from 1968-69 to 1970-71)

Treatment	Sorghum (kg/ha),		Pulse(kg/ha),		LER	Gross income (Rs./ha)
	Grain	Stover	Grain	Stover		
Sorghum – 60 cm row spacing	2478	4025	-	-	1.00	2053
Cowpea – 60 cm row spacing	-	-	751	1302	1.00	882
Blackgram – 60 cm row spacing	-	-	695	756	1.00	945
Pigeonpea – 60 cm row spacing	-	-	1104	1565	1.00	929
Sorghum rows spaced 60 cm + 1 inter row of cowpea	2157	3268	391	636	1.39	2183

Sorghum rows spaced 90 cm + 2 inter rows of cowpea	1908	3125	413	867	1.32	2056
Sorghum rows spaced 60 cm + 1 inter row of blackgram	2712	4253	222	454	1.41	2511
Sorghum rows spaced 90 cm + 2 inter rows of blackgram.	2361	3454	247	753	1.31	2264
Sorghum rows spaced 60 cm + 1 inter row of pigeonpea	2515	3577	900	1676	1.83	2790
Sorghum rows spaced 90 cm + 2 inter rows of pigeonpea	2368	3373	976	1394	1.84	2699

Pigeon pea based intercropping systems: Pigeonpea (Local) is grown with other crops in South-Eastern Rajasthan under rainfed conditions for increasing overall production. In order to find out a suitable crop for intercropping in pigeonpea, different *Kharif* crops *viz*., green gram, black gram and sorghum were evaluated in different row ratios for four years. It was observed that intercropping produced significantly higher yield as compared to sole pigeonpea. Pigeonpea + black gram (1:3) was found more productive than sole cropping of component crops (Table 3.30).

Table 3.30: Grain yield and energy value under different intercropping systems (mean data from 1976-77 to 1979-80)

Treatment	Grain yield (kg/ha)			Energy value (m kcal/ha)
	Main crop	Intercrop	Total	
Pigeonpea in 60 cm rows	921	-	921	3.12
Pigeonpea in 90 cm rows	811	-	811	2.71
Pigeonpea in 120 cm rows	780	-	780	2.61
Pigeonpea + greengram (1:1)	898	446	1344	4.56
Pigeonpea + greengram (1:2)	834	551	1385	4.77
Pigeonpea + greengram (1:3)	669	521	1190	4.05
Pigeonpea + black gram (1:1)	1018	565	1583	5.31
Pigeonpea + blackgram (1:2)	864	685	1549	5.26
Pigeonpea + black gram (1:3)	856	723	1579	5.37
Pigeonpea + sorghum (1:1)	678	817	1495	5.32
Pigeonpea + sorghum (1:2)	592	758	1350	4.62
Pigeonpea + sorghum (1:3)	529	875	1404	4.77
C.D. at 5%				1.25

Castor based intercropping system: Castor is one of the dependable crops of South-Eastern Rajasthan where abnormal occurrence of monsoon is an important limiting factor for crop production. Being a long duration and widely spaced crop it offers good possibility of intercropping. Prasad *et. al*. (1989) studied the compatibility of green gram, black gram, sesame and sorghum for intercropping in castor (Fig.3.13). The results of the study indicated that seed yield of castor was not affected when intercropped with green gram or black gram, whereas it reduced with sesame (20%) and sorghum (80%). On the basis of total productivity and land equivalent ratio castor + green gram in 1:2 rows proved superior to pure castor and other castor based intercropping systems (Table 3.31).

Fig. 3.13: Castor at early stage (left) and castor + green gram intercropping (right)

Table 3.31: Grain yield and land equivalent ratio (LER) under different treatments (mean data from 1982-83 to 1984-85)

Treatment	Castor(kg/ha)	Companion crop (kg/ha)	Castor grain equivalent (kg/ha)	L.E.R.
Castor	1364	--	1364	1.00
Greengram	--	724	633	1.00
Blackgram	--	547	514	1.00
Sesame	--	322	484	1.00
Sorghum	--	3201	961	1.00
Castor+greengram	1431	416	1796	1.62
Castor+blackgram	1399	277	1676	1.54
Castor+sesame	1090	198	1387	1.41
Castor+sorghum	262	2762	1091	1.05

Soybean based intercropping systems: Soybean has emerged as a prominent crop of rainy season in South-Eastern Rajasthan owing to higher return per unit area than traditional crops under irrigation. Farmers tilling the vast tract of drylands in the region often venture its cultivation where yield is not only low but also quite unstable due to erratic rainfall pattern. For providing biological insurance and stabilizing productivity Prasad *et. al. (1997)* studied the effect of intercropping soybean with sorghum and pigeonpea for 3 years. Soybean + pigeonpea in 4:1 rows proved superior to other treatments and yielded 712 kg/ha soybean and 830 kg/ha pigeonpea seed, which amounted to 1493 kg/ha soybean equivalent yield as compared to 1086 kg/ha sole soybean yield. This system also recorded the highest land equivalent ratio (1.26). Intercropping systems showed higher water-use and water-use-efficiency than sole sorghum (Table 3.32).

Chickpea based intercropping system:

Chickpea is one of the prominent crops raised as a pure crop or mixed with linseed/mustard/wheat on conserved moisture in the region. Dayal *et. al.* (1967) studied the performance of chickpea + wheat (1:1) crop mixture against pure crops for yield and nitrogen status at harvest for 5 years (1958-59 to 1962-63) and found that yield of crop mixture was significantly higher than pure crops. Soil nitrogen at harvest of crop mixture was also higher as compared to pure wheat. Prasad *et. al.* (1997) evaluated intercropping of chickpea with mustard and linseed in 2:1, 4:1 and 6:1 rows, 30 cm apart on yield and water use. Chickpea + linseed intercropping in 2:1 rows gave the highest chickpea equivalent yield (2079 kg/ha), which was 14.9 and 45.9% higher than sole chickpea and sole linseed, respectively (Table 3.33). This system recorded the highest land equivalent ratio (1.26). Chickpea + mustard intercropping systems showed higher water use than sole chickpea.

Table 3.32: Effect of intercropping on grain yield, land equivalent ratio (LER) water use and water-use-efficiency of crops (mean data from 1990-91 to 1992-93)

Treatment	Grain yield (kg/ ha)			LER	Water use (mm)	WUE (kg/ha/ mm)
	Soybean	Intercrop	Soybean equivalent			
Sole soybean in 30 cm rows	1086	--	1086	1.00	417	2.6
Sole sorghum in 60 cm rows	–	3517	1241	1.00	439	2.8
Sole pigeon pea in 60 cm rows	--	1313	1236	1.00	441	2.9
Soybean + sorghum in 2:1 rows 30 cm apart	408	2896	1431	1.21	439	3.3
Soybean + sorghum in 4:1 rows 30 cm apart	650	2074	1382	1.20	435	3.2
Soybean + sorghum in 6:1 rows 30 cm apart	796	1623	1369	1.20	429	3.2
Soybean + pigeonpea in 2:1 rows 30 cm apart	504	1046	1488	1.24	454	3.4
Soybean + pigeonpea in 4:1 rows 30 cm apart	712	830	1493	1.26	451	3.4
Soybean + pigeonpea in 6:1 rows 30 cm apart	846	605	1415	1.22	447	3.2
C.D. at 5%	76	--	170	0.03	18	N.S.

Table 3.33: Grain yield, land equivalent ratio (LER), water-use and water-use- efficiency (WUE) under different treatments (mean data from 1990-91 to 1992-93)

Crops/Cropping system	Grain yield (kg/ha)			LER	Water use (mm)	W.U.E. (CEY: kg /ha/mm)
	Chickpea	Intercrop	C.E.Y.			
Chickpea in 30 cm rows	1810	--	1810	1.00	130	13.9
Mustard in 45 cm rows	--	1446	2002	1.00	137	14.4
Linseed in 30 cm rows	--	926	1425	1.00	118	12.9
Chickpea + mustard in 2:1 rows 30 cm apart	739	915	2006	1.04	136	14.5
Chickpea + mustard in 4:1 rows 30 cm apart	1146	628	2016	1.07	134	14.9
Chickpea + mustard in 6:1 rows 30 cm apart	1358	506	2059	1.11	132	15.5
Chickpea + linseed in 2:1 rows 30 cm apart	1289	513	2079	1.26	128	16.7
Chickpea + linseed in 4:1 rows 30 cm apart	1535	269	1949	1.14	127	15.6
Chickpea + linseed in 6:1 rows 30 cm apart	1627	177	1900	1.09	129	14.9
C. D. at 5%	73	--	75	0.04	4	2.0

C.E.Y: Chickpea equivalent yield

3.2.1.2 Agroforestry Systems

Integration of trees along with agricultural crops helps in drought mitigation and production stabilization. Trees, besides providing fuel and fodder also contribute to soil and water conservation. However, there are divergent views about effect of trees on growth and yield of crops. Several studies were taken up to assess the effect of multipurpose tree spp. on growth and yield of associated agricultural crops. Major findings of these studies are summarized here.

3.2.1.2.1 Effect of eucalyptus on agricultural crops

A study was undertaken to select compatible crops for cultivation with *Eucalyptus tereticornis* under rainfed conditions. Sorghum, green gram and black gram in *Kharif* and taramira and safflower in *Rabi* were studied for their association with *Eucalyptus tereticornis* line (planted on field bund) by Prasad *et. al*. (1985). The tree line had adverse effect on yield up to 10 m distance in *Kharif* crops and up to 20 m distance in *Rabi* crops by competing for soil moisture and providing shade. Sorghum was found more compatible than pulses in *Kharif* and *taramira* performed better than safflower in *Rabi* season (Table 3.34).

3.2.1.2.2 Effect of *Leucaena* on agricultural crops

Leucaena can be used for fodder, fuel and soil fertility improvement. Prasad and Prasad (1997) studied the compatibility of sorghum, sorghum + pigeonpea (1:1) intercrops, green gram, black gram and castor in *Kharif* season and safflower and taramira in *Rabi* season with *Leucaena* tree line planted on field bund. Agricultural crops were raised in South-West direction and effect of trees was recorded in various quadrates perpendicular to tree line. It was found that tree line did not have any adverse effect on crop yields during initial 2 years. However, mean data of 10 years indicated that *Leucaena* tree line had adverse effect on yield of all crops up to 10 m perpendicular distance due to competition it offered for moisture and light. Sorghum + pigeonpea (1:1) intercrops and taramira proved superior to remaining crops during *Kharif* and *Rabi* season, respectively (Table 3.35).

Table 3.34: Grain yield of field crops as affected by competition from *Eucalyptus tereticornis*line (mean data from 1980-81 to 1983-84)

Distance from tree line (m)	Grain yield (kg/ha)				
	Kharif crops			*Rabi* crops	
	Green gram	Blackgram	Sorghum	Safflower	*Taramira*
0-2	291	61	1017	2	41
2-5	375	185	1362	5	65
5-10	464	289	1503	17	142
10-20	700	390	1940	86	243
20-30	824	407	2032	183	337

Table 3.35: Effect of *Leucaena* tree row on crop yields

Distance from tree line (m)	Nine years (1983-92) average grain yield (kg/ha)								
	Sor.	Pig.	Sor. + Pig. intercropping	Sor.	Bg.	Gg.	Cas.	Saf.	Tar.
0-2	626	147	773	866	242	263	429	7	33
2-5	1089	251	1340	1391	385	392	680	8	66
5-10	1733	460	2193	2168	600	616	927	39	233
10-20	2148	576	2724	2674	714	733	1135	114	350
20-30	2248	598	2846	2811	720	747	1190	130	395
CD at 5%	18	10	--	18	13	10	21	60	21

Sor. – Sorghum; Pig. – Pigeonpea; Bg. – Blackgram; Gg. - Greengram; Saf.- Safflower; Tar.- Taramira

3.2.1.2.3 Alley cropping in *Leucaena*

Well timed pruning of trees minimizes tree-crop competition for moisture and light. Alley cropping with tree spp. of good coppicing ability provides an opportunity to reduce competition between tree and crops. Prasad *et. al.* (1989) evaluated the productivity and economics of alley cropping in *Leucaena.* Higher *Leucaena* green fodder and grain yield of field crops were obtained in their pure stands. *Leucaena* rows planted 3.75 m apart reduced the grain yield of sorghum, sorghum + pigeonpea (1:1) and pigeonpea + black gram (1:1) by 14, 16 and 16%, respectively. However, crop yield reduction was compensated by *Leucaena* fodder, which ranged between 5-11 t/ha. Pigeonpea + black gram (1:1) with *Leucaena* was more remunerative alley cropping system than the sorghum and sorghum + pigeonpea (Table 3.36 and Fig.3.14).

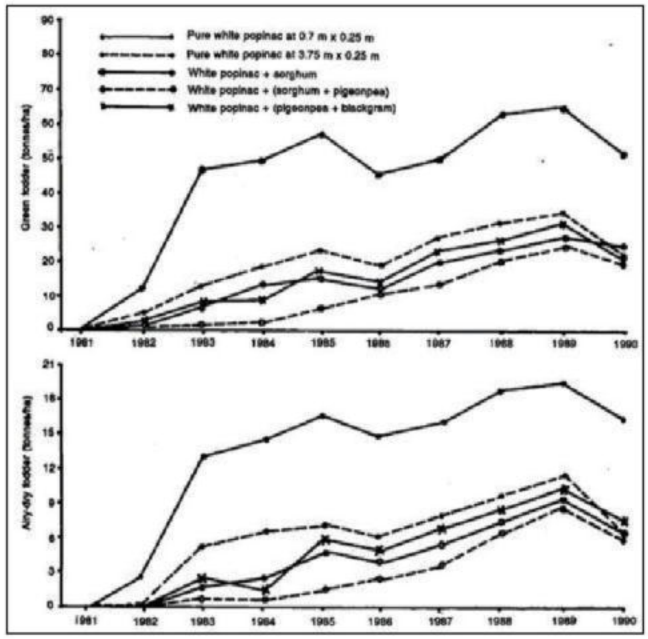

Fig. 3.14: Fodder yield of white popinac during 1981-90

Table 3.36: Yield and gross return in alley cropping (Mean data from 1981-82 to 1986-87)

Treatment	Grain yield (kg/ha)				Leu. fodder yield (t/ha)	G.R. (Rs./ha)
	Sor.	Pig.	Bg.	Sor.equ.		
T_1 – Pure Leu. (0.75 m x 0.25 m)	-	--	–	--	37.3	4476
T_2 – Pure Leu. (3.75 m x 0.25 m)	--	--	--	--	14.8	1776
T_3 – T_2 + Sorghum	1296 (2590)	--	--	1296	10.5	3852
T_4 – T_2 + (Sor. + Pig., 1:1)	1027 (2040)	564 (1410)	–	2907	5.3	5789
T_5 - T_2 + (Pig. + Bg., 1:1)	--	724 (1850)	205	2957	11.0	6125
T_6 – Sorghum	1501 (3110)	--	--	1501	--	3029
T_7 – Sor. + Pigeonpea (1:1)	1189 (2145)	689 (1705)	--	3486	--	6106
T_8 – Pig. + Bg. (1:1)	--	824 (2110)	253	3421	--	5554
C.D. at 5%	--	--	–	324	2.7	464

Leu.- Leucaena; Sor.- Sorghum; Pig.- Pigeonpea; Bg – Black gram; Sor. equ. – Sorghum equivalent; G.R.- Gross return; Figures in parenthesis indicate stover yield.

3.2.1.2.4 Survey of agroforestry practices in South-eastern Rajasthan

A sample survey conducted in 1998 in Chajawa watershed, district Baran and Polaikalan in district Kota in South-Eastern Rajasthan revealed that adoption of agroforestry practices was poor in the region (Parandiyal *et. al.*, 1998). The average tree density in the agricultural lands was 6.6 trees/ha mostly raised on field bunds. Few fruit trees found place in the midfield also. *Eucalyptus tereticornis* was the most preferred tree followed by *Psidum guajava* and *Citrus* spp. *Acacia* spp. and *Azadirachta indica*, which regenerated naturally were maintained on field bunds. Farmers were reluctant to plant *Acacia nilotica* which they feel had more adverse impact on associated crops than *Eucalyptus tereticornis* and *Acacia leucophloea.* The average crop yield reduction ranged between 60.7% in *Rabi* upto 6.6m distances from tree to 44.5% up to 4.4m during *Kharif*. Sorghum was the most compatible crop and was preferred for agroforestry.

3.2.1.2.5 Studies on tree crop association

To evaluate suitable tree crop combinations under boundary plantation system a study compared the impact of *Acacia nilotica, Azadirachta indica* and *Albizia lebbek* on associated field crops of castor and pigeonpea raised in two sequences. Two rows of seven trees each of *Acacia nilotica, Azadirachta indica* and *Albizia lebbek*, one row each in North-South and East-West direction of planting, were raised with spacing of 5 m among the trees in 1991. Castor was planted for four years (1994-97) and was subsequently replaced with pigeonpea for five years (1998-03). The reduction in the caster productivity varied from 4-6% to 73.2% with reducing distance of 15 to 5 m from *Albizia lebbek* rows (Fig. 3.15). The impact of direction of tree planting on the crop yields was not significant. The reduction in pigeon pea yield of associated crop followed the similar trend. *Albizia lebbek* showing highest adverse impact on associated crop yields followed by *Azadirachta indica.* The adverse impact of tree species on the crop yield had positive correlation with the growth rate of tree species (Parandiyal *et. al.*, 2001).

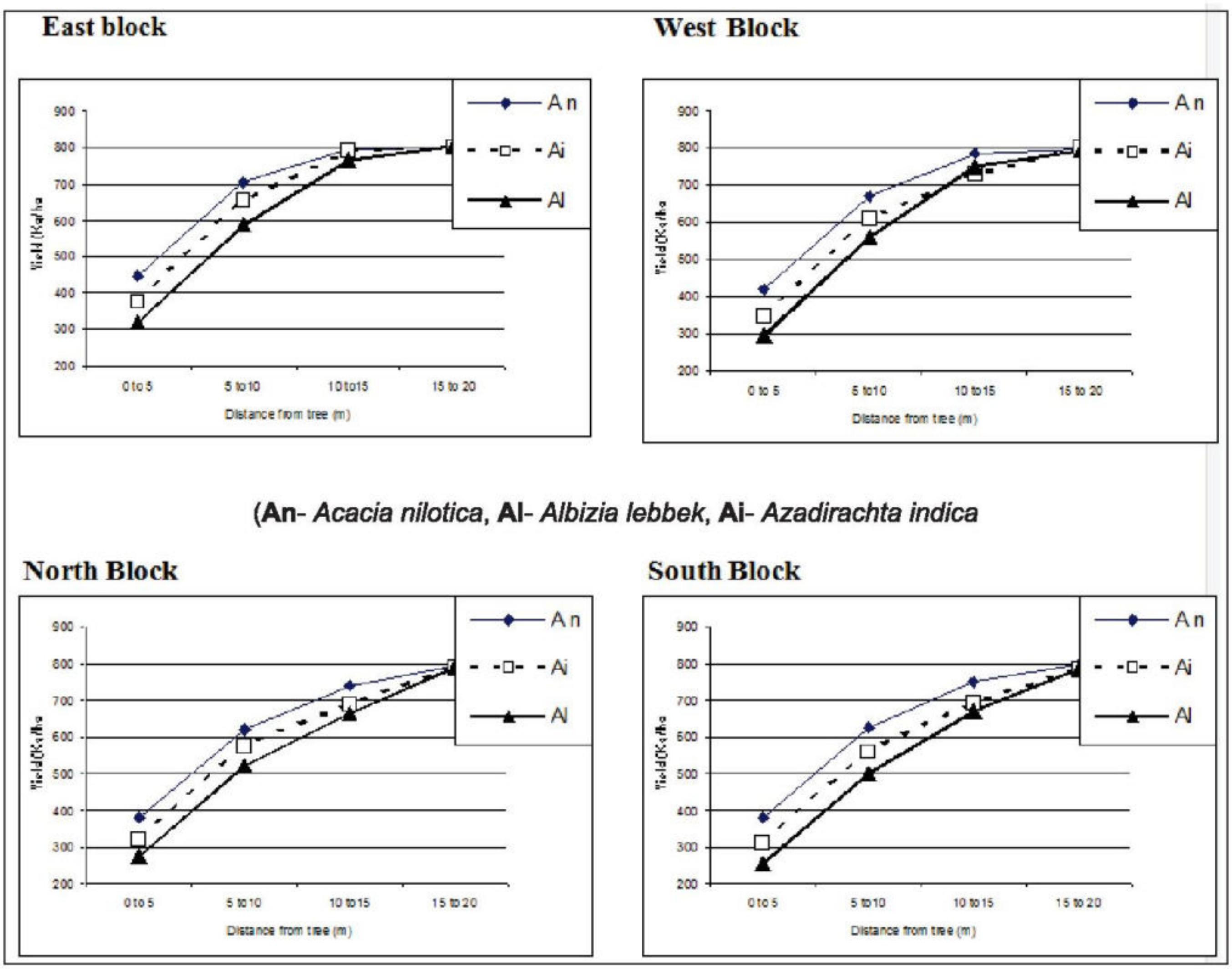

Fig. 3.15: Yield of castor crop in response to tree row direction and distance

3.2.1.3 Agri-horticultural System

A three year study (2001-02 to 2003-04) evaluated performance of green gram, soybean and sesame with lemon and guava under rainfed agri-horti system at Research Farm, as well as at farmers' fields. Green gram (var. K 851), soybean (var. JS 335) and sesame (RT 46) were intercropped with lemon (var. *Kagzinimbu*) and guava (var. L 49) plants. In general, field crops reduced the vegetative growth of fruit trees. This effect was more prominent on lemon as compared to guava. The soybean and sesame crops were most competitive with guava, whereas green gram was more aggressive against lemon. Sesame recorded maximum yield reduction in the vicinity of trees as compared to sole cropping with both fruits spp., while soybean had minimum yield reduction. Though the reduction in yield was lowest in soybean, sesame was at par in terms of economic return due to higher market price despite higher yield reduction in the agri-horticultural system.

3.2.1.4 Erosion Control Measures for Arable Lands

3.2.1.4.1 Contour cultivation

Sheet erosion is major erosion process on gentle slopes resulting in significant loss of surface soil along with essential plant nutrients through runoff and thereby reducing the productivity of soils. Verma *et. al*. (1990) evaluated the performance of along and across the slope seeding of sorghum and sorghum + pigeonpea (1:1) intercropping with respect to erosion hazards in Kota clay soil at 1% slope. It was found that across the slope seeding of sorghum and sorghum + pigeonpea intercrops reduced the runoff (7-10%) and soil loss (25-35%) and increased the yield of crops (22-49%) when compared with along the slope seeding. Another study conducted for 5 years compared the performance of along and across the slope planting of castor and castor + green gram intercropping on runoff, soil and nutrient losses and yield at 1% slope (Prasad *et. al.*, 1993). Across the slope planting of castor and castor + green gram intercropping reduced the runoff by 9.2 and 14.2% and soil loss by 25.1 and 17.6% and increased the castor yield by 26.6 and 15.4%, respectively as compared to along the slope planting of corresponding crops (Table 3.37).

3.2.1.4.2 Graded bund

The purpose of graded bunds is to make runoff to walk rather to run on the surface. For *in-situ* conservation of rainfall and to minimize erosion hazards on sloping arable lands (land slope up to 6%), graded bunds of 1.00-1.25 m^2 cross section with 0.5 to 1 m vertical interval having grade 0.2 to 0.3% have been found suitable for the region. Studies conducted in Operational Research Project Chhajawa in district Baran reveal that graded bunds reduced the runoff from 24.7 % to 7.7 % of rainfall and increased the yield of crops by 22% (Prasad *et. al*., 1996).

Table 3.37: Runoff, soil and nutrient losses, and grain yield of crops under different treatments (mean data from 1986-87 to 1990-91) (Rainfall-502 mm)

Treatment	Runoff (%) of rainfall	Soil loss (kg/ha)	Nutrient loss (kg/ha)			Grain yield of crops (kg/ha)		
			N	P	K	Castor	Greengram	Castor equivalent
Castor along the slope	27.2	2190	5.14	0.66	6.54	864	–	864
Castor across the slope	24.7	1640	4.32	0.60	5.47	1094	--	1094
Castor + greengram (1:2) along the slope	22.5	1396	3.93	0.50	5.79	830	393	1279
Castor + greengram (1:2) across the slope	19.3	1151	3.57	0.39	5.49	938	470	1476

3.2.1.4.3 Conservation bench terrace

For *in-situ* utilization of rainfall, 6 conservation bench terrace (CBT) systems of different ratios of contributing (C) to receiving (R) catchments *viz*., 1:3, 1:2, 1:1, 2:1, 3:1 and 1:0 have been evaluated by Prakesh and Verma (1985) to maximize the production of rainfed sorghum (Table 3.38). The contributing area had 1% slope while receiving area was kept level for uniform spread of excess runoff from contributing area. Among the CBT systems tried, the system having C and R in 1:2 ratio produced the highest yield (3001 kg/ha) which was 27.1 % higher than control (1:0). The CBT system 1:1 and 1:3 also yielded 12.6 and 11.4 % higher grain than control while 3:1 system slightly reduced the sorghum yield. Thus, 1:2 system is recommended for the region to minimize erosion hazards and maximize production on rainfed arable lands.

3.2.1.4.4 Surface modifications

The effect of mini bunds ($0.02m^2$) and contour furrows ($0.02m^2$) on erosion losses and yield of rainfed sorghum were evaluated in a study conducted in runoff plots at 1% slope (Prasad *et. al*., 2002). The results indicate that mini bunds spaced at 5.5 and 7.3 m horizontal interval reduced runoff by 89.3-93.6% and soil loss by 97.0-98.6%. Contour furrows opened at similar spacing also reduced runoff and soil loss by 47.1-57.1% and 71.1-78.6%, respectively. These treatments showed 9-12% improvement in grain yield of sorghum (Table 3.39).

Table 3.38: Sorghum grain and stover yield in conservation bench terrace

CBT Systems (Contributing: Receiving area ratio)	3 years Mean Yield (1982-85) (kg/ha)	
	Grain	Stover
T_1 (1:3)	2630	9161
T_2 (1:2)	3001	10469
T_3 (1:1)	2658	9471
T_4 (2:1)	2395	8625
T_5 (3:1)	2208	8163
T_6 (1:0)	2360	8207

Table 3.39: Runoff, soil loss and yield of crops with surface modification

Treatment	Runoff (%)	Soil loss (kg/ha)	Sorghum grain equivalent yield (kg/ha)
Cultivated fallow	23.8	6563	-
Sorghum at 45 cm x 20 cm	14.0	3659	1802
Sorghum with bunds at 5.5 m spacing	0.9	52	2017
Sorghum with bunds at 7.3 m spacing	1.5	111	1961
Sorghum with contour furrows at 5.5 m spacing	6.0	783	2017
Sorghum with contour furrows at 7.3 m spacing.	7.4	1056	1971
Cenchrus ciliaris grass cover	2.2	57	-

Contour furrow: In medium-deep black soils of South-eastern Rajasthan bunds are breached frequently due to swelling and shrinking soils which often accelerate erosion process by diverting the runoff into erosive streams. Considering compatibility with the prevailing farming practice, soil type and topography contour furrows are found to be a suitable conservation measure for facilitating *in-situ* rainwater conservation as well as drainage during consecutive rainfall events. These are small ditches of 20 to 30 cm in depth and 40 to 50 cm in width that follow contours across the natural slope of the land. Contour furrows break a long slope length into segments, provide additional storage depression for surface runoff and create a drainage net-work when connected to graded drainage channel. When spaced at regular intervals the furrows benefit crops all across the field through improved drainage and soil moisture availability. The furrows are usually constructed with a single-blade furrow plough or similar equipment that opens 40-50 cm wide and 20-30 cm deep furrow by pushing the excavated soil towards both sides of furrow (Fig.3.16 and Fig. 3.17). The excavated soil is pushed away from the furrow to avoid any stagnation of water outside the furrows. For correcting the improper alignment along the contour furrows and for storing water in the furrows small earthen dykes for impounding water are constructed at 10-15 m interval. The furrows create additional surface storage capacity of 11.25 mm/ha and reduce runoff by about 22% and soil loss by 1.4 t/ha/year. The net returns under contour furrow treatment are 129% higher than the farmers practice. Result of this technology at farmers' fields is summarized in Table 3.40.

Fig. 3.16: Single blade furrow opener (left) and contour furrow in Sorghum + P. pea intercropping (right)

Fig. 3.17: Contour furrows demonstrations on farmers' field

Table 3.40: Comparative performance of contour furrow on farmers' field

Year	District	No. of village	No. of farmers	Mean yield (kg/ha)		Percentage increase over farmers' practice
				Farmers practice	Contour furrow	
2012	Kota	2	3	1719	2187	27.22
	Baran	3	3	1725	2023	17.28
2013	Kota	4	5	1412	1718	21.67
	Baran	4	5	812	1275	56.96
2014	Bundi	3	4	960	1273	32.60
2015	Bundi	4	5	822	1121	36.50
2016	Bundi	5	10	1593	2046	28.43
	Baran	5	10	1702	2187	28.47

Vegetative barriers: In a 4 year study, four vegetative barriers *viz. Vetiveria zizanioides, Saccharum munja, Cenchrus ciliaris* and *Dichanthium annulatum* were evaluated by Prasad *et al.* (2005) to assess their impact on soil erosion and yield under rainfed sorghum and soybean at 1% slope (Fig.3.18). All the barriers were found equally effective in reducing erosion hazards (Table 3.41). Rainfed sorghum and soybean with vegetative barriers recorded 25.9 to 29.5% and 31.2 to 33.7% less runoff and 39.9 to 54.3% and 46.7 to 52.2% less soil loss, respectively than sorghum and soybean without barriers. In general, soybean gave less runoff and soil loss than sorghum. Vegetative barriers increased the grain yield of sorghum and soybean from 18.9 to 20.8% and 19.9 to 24.4%, respectively due to better soil moisture regime in the root zone as a result of less runoff. Vegetative barriers also showed improvement in organic carbon, available N and P at the end of experimentation. Another study compared the performance of *Vetiveriazizanioides* vegetative barrier with and without earthen bund (0.15 m^2) in field size runoff plots (80 m x 50 m) at 1.5% slope (Table 3.42). The vetiver was planted in 2 staggered lines 15 cm apart at a horizontal spacing of 20 m with and without bund having 0.4% grade. The performance of Vetiver barrier recorded 47.4 and 27.3% less runoff and soil loss, respectively than without bund under soybean + pigeonpea (3:1) intercropping system. Soybean and pigeonpea also yielded 22.0 and 21.2% higher grain due to better moisture regime in the root zone of crops.

Fig. 3.18: *Karad* (left) and *Dhaman* grass barriers

Table 3.41: Performance of Vegetative barriers (mean data from 1998-99 to 2001-02)

Treatment	Runoff (%)*	Soil loss (kg/ha)	Yield (kg/ha)
Cultivated fallow	27.0	2971	--
Sorghum without barrier	22.0	1898	1140
Sorghum with barrier of *Vetiver zezanioides* at 11 m spacing	16.2	1141	1377
Sorghum with barrier of *Saccharum munja* at 11 m spacing	16.3	868	1355
Sorghum with barrier of *Cenchrus ciliaris* at 11 m spacing	15.8	1016	1359
Sorghum with barrier of *Dichanthium annulatum* at 11 m spacing	15.5	1055	1364
Soybean without barrier	20.2	1447	562
Soybean with barrier of *Vetiveria zezanioides* at 11 m spacing	13.6	726	699
Soybean with barrier of *Saccharum munja* at 11 m spacing	13.4	704	974
Soybean with barrier of *Cenchrus ciliaris* at 11 m spacing	13.9	771	697
Soybean with barrier of *Dichanthium annulatum*at 11 m spacing	13.7	692	697
Cenchrus ciliaris grass cover	6.7	197	5760**

*Rainfall: 265.5 mm, ** Air dry forage

Table 3.42: Runoff, soil loss and yield of crops with vegetative barrier of Vetiver (mean data from 1995-96 to 1997-98)

Treatment	Runoff (%)	Soil loss (t/ha)	Yield (kg/ha)	
			Soybean	Pigeonpea
Vetiveria zezanioides without bund	25.3	3.3	726	1067
Vetiveria zezanioides with bund	13.3	2.4	886	1293

3.2.1.5 Soil management for Sustainable Productivity

A gradual decline in soil quality and productivity is a common phenomenon on erosion prone rainfed slopes where resource constrained farming systems is generally practiced. Various soil management practices have been evaluated to reverse soil degradation processes in this region. Tillage Depth and Residue Recycling: To find out the effect of tillage practices and crop residue recycling on soil moisture, soil properties and productivity of rainfed sorghum a study conducted during 1993 to 2001. Three tillage depths *viz*., 10,15 and 20 cm and 3 levels of residue recycling *viz*., 0, 2.5 and 5 t/ha were evaluated for cultivating rainfed sorghum (Table 3.43). The grain yield of sorghum marginally increased with depth of tillage and the quantity of residue recycling. On an average the grain yield of sorghum increased by 5.9 and 13.1% with 15 and 20 cm deep tillage, respectively compared to 10 cm deep tillage. Similarly, 2.5 and 5.0 t/ha residue recycling improved the yield by 12.4 and 20.6%, respectively over control. This was attributed to better moisture regime in the root zone of sorghum by deep tillage and residue recycling. Increased level of residue and reduced tillage depth also favoured soil organic matter accumulation, pH moderation and improved available N and P status (Table 3.44). Increased level of crop residue also improved water stable aggregates especially when associated with deep tillage treatment.

Table 3.43: Effect of crop residue recycling and tillage depth on sorghum grain yield (mean data from 1993-01)

Depth of tillage (cm)	Residue recycling (t/ha)			
	0	2.5	5.0	Mean
	Grain yield (kg/ha)			
10	1564	1764	1888	1739
15	1648	1879	1996	1841
20	1785	1973	2142	1967
Mean	**1666**	**1872**	**2009**	-

Table 3.44: Effect of tillage depth and residue recycling on soil properties

Depth of tillage (cm)	Residue recycling (t/ha)			
	0	2.5	5.0	Mean
	Organic carbon (%)			
10	0.30	0.32	0.42	0.35
15	0.31	0.37	0.39	0.36
20	0.27	0.30	0.41	0.33
Mean	0.29	0.33	0.41	
	pH			
10	8.27	8.14	7.95	8.12

15	8.45	8.15	8.05	8.22
20	8.72	8.55	8.28	8.52
Mean	8.48	8.28	8.09	
	Available N (kg/ha)			
10	182.0	192.2	185.5	186.6
15	152.5	168.5	179.5	166.8
20	148.2	192.8	189.5	176.8
Mean	160.9	184.5	184.8	
	Available P (kg/ha)			
10	9.25	10.17	11.72	10.38
15	8.72	9.73	10.15	9.53
20	8.85	9.15	11.72	9.91
Mean	8.94	9.68	11.20	
	Water stable aggregate < 2 mm (%)			
10	4.84	6.25	4.68	5.25
15	9.72	6.70	13.20	9.87
20	5.96	5.72	13.74	8.47
Mean	6.84	6.22	10.54	

3.2.1.5.1 Use of mulches

Various mulches have been evaluated for their effect on moisture conservation and yield of crops. Singh *et. al*. (1967) compared dust mulch, sorghum stalk @ 15 t/ha, dry grass @ 10 t/ha and polythelyne film of 200 gauge for moisture conservation and yield of rainfed wheat. It was found that all the mulches were equally effective. Another study by Prasad and Singh (1998) assessed the performance of dust mulch, stover *in-situ* mulch and dust mulch + stover *in-situ* mulch on soil moisture and yield of sorghum + pigeonpea (1:1) intercropping system. There was a 9.9, 6.1 and 2.8% improvement in sorghum grain and 32.7, 11.5 and 12.7% in pigeonpea grain as compared to no mulch, dust mulch and stover mulch, respectively due to better moisture regime in the profile (Table 3.45).

Table 3.45: Effect of mulches on yield of sorghum + pigeonpea intercropping systems (mean data from 1993-94 to 1995-96)

Treatment	Grain yield of crops (kg/ha)		
	Sorghum	Pigeonpea	Sorghum grain equivalent
No mulch	2504	865	5079
Dust mulch in pigeonpea only	2594	1030	5618
Sorghum stover mulch between the rows of pigeonpea	2676	1019	5630
Dust + stover mulch	2751	1148	6095

3.2.1.5.2 Integrated nutrient management

A four year study (Prasad and Singh, 1999) explored the possibilities of nitrogen substitution in sorghum + pigeonpea intercropping through *Leucaena* leaves. The results showed that 50% N substitution by *Leucaena* provide comparable grain yields. The N application @ 25 kg N/ha through *Leucaena* leaves + 25 kg N/ha through urea provided highest grain yield (Table 3.46).

Table 3.46: Effect of nitrogen substitution through *leucaena* leaves on crop yields in sorghum + pigeonpea intercropping (mean data from 1992-93 to 1995-96)

Treatment (N kg/ha)	Grain Yield (kg/ ha)		
	Sorghum	Pigeonpea	Sorghum grain equivalent
0	1933	640	4493
25 U	2732	1038	6848
25 L	2502	958	6334
12.5 U + 12.5 L	2592	1014	6648
50 U	3619	1256	8643
50 L	3104	1310	8344
25 U + 25 L	3300	1362	8748
C.D. at 5%	455	295	1227

U – Through Urea; L- through Leucaena leaves

3.2.1.5.3 Soil fertility management

The fertility status of soils at Research Centre indicates that available N ranges from 150-190 kg/ha (low), available P_2O_5 from 10-21 kg/ha (low) and available K_2O from 430-510 kg/ha (medium to high). Soil fertility management methods have been evaluated for prominent cropping systems. Sorghum is one of the promising crops grown under rainfed conditions in medium soils of South-Eastern Rajasthan. Nutrient requirements of sorghum were studied by Dayal *et. al.* (1965) and they reported linear response upto 90 kg N/ha in the form of farm yard manure. In a separate study 60 Kg N/ha was found optimum for sorghum (CSH-1) under rainfed conditions. Phosphorus application alone was not effective; however, it increased the yield when coupled with nitrogen application. Basal application of 75:40:30 N, P_2O_5 and K_2O was recommended for rainfed sorghum (Table 3.47). Narain *et. al.* (1980) found that inclusion of pigeonpea as intercrop in sorghum (1:1 ratio) reduced the nitrogen dose of sorghum. On the basis of long-term fertility trail conducted for 19 years (1978-97) fertilizer application @ 50:40:30 N, P_2O_5 and K_2O with 5 t/ha/yr FYM is recommended for sorghum + pigeonpea inter cropping systems. The FYM application contributed to fertility improvement. Over the period of 19 years OC % increased from 0.28 to 0.42% (Table 3.48).

Table 3.47: Yield of rainfed sorghum under different fertilizer treatments

Treatment	Yield (kg/ha)	
	Grain	Stover
No fertilizer	773	3583
37.5 kg N/ha, drilled at sowing	1197	4250
37.5 kg N/ha, half drilled and half top dressed 45 days after sowing	1209	4666
37.5 kg N/ha, half drilled and half foliar spray 45 days after sowing	1305	3917

75 kg N /ha, drilled at sowing	1532	4416
75 kg N/ha, half drilled and half top dressed 45 days after sowing	1470	4708
75 kg N/ha, half drilled and half foliar spray 45 days after sowing	1541	4500
37.5 kg N + 40 P_2O_5 /ha, all drilled at sowing	1358	4833
75 Kg N + 40 ha P_2O_5 /ha, all drilled at sowing	1535	5083
75 Kg N+ 40 Kg P_2O_5+ 30 kg /ha all drilled at sowing	1814	5125

Table 3.48: Grain yield of sorghum + pigeonpea intercrops under different fertility treatments (mean data from 1978-79 to 1996-97)

Treatment	Sorghum (kg/ha)	Pigeonpea (kg/ha)
T_1 No FYM or Fertilizer applied	778	521
T_2 Recommended fertilizer dose (50 kg/ N + 40 kg P_2O_5+ 30 kg K_2O / ha)	2085	827
T_3 Nitrogen on soil test basis (50 kg N/ha)	1305	665
T_4 Nitrogen and Phosphorus on soil test basis (50 kg N + 40 Kg P_2O_5 / ha)	1561	683
T_5 Nitrogen, Phosphorus and Potash on soil test basis (50 kg N+ 40 kg P_2O_5 + 30 kg K_2O /ha	1994	838
T_6 FYM @ 5 t/ha/year	1098	646
T_7 FYM @ 15 t/ha/3 years	1059	598
T_8 Recommended fertilizer dose + FYM @ 5 t/ha/year	2174	756
T_9 Recommended fertilizer dose + FYM @ 15 t/ha/3 years	2016	794

Green manuring: Inclusion of short duration green manure crops in fallow mustard sequence reduces erosion hazards and improves soil fertility which consequently enhances the productivity of rainfed mustard. Keeping this in view a study was conducted to identity a suitable green manure crop which can be successfully fit in fallow-mustard sequence for resource conservation and improvement in soil fertility and productivity of rainfed mustard in the region. The plot without green manure crop recorded higher runoff (15.6%) and soil loss (1.90 t/ha). Among the green manure crops the performance of Dhaincha was better than sunnhemp and cluster bean. Three years mean data indicated that Dhaincha added 3.30 t/ha dry biomass compared to 2.60 and 2.0 t/ha of sunnhemp and cluster bean, respectively. The amount of N recycled through green manuring was highest in Dhaincha and lowest in sunnhemp. All the green manure crops had significant positive effect on mustard seed yield. The average increase was 40, 52.8 and 75% under green manuring of cluster bean, sunnhemp and Dhaincha, respectively. The highest yield of mustard seed under Dhaincha green manuring was attributed to its maximum N addition in the soil through its biomass.

3.2.2 Resource Conservation Measures for Non-Arable Lands

Non-arable lands refer to lands which are not available for cultivation of seasonal crops due to either tenurial or biophysical constraints such as terrain deformation, salinization, and excessive wetness, lack of adequate soil depth or presence of gravels. Generally, these are community owned or government lands available to *grampanchayats* for productive utilization. To develop strategies for productive utilization on non-arable lands the Research Centre, Kota has conducted several studies in the Chambal ravines. Suitable tree and grass species have been identified, their management techniques, growth pattern and ecological interactions have been investigated.

3.2.2.1 Evaluation of tree and grass species

Several tree and grass species have been tried in Chambal ravines over years. The species found suitable are *Acacia nilotica, A. catechu, Azadirachta indica, Dendrocalamus strictus, Feronia elephantum, Pithecolobium dulce, Cassia siamea, Kigelia pinnata, Albizia lebbek, Acacia tortilis, Eucalyptus camaldulensis, E. tereticornis, Tamarindus indica, Casuarina equisetifolia, Mangifera indica, Phyllanthus emblica, Leucaena leucocephala, Broussonetia papyrifera, Morus alba, Soymida febrifuga, Moringa oleifera, Cassia fistula, Bauhinia purpurea, Prosopis juliflora, P. cineraria, Delonix regia, Jacaranda mimosifolia, Dalbergia sissoo, Albizia amara, Tamarix dioica, Pongamia pinnata, Ailanthus excelsa, Salvadora oleoides, Melia azadirachta, Aegle marmelos, Peltophorum ferrugineum and Salix tetrasperma.* Among evaluated species, best performers were was *Eucalyptus tereticornis, E. camaldulensis, Acacia nilotica, A. tortilis* with their respective mean annual increments of 1.02, 0.91, 0.75 and 0.70 m. Site suitability and production potential of some important species are given in Table 3.49. *Acacia nilotica* is one of the most promising species of the region. Depending on edaphic condition and biotic interference *A. nilotica* can attain 10 m height with 18-19 cm diameter at breast height (DBH). At this stage 220 kg / tree air-dry wood production has been recorded. Relationship of height and DBH with wood production has been worked out and presented in Table 3.50. In addition to fuel wood it provides thorns for fencing and leaves and pods for fodder for goats. It also helps in improving site quality through biological nitrogen fixation. *Acacia tortilis* is also quite promising for afforestation in gullies and attains a maximum DBH of 18 cm and height of 8.45 m during 15 to 20 years rotation period providing about 80 kg/ tree air dry thick (>2.5 cm) fuel wood. Mechanical thinning and pruning between 5 to 10 years can provide additional return (Table 3.51). *Acacia catechu* also performed fairly well as the species attained maximum height of 7.25 m and DBH of 10-11 m.

Table 3.49: Site suitability and production potential of suitable tree and grass species

Name of species	Planting density (m)	Planting location	Rotation period (years)	Productivity (t/ ha)	Useful products
		Tree species			
Acacia nilotica	3X3	Hump top, slope, and ravine beds	15-20	20-25	Fodder, fuel, small timber
Acacia tortilis	3X3	Hump top, slope and ravine beds	15-20	40 to 60	Fuel, fodder
Azadirachta indica	8X8	Marginal lands, hump top and beds	30-40	40-60	Fodder, fuel and timber
Balanites aegyptiaca	1X1	Hump top and slopes	15-20	30	Fuel wood, MFP
Prosopis juliflora	1X1 to 3X3	Hump top, slope and ravine beds	20-25	60-90	Charcoal, Fuel wood & fencing materials
Tamrix dioica	3X3	Swampy areas on gully bottom	15-20	20	Reclamation of saline soils, Fuel

Soymidafebrifuga	3X3	Marginal lands and hump top	20-25	20	Fodder, fuel and light timber
Eucalyptus tereticornis	2X2 3X3	Marginal lands, swampy areas on gully bottom	10 to 12	26 to 37	Poles for house construction & fuel wood
Albizzialebbek	6X6	Marginal lands, hump-top	25-30	85-90	Fodder and fuel

Table 3.50: Relationship between D.B.H., height and air dry fuel yield of *Acacia nilotica*

D.B.H. class (cm)	Height (m)	Air-dry weight (kg/ tree)		
		Thin wood (< 2.5 cm diameter)	Thick wood (> 2.5 cm diameter)	Total wood
6-7	5.65	0.92	4.74	5.66
7-8	5.95	2.65	14.50	17.15
8-9	6.25	6.42	26.34	32.76
9-10	6.64	1.66	19.66	21.32
10-11	6.84	4.09	37.99	42.08
11-12	8.37	7.31	47.96	55.27
12-13	7.66	8.01	86.88	94.89
13-14	7.96	7.96	62.26	70.22
14-15	7.23	11.77	83.87	95.64
15-16	8.83	18.57	96.89	115.46
16-17	8.25	23.94	113.94	137.88
17-18	8.38	25.27	131.93	157.20
18-19	10.00	37.15	183.10	220.25
19-20	8.50	22.74	157.47	180.21

Table 3.51: Relationship of weight and volume with DBH and height of *Acacia tortilis*

D.B.H. (cm)	Air dry weight (kg / tree)		Solid volume / tree (m^3)	
	Thick wood (dia>2.5 cm)	Total	Thick wood (dia>2.5 cm)	Total
4-5	14.700	33.250	0.0070	0.1188
5-6	15.200	34.525	0.0132	0.1596
6-7	18.200	28.100	0.0140	0.1022
7-8	22.400	44.350	0.0183	0.1799
9-10	46.075	80.550	0.0360	0.3201
10-11	31.000	71.600	0.0354	0.2280
Height (m)				
6-7	22.467	43.133	0.0176	0.1123
8-9	34.267	62.133	0.0261	0.3635
11-12	46.650	75.975	0.0372	0.3140

Among the *Eucalyptus* species *E. tereticornis* and *E. camaldulensis* were most promising in the clay loam soils of gullied areas. Survival was better in gully bottom. In 10-12 years of rotation period plantation spaced at 2 x 2 m or 3 x 3 m recorded 26 to 37 t/ha wood yield for poles and fuel wood. *Prosopis juliflora* raised in continues contour trenches, 3.75 m apart by direct sowing in 1955 were felled after 20 years. The yield data for pole and fuel wood are presented in Table 3.52. Twenty year old trees did not grow more than 15 cm dbh and 12.5 m height. *Dendrocalamus strictus* is a suitable species for gully bed stabilization. One-year-old seedlings were planted in 60 cm^3 pits at 3 m x 3 m spacing. Studies with vigour culm on three sites *viz*., top, side slope and bed of the gully, were made.

Table 3.52: Air dry pole and fuel wood yield (kg/ha) and volume weight relationship - *Prosopis juliflora*

Particular	Fuel wood type			
1. Air dry yield in different DBH classes	Poles 3 m long (mid dia 10 cm)	Poles 3 m long (mid dia 5-10 cm)	Branch wood (mid dia 2.5 – 5.0 cm)	Small wood (mid dia below 2.5 cm)
DBH. < 5.0cm	–	–	3399	1937
DBH. 5–10 cm	--	12961	3809	3108
DBH10-15 cm	5375	2587	2264	1458
Total	**5375**	**15548**	**9472**	**6503**
2. Weight of stacked wood (kg/m^3)	354	216	9	--
3. Dry matter per cent (75 day's dry age)	80.7	75.6	60.3	32.3

Table 3.53: Cultivated fodder for gullies of the Chambal River

Species / varieties	Green /air dry forage (tons/ha /yr)
Dichanthium annulatum	
SCK-45-Jodhpur-490	6.4 A
SCK-48-Jodhpur-497	6.0 A
Cenchrus cilairis	
SCK-35-Jodhpur-357	7.2 A
SCK-66- Jhansi	5.7 A
Cenchrus setigerus	
SCK-50-Agra	4.1 A
SCK-38-Jodhpur-418	3.7 A
Panicum antidotale- Kota	2.8 A
Brachiaria mutica	32 to 89 G
Hybrid napier	-
Pennisetum purpureum	11.2 to 39.9 G
P. typhoides	2.9 to 11.5 A

G = Greenforage yield, A = Air dry forage yield

On the humps of the gullies five to six vigour culms in a clump is best for bamboo management as it gave 33 culms / clump / 3 years. In the gully bed it should be 7 to 9 vigour culm as it will produce 44 to 45 culms / 3 years. The maximum height of the culms by 18 years of protection was 13.50 m. Clumps worked in 3-years cycle with and without vigour clumps recorded a height of 9.88 and 7.16 m, respectively.

Suitability of about 200 species and varieties of grasses and 80 legumes were evaluated for the region. Among the grasses tried *Dichanthium annulatum*, *Cenchrus ciliaris, C. setigerus, Cynodon dactylon, Brachiaria mutica* and *Chloris gayana* performed well. Among the legumes *Stylosanthus hamata, Macroptilium atropurpureum, Atylosia scarabaeoides* and *Dolichus lablab* werefound suitable for fodder production. Several grass legume mixtures were also tried but legumes failed to compete with grasses. Production potential of selected grass varieties is given in Table 3.53.

3.2.2.2 Soil Working Techniques

For improving survival and growth of planted vegetation several soil working techniques were evaluated for different site conditions. For regularly sloping marginal lands, humps or gully beds continuous or staggered contour furrows were found appropriate. Size and spacing of trenches may vary depending on slope and planting material. For planting *D. annulatum* furrows with 10 x 10 cm cross section at 1 m horizontal interval should be excavated. The dug soil should be placed on down slope side. Grass seeds are sown inside the furrows after pelleting or mixing with double the quantity of soil. For planting trees cross section of trench need to be increased to 45 x 45 cm with berm type of refilling. For irregularly sloping broken and steeply sloping land contour furrowing is not feasible. On such locations grasses can be planted in instantly made pocket holes at 50 x 50 cm spacing. Excavating pits of 0.45 m^3 and half slanting refilling is suitable soil working techniques for planting trees. On gully sides with precipitous slopes continuous contour trench (10 cm^2c/s) was found suitable, while in salt affected and normal water logged gully bottom conical mounds with 1.5 m diameter and 0.75 m height proved superior to other techniques. A 20 x 20 cm c/s drainage channel around the base of the mound should be provided. *Brachiaria mutica* planted on conical mounds at 2 m x 2m spacing was found more productive than other grasses in the gully bed of Chambal ravines.

3.2.2.3 Grassland Development

Grasslands in ravines are predominantly natural and occur under various stages of succession. They fall under the broad group of *Dichanthium Cenchrus* grassland type. It takes 5 to 10 years of protection to reach the climax stage, while only 2 to 3 years of over grazing can result to bare ground stage (Fig.3.19).

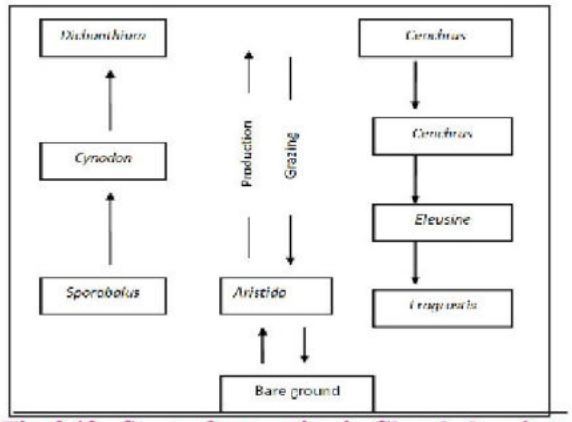

Fig. 3.19: Stage of succession in Chambal ravines grass lands

Natural legumes encountered are *Rhynchosia minima* and *Tephrosia* species. Most common weeds competing with grasses or legumes are *Xanthium strumarium*, *Abutilon theophrasti* and *Argemone mexicana.* Protection from biotic interference alone improves condition class of grassland there by increasing the fodder production from 1000 kg/ha/yr to about 10000 kg/ha/yr. Effect of tree species on forage yield under different canopy covers is presented in Table 3.54.

Table 3.54: Air dry forage yield of ground flora under various tree covers of different intensities

Species name	Air dry forage yield (kg/ha) under canopy cover				
		Below 25%	26 to 50%	51-75%	Above 75%
Acacia nilotica	G	1895 to 3141	213 to 1130	998	591
	B	521 to 852	394 to 515	358	141
Azadirachta indica	G	970	-	-	-
	B	242	-	-	-
Balanites aegyptiaca	G	975 to 4722	-	-	-
	B	598 to 1254	-	-	-

Dendrocalamus strictus	G	1566	90 to 204	-	-
	B	1283	225 to 476	-	-
Dichrostachys cineria	G	235	469	37	290
	B	484	201	268	290
Lantana camara	G	695	-	-	-
	B	695	-	-	-
Prosopis juliflora	G	190	869	685	430
	B	287	170	219	-
Eucalyptus hybrid	G	1141 to 3777	1392 to 1912	1050 to 1424	456 to 714
	B	70 to 732	42 to 470	14 to 251	112 to 752
Mixed tree species	G	1505 to 1800	285 to 1085	215 to 609	62 to 153
	B	486 to 909	239 to 401	155 to 374	90 to 286

G - Grasses, B- Browses

Steps recommended for grassland development

Cleaning: The site should be cleared for removal of shrubs and unwanted vegetation.

Soil working: To improve moisture availability and soil environment appropriate soil working, as discussed in previous section should be carried out.

Weeding: Two weedings and soil working are required in first year to clear unwanted natural growth. Soil working is done around plants. If natural legumes are seen they should be allowed to grow.

Fertilizer application: *Dichanthium annulatum* respond well to nitrogen applied as inorganic or organic manure. Basal dose of N and P_20_5 @ 30:60 kg/ha is appropriate.

Harvesting: The grass is ready for harvest in the first year and reaches its peak in the 3rd Year. The yield slowly reduces from 5th year on wards and should be replaced in 6th to 8th year. Expected green forage yields at 1,2,3,4,5 and 6 year are 1-2, 8-10, 8-20, 10-20, 10-15, 5-15 t/ha.

Grazing management: Deferred grazing is recommended. A study conducted on grazing management has shown that there was no detrimental effect on land or vegetation by grazing four goats per ha and it was more economical than stall feeding (Chinamani *et. al.*, 1985). In another study, palatability rating of 12 natural feeds of gullies was worked out. *Acacia nilotica* and *Clerodendrum phlomides* were found highly palatable to range grazed and stall fed goats. It was also noticed that stall fed as well as range grazed goats had practically no preference for *Dichanthium annalutam* grass.

3.2.2.4 Utilization of Water Logged and Saline Gully Beds

Water logging for prolonged period and salinization is quite common in gully beds of the Chambal ravines after introduction of the canal system. The performance of salt tolerant tree and grass spp. were evaluated in salt affected and water logged gully beds. Tree and grass *spp*. were planted in gully bed at 2 m x 2m spacing on conical mounds having 1.5 m diameter and 0.75 m height with 20 cm x 20 cm drainage channel around the mound base. The results indicated that *Prosopis juliflora* performed well whereas green forage yield of *Brachiaria mutica* was initially good on saline soil mounds (64.1 t/ha) and decreased with ageing. Average yields were 16.6 and 22.9 t/ha on saline and good soil, respectively. Normal gully beds without water logging and salinity could be afforested with *A. nilotica, E. tereticornis, Dendrocalamus strictus etc. Dendrocalamus strictus* could tolerate soil salinity level upto ECe 10 mmhos/cm in its root zone and it completely died when EC exceeded 20 mmhos/cm.

3.2.2.5 Evaluation of Underutilized Fruit Species for Chambal Ravines

To evaluate suitability and production potential of underutilized fruit species in ravine degraded lands a study was conducted at Research Farm, Kota with four fruit species *viz;* Bael, Lasoda, Custard apple, Karonda and four interspaces managements *viz;* Clean tilled, Clean tilled with half-moon, Half-moon *with Cenchrus ciliaris* and Half-moon with *Dicanthium annulatum* with three replications. The fruit species were planted with Bael (8x8), Lasoda (6x6), Custard apple (4x4) and Karonda (2x2) m spacing. Both the grasses *Cenchrus ciliaris* and *Dicanthium annulatum* also planted with 30x30 cm spacing. The treatments were imposed on the hump top of the ravine area. Site suitability of these fruit species is given in Table 3.55. Among the four underutilized fruit species, Bael recorded highest growth in height (6.34m) in all treatments followed by Lasoda (4.98m), custard apple (2.21m) and Karonda (1.98m). Data on plant height is presented in Fig.3.20. The maximum collar diameter was recorded in Lasoda (18.92 cm) in all treatments followed by Bael (17.84 cm), Karonda (9.15 cm) and Custard apple (7.39 cm), respectively. The highest canopy volume was observed in Bael (62.84 m^3) in all the treatments followed by Lasoda (46.02 m^3) Karonda (4.23 m^3) and Custard apple (3.78 m^3). The canopy volume data is given in Table 3.56. The maximum height, collar diameter and canopy volume was recorded in all four species under clean tilled with half-moon shaping treatment followed by clean tilled, half-moon with *C. ciliaris* and half-moon with *D. annulatum* grass. *Cenchrus ciliaris* provided highest grass yield (7.64 t/ha dry wt.) than *D. annulatum* (6.94 t/ha dry wt.). In the initial fruiting stage, the highest yield was recorded in Karonda (32.56 q/ha) because of early fruiting and highest number of plants are accommodate in per unit area in all treatments followed by Bael (29.85 q/ha), Lasoda (15.02q/ha), and custard apple (7.13 q/ha), respectively. The economic viability (B:C ratio) of different fruit plantation under different treatments are presented in Fig. 3.21.Therefore, Bael (*Aegle marmelos)* is the highly suitable and remunerative fruit species to Chambal ravines planted in clean tilled with half-moon micro catchment moisture conservation structure for long term basis.

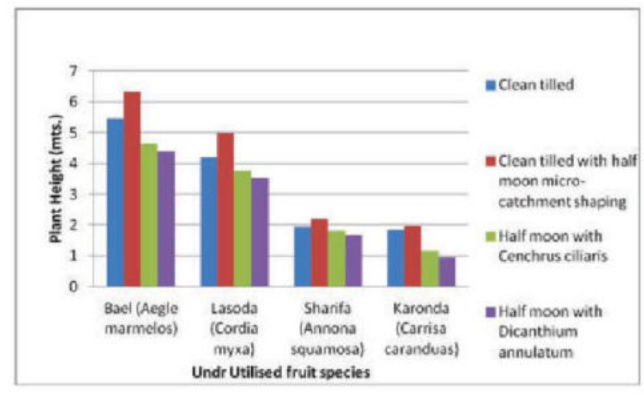

Fig. 3.20: Plant height (m) of four underutilised fruit species in Chambal ravines

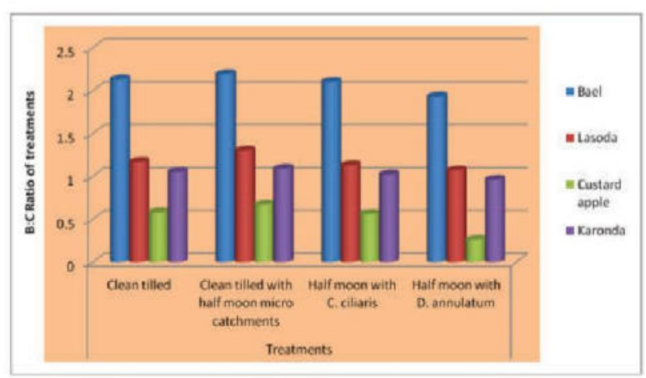

Fig. 3.21: Economic viability (B:C ratio) of fruit plantation under different treatments (Rs/ha)

Table 3.55: Site suitability for different fruit species

Species	Soil texture	pH	Soil depth (cm)	Irrigation requirement	Submergence tolerance (days)	Major constraints
Bael (*Aegle marmelos*)	Sandy loam	5 to 10	>100	I^1& I^2	1-2	A & B
Lehsua (*Cordia myxa*)	Sandy loam	5 to 8.5	>100	I^1	1-2	A & C
Karonda (*Carissa carandus*)	Loam to sandy loam	6 to 9	>60	I^1	1-2	A
Custard apple (*Annona quamosa*)	all type	5 to 7.5	>60	I^1& I^2	0	A

[a]I^1 = 12 number of irrigations for first 2 years after plantation, I^2=1 to 2 number of irrigation for quality fruits and higher production;

[b]A =wild life damage, B= Fruit cracking, C= Gummosis in clayey soil

Table 3.56: Canopy volume (m^3) of fruit species planted in Chambal ravines

Inter-space management (Treatment)	Bael (Aegle marmelos)	Lasoda (Cordia myxa)	Sharifa (Annona squamosa)	Karonda (Carrisacaranduas)
Clean tilled	59.42	42.79	2.87	3.87
Clean tilled with half-moon micro-catchment shaping	62.84	46.02	3.78	4.23
Half-moon with *Cenchrusciliaris*	43.29	34.51	2.53	3.41
Half-moon with *Dicanthium annulatum*	29.35	21.93	2.19	2.98

3.2.2.6 Alternate Land Uses for Productive Utilization of Chambal Ravines

Among several horticultural, medicinal, aromatic plants tried in the gullies of river Chambal, Ber was found promising for the region. Five ber varieties were planted in 1970-71 at spacing of 5m x 5m in 60 cm^3 pits. These Ber varieties were grafted on the local root stock of *Zizyphus nummularia.* The yield of fruits, fodder and fuel obtained through pruning are given in Table 3.57. Highest fruit yield was recorded in *Umran*, and fodder yield in *Banarsi* while fuel yield was comparable in *Banarsi* and *Umran* varieties. This shows that Ber varieties *Umran* and *Banarsi* are most suitable for Chambal ravines.

Another study compared growth performances and soil conservation value of fruit trees with forest *spp*., in degraded Chambal ravines. Two micro-watersheds (W_1 and W_2), which were earlier under the *Prosopis juliflora* plantation were equipped with gauging stations at the outlet of watersheds. Hydrological characterizations of these watersheds were gauged and topographic details of both watersheds are given in Table 3.58. The soils were very deep, clay loam in texture, low in organic carbon, available and nitrogen, medium in phosphorus but high in potassium. The pH was slightly alkaline ranging from 7.46 to 8.0. The Ec ranged from 0.50 at ravine top to 1.38 at the ravine bottom. The W1 watershed was planted with seedlings of *Acacia nilotica and Pongamia pinnata* and W2 watershed was planted with seedlings of *Annona squamosa and Aegle marmelos* raised in polybags and root trainers. Three soil working techniques namely a) Trenches (3.0m X 0.40 m X 0.30 m) b) Auger holes (0.15m X 0.60 m) and c) Saucer pits (0.45m X 045m X 0.45m) were employed. Two planting mixtures namely, a) Soil + sand + FYM and b) Soil + FYM were used. Split - split plot design of experiment was employed in the experimental areas. Out of five tree species studied four performed significantly better in the Chambal ravines while one (*Annona squamosa*) recorded very low (34%) survival even after replanting for mortality replacement during second planting season. After the first planting season highest survival (100%) was recorded in *Acacia nilotica* while the survival of *Aegle marmelos* and *Pongamia pinnata* was > 90% during first planting season and these three species recorded 100% survival following replacement of causalities after first planting season. *Annona squamosa* which recorded lowest survival during first and second planting season was replaced by *Emblica officinalis* which recorded 100% survival during first planting season and > 97% survival up to sixth year after planting. There was no significant difference in survival of seedlings raised in root trainers or polybags in any species. During the first season of planting seedlings raised in root trainer recorded higher growth in height and collar diameter in *Acacia nilotica* and *Pongamia pinnata*, but the difference was not significant. The initial advantage of root trainer raised seedlings was nullified after one year of growth in all species with polythene bag seedlings performing at par in almost all soil working treatments and all species in terms of growth. Similarly *Pongamia pinnata* recorded 10.4% and 12.04% higher growth in height and collar diameter, respectively when planted with trenches as compared to those in pits in the first year after planting but all species

Table 3.57: Performance of Ber varieties in Chambal ravines.

Variety	Yield (kg/tree)		
	Fruit	Leaf fodder	Fuel
Seo	4.3 (4)	3.0 (4)	4.5 (4)
Umran	9.6 (4)	2.5 (4)	6.3 (4)
Banarsi	2.2 (3)	4.8 (4)	7.0 (4)
Chhuhara	6.5 (4)	1.4 (4)	2.4 (4)
Tikdi	--	1.3 (1)	3.3 (1)

Figures in parenthesis indicate no. of years.

including *Pongamia pinnata* performed at par with those planted with trenches, after three years of growth, when planted in pits. During the first season after planting the seedlings raised with Soil + Sand + FYM recorded 4.1 to 15.7% better growth over those raised with Soil + Sand in height under different treatments but the initial advantage was soon nullified and from second year onwards there was no difference in growth in the seedlings with both kinds of mixtures. Similarly from second year onwards there was no difference in growth of the seedlings raised in poly bags and root trainers in almost all soil working treatments and all species in terms of growth. The observations recorded reveal that after six years of planting *Acacia nilotica* recorded highest average growth in height and collar diameter and DBH (6.1m, 13.1 cm, 10.1cm) followed by *Aegle marmelos* (5.0m, 14.1 cm, 9.7cm) and *Pongamia pinnata* (4.4m, 14.7 cm, 8.4cm) respectively. The similar trend was observed in all treatments. After six years of planting, *Aegle marmelos* recorded highest percentage of trees in fruiting among all species (65.22%) followed by *Emblica officinalis* (64.25%), *Acacia nilotica* (48.39%) and *Pongamia pinnata*, respectively (Table 3.59). The estimated average wood yield of trees of *Acacia nilotica* ranged from 39.32 to 43.12 kg/tree on fresh weight basis under different treatments. The standing biomass of six year old *Acacia nilotica* was estimated to be 42.6 t/ha to 48.0 t/ha under different treatments. There was progressive reduction in the runoff and soil loss from the two watersheds and it was positively co-related with the growth of trees. The six year average runoff and soil loss under forestry land use was 9.89% and 2.59 t/ha, respectively against 21.58% and 7.45 t/ha at the start of project while it was 11.83% and 3.62 t/ha under horticulture land use against 23.89% and 8.13 t/ha at the start of project (Table 3.60). The runoff and soil loss was brought well under control in these steeply sloping lands when these were placed under forestry and horticulture land uses.

Table 3.58: Topographic characteristics of ravine watersheds

Area (ha)	R W_1	R W_2
Area ravine top (ha)	1.0	0.55
Area ravine slope (ha)	0.4	0.22
Area ravine bed (ha)	0.2	0.13
Max. length (m)	215	130
Max. width (m)	140	105
Av. slope ravine top (%)	2.54	3.6
Av. slope ravine slope (%)	98	87
Av. slope ravine bed (%)	3.48	4.69
Drainage densitySqm	187.5	205.6
Reliefratio	3.4	3.2
Perimeter (m)	570	397.5
Form factor	0.346	0.533
Compactness coefficient	1.26	1.18
Tc (min)	6.017	3.45

Table 3.59: Fruit yield of trees seven year after planting in Chambal ravines

Species name	% of trees in Fruiting	Average yield (kg) per tree	Yield (t/ha)
*Aegle marmelos**	65.22	11.99	4.80
*Emblica officinalis**	64.25	10.23	4.09
*Pongamia pinnata***	40.79	10.06	2.57
*Acacia nilotica***	48.39	1.52	1.68

**fruits ** Pods*

Table 3.60: Hydrological behaviour of ravine watersheds under Forestry (W1) and Horticulture (W2) land uses

Year	Rainfall (mm)	Runoff (%rainfall)		Soil loss (t/ha/yr)	
		W 1	W 2	W 1	W 2
2006	817.5	21.58	23.39	7.45	8.13
2007	707.5	11.24	13.37	3.6	5.1
2008	617.5	9.17	11.2	3.4	4.53
2009	402.6	0	2.7	0	1.4
2010	398	0	0	0	0
2011	1058.1	9.96	12.35	3.34	4.48
2012	772.6	1.12	3.64	0.35	1.72
2013	1037	6.53	7.54	1.54	2.57
Mean	**726.35**	**7.45**	**9.27**	**2.46**	**3.49**

3.2.2.7 Evaluation of Promising Oilseed Tree Species under Silvi-pastoral System

The experimental study has laid out to evaluate the comparative performance of three promising oilseed tree/shrub species *viz., Azadirachta indica* (Neem), *Pongamia pinnata* (Karanj) and *Jatropha curcus* (Ratanjyot) at different topographical locations (*i.e.* ravine top, ravine slope and ravine bed) of Chambal ravines. The objective of the study was to assess the survival, growth and yield performance of different tree borne oilseed species under silvipastoral system in for productive utilization of Chambal ravines. Three hectare area of gullied lands in the research farm of ICAR-IISWC-Research Centre, Kota has been taken up and seedlings were planted at ravine top, ravine slopes and ravine bed with *Dicanthium annualatum* grass as an interspace management component. Further, Compartmental bunding and half-moon micro catchment was also laid out and compared for moisture retention and *in-situ* conservation at the ravine top with control (no conservation measure) in these plantations.

Among different treatments, *Azadirachta indica* (Neem) performed better in terms of growth characteristics *viz.,* height (6.98 m), Collar diameter (26.32 cm), DBH (16.82 cm) and Crown spread (46.38 m^2) respectively with compartmental bunding over other treatments. This was followed by *Pongamia pinnata* (Karanj) with half-moon shaped micro catchments which results higher growth of tree height (6.12m), Collar diameter (22.38 cm), DBH (10.50 cm) and Crown spread (45.71m^2) compare to other treatments (Table 3.61). Among three tree borne oilseed species, seed yield of 2.92 kg/tree recorded in *P. pinnata* followed by *A. indica* which was given 2.24 kg/tree (Parandiyal *et. al.*, 2016). In *Jatropha cursus* very poor seed formation and seed yield per plantwas observed. But its overall vegetative cover growth was excellent against soil erosion. However, it is less compared to normal land Karanj trees (*i.e.* 4-5kg/tree can be obtained in 5-6 year old trees). It might occur due to the fact that ravine lands are stress influenced ecosystem coupled with intermittently drought occurrence during the experimentation period. Due to impact of half-moon shaped micro catchment moisture conservation measure, the performance of Karanj species were fetched higher biometric growth and survival performance when compared to control. In initial years, *Dicanthium annulatum* species gives average yield of 6-7 t/ha/year upto seven years after that it may reduce due to shade effect of oilseed trees. Hence, cultivation of grass could be possible up to 7/8 years for getting average yield of 3-4 t/ha under inter-spaces of oilseed trees on ravine humps (Table 3.61). However, canopy management option is not feasible frequently for oilseed species. Because seed yield directly depends on level and intensity of branch development by oilseed trees.

Table 3.61: Growth performance of Oilseed trees/shrub in Chambal ravines (At age of 8 years)

A. Growth and seed yield of tree borne oilseed species in ravine condition						
Species	**Topographic sub-site & moisture conservation measure**	**Height (m)**	**Collar diameter (cm)**	**DBH (cm)**	**Crown spread (m^2)**	**Avg. Seed yield (kg/ tree)**
Azadirachta indica (Neem)	Ravine Top/Hump					
	T_1- Compartmental bund	6.98	26.32	16.82	46.38	2.24
	T_2- Half-moon – micro catchment	6.12	25.45	16.47	44.55	2.02
	T_3- Control (No conservation measure)	4.96	20.19	10.57	32.18	1.58
	Ravine slope	5.29	24.98	18.60	50.65	1.96
	Ravine bottom	5.16	23.16	12.68	38.10	1.72
Pongammia pinnata (Karanj)	Ravine Top/Hump					
	T_1- Compartmental bund	5.94	18.19	9.92	44.32	1.74
	T_2- Half-moon –micro catchment	6.12	22.38	10.50	45.71	2.08
	T_3- Control (No conservation measure)	5.75	17.06	9.47	43.66	1.65
	Ravine slope	5.98	20.33	13.36	56.55	2.92
	Ravine bottom	5.45	23.45	15.42	60.02	2.65
Jatropha curcus (Ratanjyot)	Ravine Top/Hump					
	T_1- Compartmental bund	3.95	20.63	9.83	33.57	0.26
	T_2- Half-moon – micro catchment	3.97	22.41	10.97	40.23	0.15
	T_3- Control (No conservation measure)	3.92	23.03	10.42	42.11	0.18
	Ravine slope	4.27	26.47	13.62	44.81	0.22
	Ravine bottom	4.80	28.11	14.15	48.53	0.34

B. Dicanthiumannualtum **-Average green fodder yield (t/ha) (*i.e.* cumulative yield of two cuts/year)**						
	Compartmental Bund		**Half-moon micro catchment**		**Control**	
Species Name	**First year**	**8^{th} year**	**First year**	**8^{th} year**	**First year**	**8^{th} year**
Azadirachta indica	10.82	3.21	8.74	3.02	9.01	3.66
Pongamia pinnata	11.83	4.41	11.27	3.83	10.02	3.16
Jatropha curcus	2.21	0	2.10	0	1.80	0

3.2.2.8 Staggered Contour Trenching

A long-term field experiment was conducted based on paired watersheds concept during 2004-14 to optimise density of staggered contour trenching (SCT) for Chambal ravine region. The experimental setup consists of four treatments: (i) control watershed without trench (W_C), (ii) treated watershed with 137 trenches /ha (W_{T1}), (3) treated watershed with 247 trenches/ha(W_{T2}), and (4) treated watershed with 417 trenches/ha(W_{T3}). The size of the trench with rectangular shaped was kept uniform in all treatment mini-watershed as 3m long, 0.45m wide and 0.45m deep. During two years calibration period (2004-05) and nine years treatment periods (2006-14) runoff and soil loss from the watersheds were measured. Results showed that the highest 86.1% reduction in mean runoff was in the W_{T3} watershed treated with SCT density of 417 trenches/ha over the control, followed by W_{T2} watershed with 278 trenches/ha (60.5%). The lowest reduction was of 37.7% in W_{T1} watershed treated with 139 trenches/ha (Ali *et. al.*, 2017; 2020). Similar trends were also recorded in soil loss reduction from the treatment watersheds. Reduction in soil loss was 124.9, 77.1 and 40.0% for the W_{T3}, W_{T2} and W_{T1}, respectively. The highest improvement in mean annual effective rainfall (27.8%) was in W_{T3} over W_C followed by W_{T2} (19.6%) and W_{T1} (12.5%) (Table 3.62). Similarly, yield of *Phylanthus emblica* fruit, *Cenchrus ciliaris* grass, and *Dendrocalamus strictus* was also found to be the highest under W_{T3} by 126.3, 28.9 and 86.9%, respectively over the W_C with B: C ratio of 3.05. However, corresponding yield increase under W_{T2} was, 50.0, 21.9 and 35.4%, respectively with B: C ratio of 2.53 (Table 3.63). The lowest increase was in $W_{T1.}$ The post-treatment saturated values of the saturated hydraulic conductivity and sorptivity were increased compare to the pre-treatment. The post-treatment values of the SOC also increased many folds than the pre-treatment values. The Available NPK content of post-treatment in watersheds at table top land and gully beds were also significantly increased by the trenching densities, and decreased at gully slopes. Results indicated that the SCT density of 417 trenches/ha was found to be the best conservation practices in combination with horti-pastoral land use system for reclaiming, improving and sustaining productivity under ravine lands of India.

Table 3.62: Average annual runoff, soil loss and effective rainfall from the ravine watersheds under different trenching densities

Micro-watersheds	Runoff (mm)	Soil loss (t/ha)	Effective rainfall (mm)
No Trenching	120.1	8.18	588.0
137 Trenches/ha	84.9	5.69	623.3
247 Trenches/ha	51.6	3.04	656.5
417 Trenches/ha	23.2	1.19	684.9

Table 3.63: Yield of *Phyllanthus emblica* fruit, *Cenchrus ciliaris* and *Dendrocalamus strictus in* the control and treated watersheds

Watershed	Yields			Economic analysis	
	P. emblica (t/ha)	*C. ciliaris* (t/ha)	*D. strictus* (culm/ha)	Net benefit (Rs/ha)	B:C Ratio
No Trenching	2.5	5.9	4567	2814	1.59
137 Trenches/ha	2.8	6.5	5367	5092	2.22
247 Trenches/ha	3.8	7.2	6183	6499	2.53
417 Trenches/ha	5.7	7.6	8533	8643	3.05

3.2.3 Hydrological Behaviour of Watershed for Conservation Planning

3.2.3.1 Runoff, Vegetation, Soil Characteristics and Management Practices

3.2.3.1.1 Consumptive use of water for crops

Excess or deficit of water in the soil is a limiting factor for crop production. Adequate and timely supply of irrigation throughout crop growth period is essential for maximizing yield. Therefore evapotranspiration (ET) studies were conducted in weighing type lysimeter (1.2 m^3) for sorghum, wheat, soybean, mustard, groundnut and chickpea at Research Centre, Kota. All the crops were irrigated at 50% depletion of available moisture except mustard and chickpea where irrigation was applied at 75% depletion of available moisture. The data presented in Table 3.64 indicate that soybean, sorghum, wheat and groundnut recorded higher ET than mustard and chickpea. Wheat recorded the highest water use efficiency and groundnut the lowest.

3.2.3.1.2 Dugout ponds

Dugout pond is one of the prevalent water harvesting structures in semi-arid tract of South-Eastern Rajasthan. The seepage loss is the major problem in such type of water harvesting structures. Runoff collected in the pond during the years 1976 through 1978 was lost rapidly by seepage. Seepage and evaporation were found to be as high as 45.0 cm per day. A study was conducted by Verma *et. al.* (1986) to assess the efficiency of lining material in controlling seepage losses from dugout pond constructed in 1976 having catchment area of 8 ha and capacity of about 0.5 ha m. For minimizing seepage loss, several lining materials *i.e.* cement concrete, 25 mm thick stone slab (*katla*), tarfelt and polythene film were considered. Eventually, High Molecular Weight High Density Polythene Film (HMW HDPF) of 500 gauge was selected as lining material. The daily evaporation + seepage loss from farm pond after lining varied from 16 to 30 mm as compared to 450 mm before lining. This confirms the effectiveness of HMWHDPF in remarkably reducing seepage loss from storage reservoirs.

Another study was conducted in two farm ponds of 1.60 ha m and 0.60 ha m capacity constructed on community lands in Badakhera watershed for harnessing the surface runoff (Singh *et. al.*, 2004). A total of 256 ha cm surface runoff was harvested annually. The percolation and evaporation losses were less than 10 mm/day. During the summer months of the year 2001 when entire region faced acute water shortage due to three consecutive drought years, the village pond maintained minimum water level up to 50% of its storage capacity. During this period the entire livestock and wildlife population in this area solely depended on this pond as the other water sources including a perennial Mej river dried up.

Table 3.64: Water budget and water-use-efficiency of crops

Particular	Sorghum	Wheat	Soybean	Mustard	Groundnut	Chickpea
Crop duration (days)	108	135	108	121	107	131
Irrigation applied (mm)	319	462	340	314	157	263
Rainfall (mm)	375	52	487	23	509	10
Profile contribution (mm)	5	38	59	93	78	143
Runoff (mm)	71	0	74	0	76	0
Deep percolation (mm)	78	26	150	0	150	0
'ET' (mm)	549	527	662	430	519	417
Mean' ET' per day (mm)	9	8	6	4	9	8
Grain yield (kg/ha)	5926	6157	4180	2680	2455	4175
Stover yield (kg/ha)	13264	7731	3333	2083	4643	5338
Water-use-efficiency (kg/ha/mm)	10.8	11.7	6.3	6.2	4.8	10.1

Table 3.65: Yield of crops and runoff water-use-efficiency under different treatments (mean data from 1979-80 to 1983-84)

Irrigation treatment	Yield (kg/ha)			WUE (kg/ha/mm)		
	Wheat	Chickpea	Coriander	Wheat	Chick pea	Coriander
No irrigation	525	276	245	--	–	--
Pre-sowing stage (5 cm)	1189 (126)	479 (74)	437 (78)	133	40	42
Pre-sowing + branching / CRI* stages (5 cm each)	1606 (206)	699 (150)	741 (202)	108	50	50
Pre-sowing + branching + flowering / CRI*(5 cm each)	2114 (303)	775 (181)	977 (299)	106	54	49

*CRI-Crown Root Initiation Stage

3.2.3.2 Efficient Utilization of Harvested Runoff

Runoff water harvested from 8 ha agricultural watershed and collected in lined dugout pond was utilized for giving supplemental irrigation at critical growth stages of *rabi* crops wheat, gram and coriander taken after a uniform *kharif* crop of black gram. The depth of supplemental irrigation was 5 cm at different stages of crop growth. The data presented in Table 3.65 show that chickpea, coriander and wheat yielded 74, 78 and 126% higher grain than control with pre-sowing irrigation only. Grain yield of all the crops showed progressive increase with number of irrigations, however, wheat (303%) and coriander (299%) recorded higher improvement in yield than chickpea (181%) with 3 irrigations. The water-use-efficiency of wheat was higher than chickpea and coriander.

Supplemental irrigation response of mustard, taramira and safflower and intercropped pigeon pea after sorghum harvest was studied by Singh *et. al.* (1992). *Rabi* oilseeds were raised after a uniform crop of black gram during *Kharif*. Three levels of irrigation applied to oilseeds were 10 cm at pre-sowing (I_1), I_1 + 5 cm at branching (I_2) and I_2 + 5 cm at flowering (I_3). The same depth of irrigation was also applied to pigeonpea after the harvest of sorghum. Mustard and *taramira* gave the maximum yield with 2 irrigations, whereas safflower and pigeonpea gave the maximum yield with 3 irrigations (Table 3.66). Water-use-efficiency was maximum with 2 irrigations in mustard (82.9 kg/ha/cm) and *taramira* (61.1 kg/ha/cm), and with 3 irrigations in safflower (77.9 kg/ha/cm) and pigeonpea (82.2 kg/ha/cm).

Early cessation of monsoon in some years adversely affects the germination and establishment of winter rainfed crops due to inadequate soil moisture in surface layers. As a result, the crops do not efficiently utilize the moisture stored in deeper layers. To overcome such a situation Prasad *et. al.* (1999) studied the effect of 3 depths of pre-sowing irrigation (0, 5 and 10 cm) and soil mulch on yield and water-use-efficiency of mustard, linseed and chickpea. The average increase in grain yield was 50, 61 and 80%, and 63, 69 and 92% in chickpea, linseed and mustard, respectively with 5 and

Table 3.66: Effect of supplemental irrigation on grain yield and water use efficiency of crops (mean data from 1986-87 to 1988-89)

Treatment	Grain yield (kg/ha)				Water use efficiency (kg/ha/cm)			
	Mustard	*Taramira*	Safflower	Pigeonpea	Mustard	*Taramira*	Safflower	Pigeonpea
I_1	970	930	1330	1030	61.1	60.6	71.2	71.6
I_2	1620	1150	1700	1450	82.9	61.1	74.1	76.1
I_3	1540	990	2050	1850	65.9	47.8	77.9	82.8
C.D. at 5%	-	-	-	-	-	-	-	-
Irrigation	43	-	-	-	2.2	-	-	-
Crop	46	-	-	-	2.6	-	-	-

I_1 =10 cm irrigation as pre-sowing; I2= I_1 + 5 cm at branching; I_3 = I_2 + 5 cm at flowering between 5 and 10 cm irrigation were of no significance. Mustard showed the highest water use efficiency (16.5kg/ha/mm) and linseed the lowest (10.2 kg/ha/mm). Soil mulch alone or in combination with irrigation was not found effective.

3.2.4 Rehabilitation of Areas Affected by Mass Erosion

The ravine lands refers to a network of gullies which are generally spread along any river system while gully is an erosion channel developed by ephemeral streams with steep banks and a nearly vertical gully head deep enough to create hindrance to the normal tillage operations. Usually these are deeper than 0.3 m. Once the process of gully erosion is initiated it rapidly extends into adjoining levelled fields converting these fertile arable lands in to severely deformed and unproductive landscape. Poor rainfall receptivity of these lands leads to formation of water stressed ecosystems. Loss of vegetation and biodiversity results in overall degradation of livelihood support systems of local inhabitants. Awaiting adequate ravine area restoration initiatives, gully network continue to outspread endangering habitations, roads, railways, power and communications network etc. There are significant off-site implications of gully erosions as well, which include accelerated siltation of rivers and reservoirs, increased risk of floods and torrential flows, loss of aquatic fauna and biodiversity due to deterioration of surface water quality. Located along the river systems on deep alluvial soils, ravine lands have high potential productivity. Extensive areas under medium-deep and deep ravines continue to remain unattended despite exorbitantly escalated land value and available economically viable and ecologically sustainable ravine reclamation technology developed and demonstrated by ICAR-IISWC, Research Centre, Kota over a period of about sixty years.

3.2.4.1 Ravine Reclamation Technology

The recommended ravine reclamation packages can transform these waste lands to productive ecological parks with high silt and carbon entrapment and water harvesting potential. The ravine reclamation package include following seven steps:

1. Classification of ravine landscape based on terrain roughness and soil and backflow conditions following a 'Gully Reclamability Classification System'.
2. Installation of 'Peripheral or Marginal bund' between tabletop arable lands and ravine lands.
3. Runoff management in upstream arable land with suitable drainage line treatment measure.
4. Gully head stabilization with suitable type of spillway.
5. Gully bed stabilization with a series of check dams.
6. Vegetation establishment with the support of runoff management measures.
7. Establish sustainable livelihood support system for ensuring sustained benefits ravine reclamation plan.

3.2.4.1 Gully Reclamability Classification System

The reclamation strategy for a ravine land largely depends on degree of terrain deformation and soil quality. A comprehensive gully classification scheme evolved at ICAR-IISWC (Table 3.67) classifies the gully network into size categories based on gully dimensions, soil characteristics, water availability and climate. With progressively increased terrain deformation from class 1 to class 6 land in this gully rating scheme, there is a corresponding increase in erosion hazards and land-use restrictions.

Marginal lands at the periphery of ravine system with occasional presence of shallow gullies are classified as Gully Reclaimability Class I (GRC-I). These lands require minor levelling work on gently sloping sides and bed for reclamation. Favourable soil texture and deep soil depth facilitate cultivation of most crops possible and also alleviate levelling and maintenance cost of these lands. Narrower and deeper gullies make the reclamation process expensive and challenging. Accordingly, land use restrictions are imposed GRC degrades from GRC-I to GRC-VI. Generally, GRC I to IV are recommended for cultivation with increased level of management and restriction.

Table 3.67: Gully Reclamability Classification Scheme

Class	Texture	Bed width (m)	Gully depth (m)	Side slope (%)	Climate
1	sicl, cl, l, sl, sil, scl	>18 or <6, (W_3) (W_1)	< 1.5 (gd_1)	< 5% (S_1)	Humid climate with well distributed rainfall or having perennial irrigation.
2	sicl, cl. sl, sil, scl.	6-18 (W_2)	1.5-3.0 (gd_2)	5-10% (S_2)	Humid climate with occasional dry spells or dry-cum-wet irrigation.
3	sc, sic, c,ls	> 18 (W_3)	3-6 (gd_3)	10-15%(S_1)	Sub-humid climate or situated at tail end of an irrigation system where water is occasionally not adequately available.
4	Any texture excluding sand and with gravel	Any width	6-9(gd_4)	10-15% (S_3)	Semi-arid climate (without irrigation) with enough rainfall to sustain hardy horticultural plants.
		Reclaimable classes decrease in priority for reclamation for agriculture from Class 1 to 3. Class 4 may be put under horticulture.			
5		Reclaimable classes 1 to 4 having the following hazards: Water logging/salinity has developed due to irrigation system. Back flow and flooding from a nearby stream or river. Hence, the gully need not be reclaimed for agriculture. It may be put under any suitable grass or tree spp.			
6	Any texture including gravelly *etc.*	Any width	>9 (gd_5)	15% irregular (S_4)	Semi-arid with long dry spells and arid.
		Gully humps may also be included in this class.			

GRC-V has similar topographic feature as of GRC-I to IV, but this cannot be reclaimed for agriculture or horticulture as the gully is prone to seasonal backflows from a nearby river or it has developed water logging, salinity due to irrigation or any other adverse factor like arid climate. Such lands may be put under perennial vegetation like suitable fuel and fodder trees and grasses. Grass cutting for stall feeding may be allowed. Fuel trees may be exploited on rotation basis. GRC-VI lands present limitations severe than in GRC-IV in any one or more soil, topographic or climatic, and, are best suited for perennial vegetation and wild life. Eco-tourism can also be a possible economic activity suited to these lands.

3.2.4.2 Installation of Peripheral Bunds

For regulated entry of runoff into ravine lands, marginal bund of 1.5 sq. m cross section (bottom width, 2.5m; top width, 0.5m; height 1.0m) with 0.1 to 0.2% grade should be constructed at the periphery of agriculture land to demarcate the agricultural table land and the ravines (Fig. 3.22). The cross section of bund may reduce to 0.6 sq. m towards the ridge. The bund should be constructed at a distance of twice the depth of active gully heads. Runoff diverted by peripheral bunds is then safely discharged into gully network through appropriate type of spillways are planned for the given vertical fall at gully head and gully catchment area..

Fig. 3.22: Peripheral bunds without (left) and with (right) vegetation protection

3.2.4.3 Runoff Management in Upstream Arable Lands

Leveling and terracing of multidirectional slopes is recommended on the upstream side of peripheral bunds. Suitable conservation measures are adopted for promoting *in-situ* moisture conservation such as deep summer ploughing, contour tillage, intercropping, vegetative barriers, contour or graded bunding with contour furrows in inter-bunded areas *etc.* A detailed discussion on evaluation suitable conservation measures for arable lands has been presented in previous section.

3.2.4.4 Gully Head Stabilization

Preventing the gully-head extension through appropriate head stabilization measures is much easier and less expensive than reclaiming ravine lands. Therefore, planning regulated and safe disposal of runoff from gully catchment to ravine system is the key component of any gully control programme which is supported by catchment treatment for reducing and diverting of surface runoff by the structural and non-structural measures. Providing appropriate type of spillway is an effective gully head control structure. Three types of spillways are generally recommended based on the expected peak runoff volumes and over fall of the gully head, which is the elevation difference between the land above the gully head and gully bed (Table 3.68). The straight drop spillways are adapted to control the gully head with less than 3 m fall. The low straight drop is also advisable for small gully head cuts (1-2 m). The chute spillways are preferred for gully heads with 3.6 m fall and large drainage area. The pipe spillway is usually constructed in conjunction with earthen embankment with no provision for permanent water storage behind the structure and very little detention storage above the spillway inlet. For identifying suitable site and type of spillway for gully head stabilization, the potential sites need to be surveyed with depth and width measurements. Stability of gully head banks should be studied carefully for proper anchoring of the head wall extensions into banks. The spillway is designed for expected peak discharge volumes from the catchment.

3.2.4.5 Stabilization of Gully Bed and Side Slopes

The second step in rehabilitation process of medium-deep gullies is establishing a series of check dams to stabilize gully beds and side slopes. The type of check dam, its size and placement is scientifically planned to optimize cost and conservation efficiency of these structures (Table 3.69). The selection of the check dams depends on the size of the gully catchment area, the gradient and the length of the gully channel. A gully network treated with a series of check dams eventually gets transformed from silt producing site to silt entrapment site. Gradually, the terrain roughness is diminished giving rise to levelled and fertile gully beds. During initial years these structures act as embankment type water harvesting structures and promote ground water recharge. Bio-engineering measures are planned for stabilization of steep side slope of deep gullies and river banks. For stabilizing gully side slopes 1:1 slope-easing treatment is desirable to establish a good cover. *Dichanthium annulatum* was found very suitable for sodding the eased slopes. This type of work is expensive, and is recommended where protection of costly construction like roads, buildings *etc.*, is required. The gully stabilization can also be achieved slowly if the area is protected against grazing.

Table 3.68: Types and suitability of spillways as gully head control structure

Type of spillway	Site suitability		Advantages	Disadvantages
	Overfall (m)	Peak runoff (m^3/s)		
Drop pillway	<3	>2.5	Relatively stable and safe, Easy to construct and maintain	Require stable grade on either side, unsuitable for detention storage, high initial cost
Chute pillway	3-6	<2.5	Relatively low cost	Susceptible to failure due to seepage or rodents activity
Pipe pillway	>3	Any	Suited for upstream detention storage, road culverts, economical, stable and safe	Sensitive to clogging by debris, require careful field execution to avoid channeling along pipe.

Table 3.69: Different types of check dams for gully bed stabilization

Check dam type	Site suitability				Advantage and disadvantage
	Stream order	Catchment size (ha)	Peak runoff (m^3/s)	Slope (%)	
LBCD	1^{st}	<2	<0.25	<1	Low cost, easy to plan and install, reduce the runoff velocity and soil loss, improved moisture availability and vegetation establishment, silt deposited behind structures leads to stabilization of gully beds **Limitations:** These are temporary structure with life span of 3-5 years
Earthen gully plug	1^{st}	<2	<0.25	<1	-
Bori bunds	1^{st}& 2^{nd}	<2	<0.25	<3	-
Earthen CDs	2^{nd}	2-20	0.25-2.5	<3	Very effective in medium deep gully, retain large quantity of runoff and silt, improve groundwater availability, promote vegetation/ regeneration, helps in drought mitigation. Longer life span. **Limitations:** High initial cost, requires good technical know-how for planning and execution,
Masonry CDs	3^{rd} & higher order	>20	>2.5	Any	-
Composite CDs	3^{rd} & higher order	>20	>2.5	Any	-
Bio-engineering measures	1^{st}	<2	<0.25	<1	Low cost and easy to install, effective Reduce the runoff velocity, help in reduction of soil loss, help in filtering of the soil moving with the water, improved moisture availability, leads to better survival and growth of vegetation, **Limitations:** temporary conservation measures, life span is less than 5 years

3.2.4.6 VegetationEstablishment

The ravine area vegetation in India is in highly degraded condition with very low density of xerophytic vegetation. Excessive erosion and biotic pressure little scope for natural regeneration of trees and grass. Any growing tree would be heavily grazed or lopped for fuel. Sustainable restoration of ravine lands is possible only if these lands are vegetated with ecologically efficient and economically viable perennials (Table 3.70). A successful vegetation establishment programme would effective control over biotic interferences. Empowering local beneficiaries to develop a social mechanism or social fencing is an effective and very well tested tool for regulating biotic pressure on the planted vegetation. It offers an opportunity to local stakeholders to formulate a strategy to control grazing and protect the planted vegetation with the aim of utilizing the developed resources in a socially and ecologically acceptable ways. The hardy and thorny species like *Agave americana, Agave sisilana, Caesalpinia bonduc, Caesalpinia decapetala, Jatropha curcus and Euphorbia spp.* in conjugation with ditch-cum-wire fences may be erected to provide protection to vegetation during initial years of resurrection. The community land may preferably be utilized for silvi-pasture while other revenue land can be utilized for bamboo, MPTs plantation or silvi-pasture. Severely degraded government land can also be made productive through appropriate MPTs plantation and assisted natural regeneration. Animal production systems are major livelihood source in ravine areas. Shifting of focus to cash crops from traditional cereal and millet crops in past few decades has also reduced the availability of fodder from cropped lands. There is need to augment supply of fodder for improving productivity of animal production system.

Silvipasture systems provide opportunities for farmers to utilize marginal and waste lands to increase productivity on a unit of land by producing both livestock and timber products. Trees can be planted in pastures or existing woodlots can be thinned using timber stand improvement techniques to create environ-ment that will support both forage and tree production. Suitable tree, shrub and grass species for ravine region have been evaluated and are listed in previous sections.

Table 3.70: Criteria for selection of land use and species in ravines

Topographic location	Soil type	Resource availability	Land use	Tree / shrub species	Land ownership
Marginal lands along ravines	Heavy	Supplemental Irrigation available	AHS	Amla, Guava, Lemon, Bael, Anaar, Ber, Karonda, Lasoda, Tenti	Private and community lands
Marginal lands along ravines/ reclaimed shallow ravines	Heavy	Supplemental Irrigation available for crops	AFS Boundary plantation	Desi babul, Khejidi, Subabul, Neem, Siris, Rohan, Ratanjot	Private/ community/revenue forest lands
Marginal lands along ravines	Light	Supplemental Irrigation available	AHS	Amla, Guava, Lemon, Bael, Ber, Karonda, Lasoda, Sharifa	Private and community lands
Marginal lands along ravines / reclaimed shallow ravines	Light	Supplemental Irrigation available for crops	AHS Boundary plantation	Shisham, Desi babul, Khejari, Khejidi, Subabul, Bakain, Semal, Ardu, Neem, Siris, Rohanju, Ratanjot, Pilu and Marwari teak	Private/ community/ revenue forest lands
Medium and deep ravines Ravine top gently sloping	Heavy	Rainfedlife saving irrigation available	HPS	Amla, Lemon, Belpatra, Anar, Ber, Lasoda, Tenti + Grasses, (Karad, Dhaman, Rodes)	Private and community lands
Medium and deep ravines Ravine top gently sloping	Light	Rainfedlife saving irrigation available	HPS	Amla, Lemon, Bael, Ber, Lasoda, Drumstick + Grasses : Karad, Dhaman, Black Dhaman, Rodes, Stylo (legume)	Private and community lands
Medium and deep ravines slopes <33%	Heavy	Rainfed	MPTS/ Grass production	Neem, Churel, Ratanjot + Grasses	Private/ Community / Revenue lands
Medium and deep ravines slopes <33%	Light	Rainfed	SPS	Neem, Churel, bakain + Grasses	Private/ Community / Revenue lands
Ravine slopes > 33%	Heavy or light	Rainfed	Grass production	Karad, Dhaman, Black Dhaman, Rodes	Community / Revenue lands
Medium and deep ravines - Beds	Heavy	Rainfed	MPTS / bamboo cultivation	Bamboo,Cassia, Desi babool, Khejidi, Subabool, Neem + grasses	Private/ Community / Revenue lands
Medium and deep ravines- Beds	Light	Rainfed	MPTS / bamboo cultivation	Bamboo, Shisam, Desi Babool, Khejiri, Cassia, Subabool, Bakain, Ardu, Neem+ grasses	Private/ Community / Revenue lands
Waterlogged ravine Beds	-	-	MPTS/ Grass production	Tamarixspp, Para grass	Wastelands/ Revenue lands

**MPTS- Multi Purpose Trees and Shrubs, AFS – AgroforoestrySytems, *AHS – Agri-Horticulture Systems, SPS – Silvi-pastural Systems, HPS - Horti-Pastoral Systems*

3.2.4.7 PerformanceEvaluation of Ravine Reclamation Works

Ecological and socio-economic benefits of ravine reclamation were assessed in Badakhera watershed of district Bundi (Rajasthan) which was treated during 1998-03 with limited budgetary provisions under Integrated Wasteland Development Programme. The direct and indirect benefits accrued from major watershed interventions are listed in Table 3.71. Despite abnormal monsoon pattern and severe drought conditions experienced during the project period the overall B:C ratio worked out at the project completion was 1.54 (Singh *et. al,* 2004). Reclamation of gullied land and increased soil moisture were the most apparent and immediate benefits experienced. With improved cropping practices these ameliorative effect can be enhanced to quickly recover the cost of conservation measures. Bunding and levelling require high initial investment in ravine reclamation plan, which can be recovered in following 3-5 years period through increased crop productivity (Singh *et. al.*, 2005). Strengthening existing water harvesting structure and developing additional village pond effectively reduced drought effect. Erosion control measures with and without vegetative support reduced soil loss by 68 and 55% compared to untreated area. About 57000 ton of soil was retained in upstream side of 36 check dams having catchment of 507 ha. Therefore, as cumulative effect silt retained behind gully control structure was equivalent to arresting 112.5 t/ha of soil. These structures reclaimed 9.12 ha of severely gullied land and 24.6 ha the moderately degraded land. Structures in upper reach retained greater soil volumes compared lower reach structures. It is estimated that the runoff from watershed was about 30% during the initial years which reduced to less than 10% in response to conservation measure. Similarly in Yamuna ravines at Agra district a five year (2010-14) field study evaluated impact of minor land levelling and peripheral bunding on crop yields (Singh *et. al.* 2016). Grain yields of pearl millet, green gram and sesame improved by 90, 164 and 179% over respective yields received from untreated area.

Table 3.71: Economic returns from different interventions in Badakhera (Dist. Bundi)

Intervention	Total cost (Rs.) for 6 yr period	Area covered (ha)	Direct benefits	Indirect benefits	Estimates value of benefits (Rs./yr)
Bunding & leveling	169611	90.3	Increased crop yield (89% increase in mustard observed)	Improvement in land quality Ground water recharge	328500/-
Spillways	888172	381.9	Increased crop yield through increased moisture regime in the vicinity of structures (24.6 ha)	Improvement in land quality Ground water recharge	89446/-
Gully control structures	342727	131.6	Increased area under cultivation (9.12 ha) Increased fuel & fodder production[2]	Improvement in land quality Ground water recharge	70350/-
Water harvesting structures	576873	21.65[1]	Increased water availability for irrigation and drinking for cattle	Ground water recharge	135846/-
Crop demonstrations	19466	17.6	Increased crop yields	Sustainability in agriculture production	24262/-
Horticulture plantations	7200	1.3	Increased fruit production from 5th yr onwards	Sustainability, stability and diversification in agriculture production	72200/-
Afforestation works	15298	38.5	Increased fuel & fodder production[2]	Erosion control Microclimate improvement	NIL

[1]cultivated area estimated to receive lifesaving irrigation; [2]The benefit could not be realized during project period due to severe biotic interference and persistent drought;

3.2.5 Participatory Integrated Watershed Management

3.2.5.1 Participatory Watershed Management and Impact Assessment

For field demonstration and evaluation of recommended soil and water conservation technologies on watershed scale, three watershed projects were implemented by the Centre, which are located at Chhajawa and Dhoti watersheds in district Baran while Bada Khera in Bundi District of South-Eastern Rajasthan. These watersheds were monitored for ecological and socio-economic parameters and detailed account of project implementation and impact assessment have been well documented (Prasad *et. al*., 1996 and Singh *et. al.*, 2004, Dhyani *et. al*., 2016, Kumar *et. al.,* 2017). In addition, research studies on impact of watershed projects on soil and plant biodiversity were also taken up. The results of these projects and studies are summarised here:

3.2.5.1.1 Chhajawa watershed project

Chhajawa in Baran district, is a typical agricultural watershed representing dry sub-humid tract of South-Eastern Rajasthan, was developed during 1983-89. The watershed is located at 25° 05' N latitude and 76° 25' E longitude on Baran-Atru road at 12 km away from Baran city. Out of the total area of 453.75 ha, nearly 92 % is under agriculture and rest is under wastelands (4.4%) and gullies (3.5%). One main drainage channel with 3 subsidiaries drains the watershed. The annual average rainfall is 874 mm, of which, more than 90 % is received during July to September. Soils are typical vertisols, low to medium in fertility, neutral to alkaline in reaction and very deep having low permeability. Moderate to severe soil erosion, poor ground water recharge due to excessive runoff, traditional cropping with negligible to nil application of fertilizers, very low productivity of arable lands, overgrazed wastelands, heavily lopped scanty trees, and very poor socio-economic condition of the farmers were the major problems of the area during pre-project period.

The watershed management plan included installation of graded bunds of 1 to 1.5 sq. m cross section in 360 ha area having a bunding length of 27.4 km, construction of dry stone waste weirs for safe disposal of excess water from bunded area, gully stabilisation through permanent gully control structures (7 Nos.), low height masonry check dams (29 Nos.), gabions (7 Nos.) and loose boulder check dams (8 Nos.). Under crop improvement programme, 252 demonstrations of improved package of practices were organised. Field bunds and block plantations of *Eucalyptus tereticornis* were demonstrated under agroforestry. The plantation of guava and lemon was also done on arable lands to meet the partial fruit demand of farmers. For rehabilitation of overgrazed wastelands, seedlings of forest trees and rooted slips of *Cenchrus ciliaris* were planted. *Ipomoea carnea* cuttings were planted at vulnerable sites in gullies. Watershed management treatments reduced the runoff from 24.7 to 7.7%. The ground water recharge substantially got improved as the number of wells and gross irrigated area increased from 16 to 39 and 32.5 to 300.4 ha, respectively from 1985-86 to 1992-93. Similarly, cropping intensity increased from 80.5 to 1116.8%, total grain production from 280 to 839.8 tons, average productivity of arable lands from 670 to 2210 kg/ha/year, fodder production from 506 to 827.5 tons and milk production from 51.9 to 123.9 kilo litres during 9 years period (Table 3.72). Total employment generation increased from 36049 to 58849 man days/year indicating 63.2% higher employment generation over pre-project period. The annual per capita net income also increased from Rs. 658 in 1985-86 to Rs. 4234 in 1994-95, showing thereby more than 6 times increase over pre-project period. Economic evaluation also confirmed economic viability of the project with benefit cost ratio of 2.06. Study conducted by Dhyani *et. al,*. 2005 using primary data of 50 farm families revealed that watershed management project at Chhajawa had improved resources availability increased resource-use efficiency and total production from arable and non-arable land. The programme significantly increased employment opportunities in the watershed. Irrigated area, capital recovery factor to investment on soil and water conservation technologies and cropping intensity were found to be the most important determinants for enhancement of regular employment opportunities in the watershed.

Table 3.72: Year wise total cropped area, cropping intensity, grain production and average productivity

Year	Cropped area (ha)	Grain production (tons)					Av. productivity (kg/ha)
		Cereals	Pulses	Oilseeds	Coriander	Total	
1985-86 Pre-project	336.1 (80.5)	137.2	73.5	24.6	44.7	280.0	670
1986-87	384.8 (92.1)	136.2	130.0	34.5	41.0	341.7	818
1987-88	426.4 (102.1)	195.8	76.1	51.0	189.9	512.8	1227
1988-89	453.1 (108.6)	133.6	131.3	143.4	92.4	55.9	1199
1989-90	459.9 (110.3)	273.2	126.9	144.0	55.7	599.8	1435
1990-91	469.4 (112.2)	226.6	159.9	207.8	85.6	679.9	1627
1991-92	445.1 (106.7)	219.9	95.1	216.7	85.7	617.4	1478
1992-93	487.9 (116.8)	255.9	95.8	391.7	96.8	839.8	2010

Figures in parenthesis indicate cropping intensity (%)

For assessing long term sustainability and effectiveness of conservation measures on the productivity, the watershed was evaluated after 8 years of project completion (Kumar *et. al.*, 2001, Kumar *et. al.*, 2006) using two approaches simultaneously *i.e.* "Before and After" and "With and Without" to ascertain the overall impact on rural households. The evaluation based on households' survey of all the beneficiaries indicated that land utilization and gross irrigated area increased by 57% and 1059% (from 32.5 ha to 376.7 ha) over a period of 12 years. The cropping pattern has shifted in favors of more remunerative and quality crops such as soybean in monsoon season and mustard, coriander and wheat in winter season with remarkable improvement in the yield. The average productivity of agriculture and dairy has increased by 87% and 8 times with benefit cost ratio of 2.34 and 1.30, respectively. The overall B-C ratio of 2.03 at 12% discount rate suggests that watershed management projects for improvement of rain fed ecosystems are economically viable in the region. The study also examined the changes in socio-economic status of beneficiaries brought out by the implementation of watershed management project over non-beneficiaries (Kumar *et. al.*, 2006). The consumption of nitrogenous and phosphate fertilizers inside watershed was 72 and 63% higher than adjoining area which led to improve overall productivity ranging from 20.93 to 60.3% (Table 3.73). The increased productivity as a result of soil and water conservation treatments led to higher net income by 57% as compared to outside watershed. The study also found 134% more investment in farm assets by beneficiaries in comparison with non-beneficiaries. The important indicators presented in Table 3.74 indicate that watershed based approach plays very significant role in improving the rural livelihood in rainfed areas of the region.

Table 3.73: Impact of watershed management project on productivity of selected crops

Crop	Inside watershed	Outside watershed	% Difference
Sorghum			
Yield (q/ha)	15.60±1.01	9.78±0.48	59.50*
Cost of cultivation (Rs./ha)	4052.00±102.8	3378.00±66.44	20.66*
Cost of production (Rs./q)	259.70±16.37	343.35±12.80	-24.36*

Soybean			
Yield (q/ha)	13.03±0.47	8.13±0.58	60.27*
Cost of cultivation (Rs./ha)	4730.00±45.60	4388.00±46.11	7.79*
Cost of production (Rs./q)	363.04±10.14	539.72±26.84	-32.73*
Gram			
Yield (q/ha)	11.61±0.56	9.6 ±0.27	20.93*
Cost ofcultivation (Rs./ha)	5294.00±154.42	4751.00±79.75	11.42*
Cost of production (Rs./q)	456.56±16.44	494.8 ±9.75	-7.82
Coriander			
Yield(q/ha)	10.82±0.33	8.36±0.34	29.42*
Cost of cultivation (Rs./ha)	5546.00±60.51	4639.00±77.7	19.55*
Cost of production (Rs./q)	512.54±12.28	554.90±18.54	-7.70*
Wheat			
Yield (q/ha)	32.72 ±0.87	24.2 ±.708	35.20*
Cost of cultivation (Rs/ha)	9238.00±213.45	8481.00±174.6	8.92*
Cost of production (Rs./q)	282.35±3.38	350.40±4.45	-19.42*
Mustard			
Yield (q/ha)	16.15 ±0.33	11.17±0.37	44.58*
Cost of cultivation (Rs./ha)	4897.00±56.23	4138.00±54.00	18.34*
Cost of production (Rs./q)	303.23±5.35	370.40±6.50	-18.13*

± indicate SE of mean,* Significant at 5 % level of probability

Table 3.74: Impact indicators of integrated watershed management project at Chhajawa

Indicator	Inside watershed		Outside watershed (1997-98)
	Before project (1985-86)	After project (1997-98)	
Av. size of land holding (ha)	3.86	3.86	5.12
Cropping intensity (%)	80.46	126.31	99.10
Av. Productivity (kg/ha)	833	1557	1100
Irrigated area (%)	4.91	39.79	16.25
No of wells*	16	62	35
Fertilizer use (kg/ha)			
N	9.3	42.67	24.78
P_2O_5	12.3	24.15	14.78
Gross agricultural income /Household (Rs./year)	6031	63935	46944
Value of farm assets (Rs.)	---	80847	34524
Vegetation cover (trees/ha)	0.56	5.29	2.2
Milch animal in SAU**/Household	1.90	2.16	1.58
B:C Ratio of project:			
Crop production		2.34	-----
Animal husbandry	—	1.30	---
Overall		2.03	-----

**Including bore well. **Standard animal unit*

3.2.5.1.2 Integrated watershed development project, Badakhera

Socio-economic analysis of Badakhera Watershed project has been carried out, which was taken up in 1996-97 in Bundi district of South-Eastern Rajasthan by Research Centre, Kota to demonstrate field implementation of conservation technologies with financial assistance from Department of Land Resources, Ministry of Rural Development, Government of India, New Delhi. Out of 682.5 ha watershed private owned agriculture land was 378.9 ha and community land was 303.6 ha. The actual execution of watershed works was carried out during 1997-98 to 2002-03.

Major components of the project were various soil and water conservation works andcrop improvement packages. Rehabilitation of community lands was also attempted by planting fuel and fodder species. To ensure active participation of stakeholders, a watershed development committee was constituted with an executive body. Planning and field execution of developmental activities were carried out by this committee under the supervision of Watershed Development Team. Users Groups and Self-Help-Groups were organized and trained to develop specialized skills. Conservation measures applied in arable lands included construction of graded and peripheral bunds strengthened with grasses, land leveling in inter-bunded areas, and construction of masonry, gabion or loose boulder spillways for safe disposal of excess runoff (Singh *et. al.*, 2004 & 2005). Drainage lines were treated with straight drop masonry or gabion spillways constructed at gully heads and series of check dams, gully plugs and live hedge barriers to stabilize and flatten the gully beds. Two farm ponds of 1.6 and 0.6 ha-m capacities were constructed. Improved package of practices were introduced through crop demonstrations. Simultaneous monitoring on ecological and socio-economic parameters was carried out for impact evaluation of watershed project.

Although abnormal monsoon pattern and severe drought conditions experienced during the project period restricted desired level of project benefits, the basic objectives of the projects were fulfilled with fair degree of success. Reclamation of gullied land and increased soil moisture were the most apparent and immediate benefits experienced. With improved cropping practices, these ameliorative effects can be further enhanced to quickly recover the cost of conservation measures. However, under severe drought conditions, as experienced during the year 2002, conservation measures and improved cropping practices were found inadequate to sustain even a minimum level of productivity required to support livelihood of human and cattle population of the watershed. Strengthening of existing water harvesting structures and augmentation of village pond capacity effectively helped in mitigating effect of drought.

Economic evaluation and impact analysis of Badakhera project (Singh *et. al.*, 2004) revealed that soil loss reduced to 45% and 32% by applying mechanical and mechanical +vegetative measures compared to untreated watershed. About 57000 tons of soil was retained in the upstream side of 36 check dams constructed in the watershed, having catchments area of 506.6 ha. Therefore, as cumulative effect, the silt retained behind these structures was equivalent to arresting 112.5 t/ha of soil loss. These structures reclaimed 9.12 ha of severely gullied land and 24.6 ha of moderately degraded land. From the watershed as a whole the estimated pre-project soil loss was about 40 t/ha which reduced to about 10 t/ha after project implementation. Bunding alone and bunding + leveling increased mustard seed yield by 89 and 200%, respectively (Fig. 3.23). Chickpea, soybean and sorghum also recorded 65 and 108%, 29 and 84%, 30 and 90% improvement in seed yield, respectively. On an average, improved package of practices with bunding and bunding + leveling recorded 74.7 and 44.1% higher grain yield of crops during *Kharif* and *Rabi* season, respectively than traditional cropping in the watershed. Crop Diversification Index (CDI) decreased from 0.799 initial values to 0.542 due to switch over to high yielding food and remunerative cash crops as a result of better resource availability. Crop Fertilizer Index (CFI) values worked out showed a significant improvement in fertilizer use after the watershed programme. The impact of the project on environment was also assessed by calculating watershed eco-development index which increased by 5.39% after project implementation (Fig. 3.24). Crop Productivity Index (CPI) indicated an improvement in productivity of crops by showing the CPI values from 0.829 to 0.995. But cultivated land utilization index (CLUI) showed slight improvement only in irrigated area. The highest community participation at the planning stage (64.37%) followed by implementation stage (38.43%) indicate that stakeholders in the watershed were reluctant in taking part in community related developmental works and they only showed greater interest in the developmental activities taken up on their own fields (Table 3.75). Farmer's contribution was only made for the works taken up at private agriculture fields and contribution for community lands was almost negligible. Total family income increased by 44 % .The maximum overall incremental family income was observed in case of large farmers (62%) and minimum in marginal category of farmers (28%). However, increase in income from agriculture interventions was highest for small farmers. Benefits from different interventions in Badakhera ravine watershed have been valued by Singh *et. al.,* 2004and presented in Table 3.71 in previous section. Reclamation of shallow ravine has been reported to have tangible benefits in terms of improved value of land and crop yield improvement to the extent of 200% as a result of improved moisture level. The overall benefit cost ratio worked out assuming 20 years of project life and 10% discount rate for this watershed as 1.54 was quite favorable. This suggests that watershed management project in ravine areas helped not only to increase production and productivity but also restored the ecological balance by upgrading the environmental status. However, the implementation of watershed development project in Badakhera has highlighted some of the concerns and constraints which need to be focused upon by research and developmental agencies. Excessive biotic interferences restricting the successful establishment of vegetation in community pasture lands, formation of surface and sub-surface cracks and pot-holes due to high clay content and lack of remunerative alternate land use options for drought mitigation were the issues need to be addressed on priority.

Fig. 3.23: Effect of bunding and improved packages of practices in Mustard

Fig. 3.24: Use of reclaimed gully bed for wheat cultivation

3.2.5.1.3 Dhoti watershed project

Dhoti watershed in Baran district of Rajasthan was developed by Research Centre, Kota during 2008-09 to 2013-14 under the National Watershed Development Programme for Rainfed Areas (NWDPRA) with the objectives to demonstrate suitable soil and water conservation interventions and technological packages for the development of agriculture and other rural livelihood activities for adoption by the farmers through a participatory approach. To ensure active participation of stake holders a watershed development society was organized for planning and field execution of developmental activities under the supervision of watershed development team. Special emphasis during the project implementation was given to people's participation at all stages of programmes *viz.,* resource appraisal, planning and implementing the programme, besides educating and motivating farmers for adopting improved package of practices. The total area of watershed was 677 ha and developmental programme included crop demonstrations, construction of graded and peripheral bunds strengthened with grasses, land leveling in inter-bunded areas, and construction of masonry, gabion or loose boulder spillways for safe disposal of excess runoff. Drainage lines were treated with drop masonry series of check dams, gully plugs and live hedge barriers to stabilize and flattening the gully beds. Three embankment type farm ponds of 118.2, 115 and 26 ha catchment area with capacity of 2.07, 4.85 and 4.4 ha-m, respectively were constructed. Simultaneous monitoring on ecological and socio-economic parameters was carried out for impact evaluation of different interventions;which revealed significant reduction in runoff (23.6% to 4.6%) and soil loss from 21.3 t/ha to 3.2 t/ha, respectively after the imposition of treatments (Kumar *et. al.,* 2014 and Dhyani *et. al.,* 2016). Land use pattern show an increase in area under crops by 55% in *Kharif* which reduced fallow land area by 13%. West weir with contour bunds and Contour furrow interventions increased soybean yield by 68 and 26%, respectively over control. Crop demonstrations of improved package of practices in different crops like soybean, green gram, black gram, sesame, maize and mustard showed an improvement in net returns by Rs. 3900-6600 / ha over the farmers' practice. Cropping intensity increased by 11% point due to increase in area under crops in both the cropping season. Increased values of Cultivated Land Utilization Index CLUI (0.34 to 0.37), Crop Productivity Index CPI (0.73 to 0.79), Diversification Index CDI (0.44 to 0.49) watershed under pre and post situation clearly indicated the impact of watershed interventions. Induced Watershed Eco-Index (IWEI) represents an additional area made green through watershed treatment as a proportion of the whole watershed area indicate an 9% increase in green cover .Total production from the watershed increased by 19%. A marginal increase in milk production was also observed despite of decrease in bovine population. Impact of various conservation measures on improving groundwater recharge and its availability showed a rise in groundwater table ranging from 12.1 to 18.4 meter in the vicinity of the structures. Casual employment opportunities to the tune of more than 6400 man days have been generated during implementation of the project activities. The survival of tree and grass species on pasture land was also monitored and found that *Acacia* (97%) followed by Siris (*Albezia lebbek*) 25% and Shisham (*Dalbergia sissoo*) 27% recorded highest survival rate. The total air dry fodder as a result of planting grass slips in silvi –pasture system was produced in the range of 6.87-9.12 t/ha during 2011 to 2014-15.Increase in income of watershed community is estimated by 13.5% from different sources. The increase in income from agriculture interventions was highest for small farmers (33%) due to adoption of improved packages of practices and irrigation besides better watch and ward efforts.

Table 3.75: People's participation index (PPI) in Badakhera watershed

Level of participation	Project stages		
	Planning	Implementation	Overall
Low	15 (18.75)	11 (13.75)	17 (21.25)
Medium	39 (48.75)	66 (82.5)	48 (60.00)
High	26 (32.50)	3 (3.75)	15 (18.75)
Total	**80 (100.00)**	**80 (100.00)**	**80 (100.00)**
PPI	64.37	38.43	51.40

Figures in parenthesis show percentages of total

3.2.5.1.4 Impact assessment of watershed projects implemented by state agencies

Several watershed evaluation studies have been taken up by the individual researchers and organizations on the instances of funding agencies in Rajasthan state with diverse approaches to deal with different economic, biophysical, institutional and environmental aspects. The basic difference in ICAR institute and state government studies was non-availability of bench mark or baseline data with state agencies as most studies conducted were mainly based on household survey conducted after projects completion. This approach is constrained for data authenticity and further accounting for qualitative as well as quantitative variables important for quality assessment of watershed projects. The impact analysis presented here in brief is based on the three evaluation studies conducted by the Centre and nine other watersheds evaluated by different agencies as listed below (Table 3.76).

Table 3.76: List of watersheds evaluated for impact assessment

Name of watershed	Total area (ha)	Name of scheme	Implementing agency	Evaluating agency
Pipalwara-1	519	DPAP	Deptt. of Soil Cons. and Watershed Development, Govt. of Rajasthan	CECOEDECON (1997)
Meda-Uperla, Jalore	1900	DDP	--do--	IIRM, Jaipur (1997)
Atbare, Pali	1320	NWDPRA	--do--	--do--
Kaparda, Jodhpur	1996	IWDP	--do--	--do--
Sri EklingNath, Udaipur	1943	IWDP	--do--	Marudhara Academy, Jaipur (1997)
Amerpura, Banswara	2451	NWDPRA	--do--	--do--
Bhandarej, Dausa	4150	NWDPRA	--do--	--do--
Napanie, Chittorgarh	3456	NWDPRA	--do--	--do--
Rode, Bikaner	1115	NWDPRA	--do--	--do--
Chhajawa, Baran	454		IISWC, RC, Kota	IISWC, RC, Kota
BadaKhera, Bundi	682	IWDP	IISWC, RC, Kota	IISWC, RC, Kota.
Dhoti, Baran	677	NWDPRA	IISWC, RC, Kota	IISWC, RC, Kota

Watersheds treated with suitable conservation measures show quite strong positive response on land and water resource (Table 3.77). The project implementation reduced runoff and soil loss to about 35% as recorded in Badakhera watershed. Similar impact was also observed in Chhajawa and Dhoti but these data were not available for other watersheds. Significant improvement in ground water levels and drinking water availability has also been recorded at Badakhera and Chhajawa and Dhoti Watersheds. Silt retention behind the check dams resulted in reclamation of gullied lands. Bunding and terracing also helped in reducing terrain roughness as measured by land improvement index (Singh *et. al.*, 2004). More data are required for impact assessment on quantitative and qualitative degradation of land and water resources. Severe biotic interference and lack of social fencing permitted limited success in improving the total green cover in the watersheds. Bio-diversity is an important ecological indicator but data from treated watersheds are lacking on this aspect. However, more number of birds is observed in the vicinity of farm pond in Badakhera watershed (Fig. 3.25), which shows that conservation of water resources helps in checking migration of birds in the watershed area. As a result of increased net sown area, cropping intensity, use of inputs there has been substantial increase in the total crop production from the treated watershed (Table 3.78) in the normal monsoon conditions. However, as observed in the Badakhera watershed, crop production sharply declined under severe drought situations. Livestock population and milk production also increase as the availability of fodder and water improves. The data on other livestock products are lacking, which in fact are major component of rural economy in several parts of Rajasthan.

Table 3.77: Ecological impact of watershed projects in Rajasthan

Parameter	Impact indicators	Watersheds implemented by the centre			Watersheds implemented by the State agencies	
		Badakhera	Chhajawa	Dhoti	Semi-arid region	Arid region
Hydrology	Surface runoff reduction	XXX	XXX	XXX	-	-
	Ground water recharge	XX	XX	XX	X	X
	Drinking water availability	XX	XX	X	-	-
	Water quality	-	-	–	-	-
Land	Soil loss reduction	XXX	XXX	XXX	-	-
	Land quality improvement	XX	XX	X	-	-
	Soil fertility	X	XX	X	-	-
Vegetation	Green cover	XX	XX	X	X	X
	Biodiversity	-	-	-	-	-

XXX- Strong positive impact, XX- Moderate impact, X- Low impact, -Information not available

Table 3.78: Impact of watershed projects- Agriculture and livestock

Parameter	Impact indicators	Watersheds implemented by the centre			Watersheds implemented by the State agencies.	
		Badakhera	Chhajawa	Dhoti	Semi-arid region	Arid region
Crop production	Net sown area	XXX	XXX	XX	X	X
	Cropping intensity	XX	XXX	X	X	X
	Crop diversification	XX	XX	X	-	-
	Use of inputs	XX	XXX	XX	X	XX
	Crop productivity	XXX	XXX	XX	X	XX
Livestock production	Milk production	X	XXX	X	X	X
	Livestock population	X	XX	X	-	X
	Meat production	-	-	–	-	-
	Poultry production	-	-	–	-	-
	Fisheries	-	-	–	-	-
	Wood and other products	-	-	—	-	-
Agro -forestry	Fruit and vegetables	X	X	X	-	-
	Fodder	0	XX	XX	0	0
	Fuel	XX	XX	X	0	0
	Timber	0	0	0	0	0

XXX-Strong positive impact,XX- Moderate impact, X- Low impact, 0-No impact

Unless active and well organized community participation is ensured in watershed projects post-project success and sustainable benefits cannot be secured. It is, therefore, important to assess project success on impact indicators for awareness generation, community organization, social equity and economic development. Unfortunately, these indicators are grossly ignored in the project evaluation studies conducted for watersheds implemented by State agencies (Table 3.79). Projects evaluated by the Centre show strong positive impact in terms of awareness generation, community organization and improving income levels. There is, however, need to improve and monitor conflict management skills, establishment and strengthening organizational support for improvement of common property resources and equity in benefit distribution.

Fig. 3.25: Farm pond providing shelter for several birds spp

Watershed developed by State agencies: Two micro-watersheds namely Dhoti-B and Kherli-A of Kota district developed with a cost of Rs. 20 lakh each under NWDPRA scheme by the State Soil Conservation Department were compared with adjoining non-project watershed. Bunding was the major activity besides pasture development (Kumar *et. al.* 2005). The survey of 60 farmers each from project and non-project watersheds indicated that the average productivity and employment generation increased by 26.10 and 47%, respectively in treated watershed as compared to untreated watershed. However, participation of females in soil and water conservation related activities on regular basis was completely absent in both the category of sample households (Table 3.80). The common property resources (CPRs) developed in watersheds had severely suffered due to biotic interference as no initiatives were taken by the panchayats in devising suitable usufruct share mechanism and providing social fencing to protect them.

Table 3.79: Socio-economic impact of watershed projects in Rajasthan

Parameter/variable	Impact indicators	Watersheds implemented by the Centre			Watersheds implemented by the state agencies	
		Badakhera	Chhajawa	Dhoti	Semi-arid region (5 WS)	Arid region (4 WS)
Awareness generation	Level of knowledge	XXX	XXX	XXX	-	-
	Organizational awakening	XXX	XXX	XXX	-	-
	Cooperation among villagers	XX	XXX	XX	-	-
	Migration reduction	X	XXX	X	X	-
Community organization	Peoples' articipation	XX	XX	X	-	-
	Transparency	XXX	XXX	XXX	-	-
	Performance of SHGs and UGs	XXX	-	X	-	-
	Level of conflicts	-	-	-	-	-
	Improvement in CPRs	X	XX	XX	-	O
Social equity	Gender parity	X	X	X	-	
	Economic equity	XX	-	–	-	-
	Equity in access to resources	-	-	XX	-	-
Economic indicators	Employment generation	X	XX	XX	-	X
	Education	XX	XX	–	-	-
	Health improvement	-	-	–	-	-
	Income level	XXX	XXX	XX	-	-
	B:C ratio	XXX	XXX	—	XX	XX

XXX- Strong positive impact, XX- Moderate impact, X- Low impact, O- No impact

Table 3.80: Impact of soil and water conservation programme on employment generation

Activity	(Mandays /household /annum)	
	Beneficiaries	Non-beneficiaries
A. Crop Production	202.56	156.30
B. Dairy Production	151.75	128.60
C. Soil Conservation I. Casual Employment (during implementation of project)	16.93	-----
II. Regular Employment a. Renovation of bunding/other structures (4.00) b. Horticultural plantation (36.21) c. Self-help group (sewing work) (7.60) Total (a+b+c = 47.81)	47.81	-----
Total	**419.05**	**284.9**

The net returns accrued from crop production and return per rupee of investment for the dairy enterprises were higher in treated watersheds. The investment on agriculture and agri-horti systems was found profitable at 10% discount rate assuming 10 years for agriculture and 25 years for horticultural plantation as project life. Agriculture sector with an overall B:C ratio of 1.56 and IRR 26.49% was found to be profitable after taking into account costs of treatment. Under agri-horti system, orange plantation was found more remunerative than guava due to higher sale price of orange, however, both the fruit species were found economically viable (Table 3.81).

Table 3.81: Economic viability of different agri-horti systems on beneficiary households

System	BCR @ 10 % discount rate	IRR	NPV (Rs/ha)@10 % discount rate
Guava+ fodder	1.29	18.57	59032.00
Orange+ barley	1.38	19.88	84713.60

3.2.5.2 Integrated Farming System

Study conducted during 2008-09 to 2016-17 on one farmer field in Dhoti watershed of Baran district to validate the MCDM tool (Multi-objective programming) for maximize income and farmers objectives of optimizing resource conservation and productivity.

The input-output data of existing cropping system along with the present resource availability and use, as reported by a selected farmer, were analyzed and utilized through this optimization tool to suggest the optimal farm (IFS) plan for him. The optimum plans for first and second phase generated through MCDM tool for execution in real field conditions to validate the model is presented in Table 3.82. The net returns from formulated optimal plans compared with the net returns from the actual executed plans in the field and presented in Table 3.83. Results revealed that returns realized during an experimental period were higher as compared to those estimated in formulated plans except for the years of 2009-10 and 2013-14.

The validation result of MCDM model concludes that this model can be used to generate optimal plans by optimizing resources to achieve multiple objectives such as income maximization and food security as envisaged by the selected farmer in the present case.

Table 3.82: Existing and generated optimal plans with expected values of objective functions

Particular	Area (ha) under phase 1 (2009-10 -*Kharif* 2014-15)		Area (ha)under phase 2 (2014-15 *Rabi* onwards)	
	Existing plan	Optimal plan	Existing plan	Optimal plan
IFS component - cropping system				
Soybean (*Kharif*-irrigated)	0.88	0.8	0.8	1.5
Soybean +Maize (*Kharif*-irrigated)	0.4	0.7	0.7	--
Moong (*Kharif*-irrigated)	0.32	0.1	0.1	0.1
Wheat var.lok1(*Rabi*-irrigated)	0.4	0.5	0.5	0.5
Wheat var.RJ3765(*Rabi*-irrigated)	0.4	0.6	0.6	0.54
Coriander(*Rabi*-irrigated)	0.8	0.5	0.5	0.56
IFS component - animal husbandry				
Buffalo (No.)	4	4	4	4
Cows (No.)	3	3	2	2
Objective function values				
Net Returns (Rs.)	106178	108505 (2%)	183205	194197 (6%)
Food Security (Thousand K cal)	25418	28773 (13%)	27022	27289 (1%)

Figures in parenthesis are percentage increase/decrease potential in optimal plan as compared to Farmer existing plan

Table 3.83: Actual changes in values of farmers' objective(s) after implementation of IFS plans for validation of Model

Year	Max-net returns (Rs.)	Max-energy ('000:Kcal)	Difference between optimal plan over existing farmer plan (%)	
			Max-net returns(Rs.)	Max-energy ('000:Kcal)
2009-10	100377	31148	-5(2)	23(13)
2010-11	120440	36829	11(2)	28(13)
2011-12	138031	39652	30(2)	56(13)
2012-13	144311	39994	33(2)	39(13)
2013-14	73263	26689	-31(2)	5(13)
2014-15	214350	35939	17(6)	33(1)
2015-16	199693	30805	9(6)	14(1)
2016-17	221678	31886	21(6)	18(1)

Figures in parentheses were the expected changes in values of farmer's objectives as per IFS plans generated and executed in comparison to the existing farmer plan

3.2.5.3 Common Property Resources Management

Study conducted in central plateau & hill region of Rajasthan state covering two districts namely Udaipur and Kota to examine type, status and present institutional arrangements of community based water storage structures (CBWS) and to assess their impact on rural households. The results revealed that out of 30 CBWS covered under study, only two (Sukher ka naka and Chalwa) were managed by water user association (WUA) and all others were looked after by Gram Panchyats. The catchment area of these ponds were ranged from 2 to 15 km^2 while actual and potential command area varies from 20 to 260 ha and 50 to 600 ha. The actual irrigated areas under these ponds decreased up to 2 meters, over the time, due to heavy siltation apart from damaged conveyance systems and distribution channels which creates the problem of higher water losses. The proportion of irrigated area to total irrigated area from CBWS for sample households was observed 48% in case of medium and 100% in marginal and small farmers in Udaipur while, it was 5.88 to 26%, respectively in Kota district. The net income generated from agriculture in Udaipur varied from Rs. 7802 to Rs. 49098 /ha/year whereas, share of CBWS in income ranged from 2.69 to 59% (Kumar *et. al.,* 2018). The highest income from agriculture in Kota district was observed as 36.36% in Borawas CBWS. The water productivity was calculated by ratio of crops and livestock net beneficial output to the amount of water used. The result indicates that average economic water productivity of crops in Udaipur was worked out as Rs. 7.34/M^3; which ranged between Rs. 4.45/ M^3 (Chalwa) to Rs. 10.67/M^3 (Tutamahuda) CBWS. But the economic water productivity was comparatively high in Kota district because of soybean- mustard cropping system which required less water and gave high returns. The values of economic water productivity in Kota district varies from Rs. 6.12/ M^3 to Rs. 24.66/M^3 with an overall average of Rs. 13.18/M^3. Pooled analysis show overall average economic water productivity of the central plateau & hill region as Rs. 9.94/M^3. Demand and supply gap of water in CBWS under study shows an average supply of water exceeded by 34 and 91% in Udaipur and Kota district, respectively, if they filled fully at least once in a year. The reason for excess supply was due to decreased command area in view of installation of private tube wells, poor conveyance and management systems especially in Kota district. Study also revealed that 94% of the sample household's perceived increased benefits in terms of income and employment generation from CBWS in last 20 years while. 63% of the sample households have the opinion in favor of increased duration of water availability in these structures especially during summer as compared to the situation 20 years back. However, 37% respondents reported decreased water availability in CBWS in view of changing rainfall pattern, encroachments in CBWS catchments and submerged area, siltation in ponds *etc.* which warranted sensitizing farming community for organizing water user groups and associations for better management, operation, maintenance and cost recovery of water besides removal of nutrient enriched silt from the tank bed in participatory mode to restore storage capacity of these structures.

3.2.5.4 Eco-Payment Services and Rural Livelihood in Chambal Ravine Region

To understand the interrelationships between ravine ecosystem services and farmers' livelihood in Chambal ravines and to devise suitable incentive mechanism for ravine ecosystem development and to have an economic assessment of these services a study was conducted during 2016-17 in sample ravine villages from four selected districts of Kota (Dheepri Chambal), Bundi (Roteda), Sawai Madhopur (Sewati Kalan) and Bhind (Ranipura). These were location where some development works were under taken by government agencies under ravine reclamation scheme. To have a valid comparison, one ravine village (Soonagar-Bundi, Dhansuri-Kota, Ankoda-Sawai Madhopur, and Dinnpura- Bhind) having degraded ravines with scrubs and obnoxious weeds also selected as control. Based on results covering 240 sample households from 8 ravine villages, it was found that. 83% sample farmers perceived ravines an important source of their livelihood. Majority (95% farmers) perceived increased availability of fuel wood but decreased availability of fodder (96% farmers). The reason was aerial seeding of *P. juliflora* by forest department in ravine areas which suppressed majority of the grasses. 59% of the sample households were not sure or against to be involved with imposing payment for eco-services (PES) or developmental schemes. However, 48% sample households have an opinion about voluntary involvement and involvement with compensation (52%) from authority. Farmers were willing to pay Rs. 372/ha/year and Rs. 350/ha/year if the ravines are managed by Gram Panchayat and the Government Department, respectively. The total biomass in managed and un-managed ravine was 54.2 t/ha and 38.4 t/ha, respectively. The soil carbon stock in managed and un-managed ravine was 9.9 t/ha and 7.4 t/ha, respectively. Thus, the total carbon stock in managed and un-managed ravine was 31.6 t/ha and 24.2 t/ha, respectively. Total carbon sequestration in managed and un-managed ravine was 115.9 t/ha and 86.0 t/ha, respectively (Kala *et. al.,* 2018). In Chambal ravines, the ecosystem benefits estimation revealed fuel wood benefits (Rs. 1576.4 million much higher than fodder benefits (Rs. 187.83) in view of infestation of *Prosopis juliflora* in Majority of the ravine areas. The indirect benefits of carbon sequestered and soil nutrient in the soil were estimated at worth Rs. 8577.4 million and Rs. 1649.6 million, respectively. However, there is tradeoff between direct and indirect benefits. In absence of proper ravine management, extraction of direct benefits would adversely affect indirect benefits. Chambal ravines are largely owned by State Government department (Government-60%, Private-31%, Panchayat -9%). So, the management issue in Chambal ravine region is largely legislative not on payment or incentive based.

3.2.6 Human Resource Development and Technology Transfer

3.2.6.1 Capacity Development Approaches and Information and Communication Technology (ICT)

3.2.6.1.1 Regular soil conservation training course

In order to have adequate number of trained man power to address the problems of soil erosion in the country the Centre has been conducting 5½ months regular training in soil conservation and watershed management for in-service graduate assistants and gazetted officers from various state governments and union territories since February, 1956. In all 1546 graduate Assistants in 78 batches and 89 gazetted officers in 6 batches have been trained up to 31st March, 2018. The state wise break-up is given in Table 3.84 and Table 3.85.

Table 3.84: Graduate assistants trained in regular course of 5½ months in 78 batches

State	Number of trainees with different professional backgrounds				
	Agriculture	Forestry	Engineering	Others	Total
Andhra Pradesh	5	0	0	0	**5**
Arunachal Pradesh	5	0	0	0	**5**
Assam	2	0	0	0	**2**
Bihar	115	0	0	0	**115**
Chandigarh	0	4	0	0	**4**
Chhattisgarh	29	0	0	0	**29**
New Delhi	21	1	1	1	**24**
Goa	0	1	0	0	**1**
Gujarat	71	3	1	0	**75**
Haryana	47	10	0	0	**57**
Himachal Pradesh	22	1	1	1	**25**
J&K	108	0	0	0	**108**
Karnataka	24	0	0	0	**24**
Kerala	1	0	0	0	**1**
Maharashtra	30	0	0	0	**30**
Meghalaya	7	0	0	0	**7**
Mizoram	7	0	0	0	**7**
Madhya Pradesh	616	26	4	0	**646**
Odisha	4	4	0	1	**9**
Punjab	103	6	0	2	**111**
Rajasthan	124	12	0	4	**140**
Tamil Nadu	0	2	3	0	**5**
Tripura	1	0	0	0	**1**
Uttar Pradesh	112	0	1	0	**113**
Uttarakhand	1	0	0	0	**1**
West Bengal	1	0	0	0	**1**
Grand Total	**1456**	**70**	**11**	**9**	**1546**

Table 3.85: Gazetted officers trained in regular course of 5 ½ months in VII batches

State	Number of trainees with different professional backgrounds				
	Agriculture	Forestry	Engineering	Others	Total
Bihar	25	1	4	0	**30**
ICAR	1	0	0	1	**2**
J&K	35	1	0	0	**36**
Meghalaya	2	0	0	0	**2**
Maharashtra	1	0	0	0	**1**
Madhya Pradesh	16	0	0	0	**16**
Punjab	0	0	1	0	**1**
Tamil Nadu	0	0	1	0	**1**
Grand Total	**80**	**2**	**6**	**1**	**89**

3.2.6.1.2 Short courses on watershed management

Need based specially tailored short courses on various aspects of watershed management for the various levels of functionaries were successfully conducted. In 190 short courses (Table 3.86 and Table 3.87) conducted so far, 5617 officers, field functionaries, farmers and students deputed for summer training have been trained at the Centre.

Table 3.86: Number of short courses conducted for different stakeholders (up to March 2018)

Stakeholder	Courses duration (days)			
	<5	6-10	11-21	>21
Farmers & Field functionaries	141*	08	-	-
B.Tech (Ag. Engg) students	-	-	-	17
Middle level officers	1	-	23	-

*included three study tours of three days duration each

Table 3.87: Number of courses conducted on different topics (up to March 2018)

Major topic	Course duration (days)				Total No. of participants
	<5	6-10	11-21	>21	
Watershed Management and Soil & Water Conservation	142	08	-	-	5268
Soil & Water Conservation and Watershed Management	-	-	-	17	178
Watershed Management and Ravine Reclamation	-	-	23	-	171

3.2.6.1.3 Assessment of training need and impact of capacity building

To provide timely feedback to administrators, policy makers and trainers, training activities for number of stake holders *viz.*, Government officers, graduate assistants, farmers, personnel from NGOs, *etc.* on soil and water conservation in general and watershed management in particular having different durations and organized at Indian Institute of Soil and Water Conservation, Dehradun and its regional stations were evaluated to assess training needs and training impact in implementation of soil and water conservation works in field conditions by selecting trainees who have imparted training at IISWC, Dehradun and its regional station Kota. Using three to five point rating scale it was reveals that structural measures for S&WC in non-arable lands (2.57), application of RS and GIS and Map reading, delineation and characterization of watershed (2.38), water harvesting, storage and recycling for irrigation planning (2.33),knowledge about data source (2.29), aquaculture in farm ponds under watershed management (2.29), economic evaluation (2.27) and design, costing & execution of mechanical measures (2.26) were the top ranked areas of training needs under present situation to implement the watershed programmes satisfactorily. The study also identified administrative, technological, social and financial constraints faced by the trainee respondents in implementation of soil and water conservation works. Among identified administrative constraints "inadequate opportunities for the trained manpower" (3.38) followed by "lack of requisite facilities" (3.32) as the most serious administrative constraint. "Non-availability of suitable literature on SWC technologies" (2.76) and "the low applicability of technical knowledge gained in field conditions" (2.46) were main technological constraints. Study also identified that "legal issues related to group action benefit sharing and maintenance mechanism after withdrawal of the project" (3.07) and "negative mind set of the people about programme implementing agencies" (3.03) were most prominent social constraints. This may be due to low educational level and lack of awareness about benefit of the programme. Late release of funds and lack of credit facilities for the adoption of soil and water conservation technologies were financial constraint perceived by the trainees. Impact of training on watershed implementation as perceived by the trainees' revealed improvement in quality of work followed by use of latest know-how and technologies besides enhanced production in watersheds.

3.2.6.1.4 Effectiveness of communication methods

To test the efficacy of various communication media in dissemination and adoption of soil conservation technologies, a study was conducted in Chhajawa watershed of Baran district in South-Eastern Rajasthan by Singh (1999). The methods (media) used for communicating soil conservation technologies were categorized into three broad heads as personal localite (PL), impersonal cosmopolite (IC) and the personal cosmopolite (PC). The technologies considered in study were leveling, bunding, nala-bunding, contour cultivation and intercropping. The findings clearly indicate that personal contact of farmers with scientists and technical personnel was the best source to disseminate the appropriate technology under PL, whereas demonstrations were the most effective communication channel in PC followed by meetings and group discussions. Socio economic status of farmers had no significant influence on the effectiveness of communication channel.

3.2.6.2 Participatory Technology Dissemination and Adoption

With rapid development of new technologies and information explosion in different disciplines, technology transfer to target groups and human resource development for facilitating adoption of the recommended technology is an important part for any research system. Therefore, a number of studies have been conducted to identify various socio-economic issues that can help in devising and developing user-friendly technologies. Dissemination of conservation technologies through regular training programmes, short courses, lab-to-land programme, crop demonstrations, farmers fare and through radio and press media has been an integral part of the Centre's activities.

3.2.6.2.1 Adoption of soil and water conservation technologies

In view of importance of adoption rate of technologies for enhancing the productivity in agriculture besides conserving resources, a study was conducted in Dhoti and Kherli watersheds in Kota district of South-Eastern Rajasthan developed by the State Soil Conservation and Watershed Development to identify the extent of adoption of different technologies implemented and the constraints in adoption (Singh *et. al.*, 2006). It was found that bunding (62.5%) was most popular and adopted by the farmers followed by loose boulder (15.8%) and masonry check dams (15.8%). The higher rate of adoption for bunding was due to the fact that it is simple to understand and less expensive. Besides traditional knowledge about its benefits is high. Some of the farmers also adopted agri-horti system to diversify their subsistence farming for enhancing income on regular basis. Poor economic condition was the major constraint followed by lack of knowledge about probable benefits.

Another study conducted by Kumar *et. al.*, 2019 in five watersheds of South -Eastern Rajasthan found 79% of the SWC technologies were continued by the beneficiary farmers in selected watersheds even after 10-20 years of projects withdrawal in the region and only 21% SWC technologies discontinued because of changes in cropping pattern, unable in improving yield and moisture conservation due to poor design and specifications beside non availability of funds with farmers to maintain.

The study also highlighted that 9% of SWC technologies were adopted with technological gap but 42% farmers diffused the technology in nearby areas for the conservation of natural resources. The study also determine factors influencing adoption of SWC technologies which vary from watershed to watershed and this makes generalization nearly impossible. Therefore, it was suggested that any intervention for SWC and sustainable land use ought to begin with an empirical and local specific understanding of the multiple factors influencing adoption of technology decision of farmers.

3.2.6.2.2 Constraints in adoption of soil conservation technologies

Various constraints responsible for non-adoption of soil conservation technologies were studied different land uses in six villages of Kota district of Rajasthan having irrigated, rain fed and ravine conditions (Singh and Kumar, 2001).The majority of the farmers (60%) of irrigated area were of the opinion that watershed works were not very useful while resource poor farmers of rainfed area (76%) indicated high cost of technologies the major constraint. In their opinion it was the government's job to take up these costly measures. In ravine farm situation, the constraints faced by the farmers were almost similar (Table 3.88).

Constraints in technology adoption: Study conducted to examine the post adoption behavior of beneficiary's farmers in five watersheds of South-eastern Rajasthan by Kumar *et. al.*, 2019 revealed technological gaps in soil and water conservation (SWC) technologies adopted by the farmers restricting realization of full benefits of the technology. The reasons of technological gap in extended technologies perceived by the farmers were recorded and presented in Table 3.89. Lack of technical competence at the farmers' level to maintain structures, lack of knowledge, unavailability of farm implements, labour intensive technologies and non-availability of funds with farmers for subsequent maintenance were the main inhibitions as expressed by farmers.

Table 3.88: Constraints in adoption of soil conservation technology

Constraint	Irrigated Farm (N=50)		Rainfed farms (N=50)		Ravine farms (N=50)	
	No. of response	%	No. of response	%	No. of response	%
Lack of knowledge about recent technological know-how	13	26	28	56	26	52
Very expensive and labor intensive	12	24	38	76	44	88
It is a highly technical job	16	32	32	64	38	76
Fragmentation of land into unconventional shape and size	10	20	16	32	15	30
Land wastage in bunds and channel	30	60	18	36	22	44
Long gestation period in accrual of benefits	22	44	32	64	34	68
Problem in maintenance due to labour intensive	17	34	30	60	40	80
Danger to land if structure is not properly maintained	10	20	18	36	22	44

Lack of conviction about its utility	20	40	22	44	25	50
Common belief that it is a job of the Government	18	36	38	76	42	84
Restrictions of proper implementation of the practice on the farmers field	10	20	20	40	32	64
People forget hazards and damages after some time and do not pay attention afterwards	20	40	25	50	26	52
Poor resources	10	20	35	70	36	72
Inadequate linkages between the farmers and the organizations	9	18	28	56	31	62

N=nos. of sample farmers

Table 3.89: Farmers' responses on reason for technological gap in extended technologies

Technology	Reason	As perceived by the farmers (%)				
		Chhajawa	Badakhera	Haripura	Hanotiya	Semligokul
Bunding	Labour intensive	24	18	40	27	22
	Lack of technical expertise)	40	42	24	6	8
	Money crisis	36	24	56	3	16
Levelling	Lack of Money	22	40	28	20	46
	Lack of farm implements	30	20	16	18	60
	No government help	50	36	28	12	44
West weir	Lack of technical expertise	56	62	42	60	28
	Lack of knowledge	46	44	22	20	48
	Lack of fund to maintain	4	12	52	20	6
Anicut	Lack of technical expertise	26	46	64	18	28
	Lack of fund to maintain	50	36	78	68	24
Loose boulder check dams	Technical expertise	54	26	64	52	20
	Lack of knowledge about Scientific specifications	28	8	16	32	48
Plantation	Lack of knowledge	4	--	4	---	10
	Labour intensive	58	48	72	16	4
	Availability of inputs	34	48	64	36	54
	*multiple responses					

Gender Role: An attempt was made by IISWC, Research Centre, Kota to identify the socio –economic status of the farm women and their role in facilitating adoption of watershed management and recommended soil conservation technologies in two watersheds namely Kurad II and Roshalliya of South-Eastern Rajasthan. For comparison, samples of same size were also drawn from two untreated watersheds (Khajoori and Kamolar). It was found that there was no significant difference in socio-economic status of farm women in treated and untreated watersheds and the majority belonged to medium socio-economic status. The knowledge of women for agronomical measures was highest in all watersheds as they had active participation followed by animal husbandry. The participation of women was very low in horticulture, forestry and grassland development activities in the untreated watersheds. In the treated watersheds women participated more in horticulture development (38%), than forestry (18%) and grassland development activities (12%). In the development of soil and water conservation structures the overall participation of women was higher (43%) in treated watershed than in untreated watershed (27%).

3.2.6.3 Impact Assessment of Disseminated Technology

The process of technology dissemination began shortly after the establishment of the Centre. In 1959, Borkhandi Soil Conservation Project was taken up in 146 ha near Kota, in which soil and water conservation measures were applied as per need of the area after conducting detailed soil survey and land capability classification. Subsequently the process continued with different programmes such as National Demonstrations (1969 onwards), Lab to Land Programme (1979-onwards), Operational Research Project, Chhajawa (1985-90), Integrated Waste Land Development Project, Bada Khera (1997-2003) and NWDPRA- (MMA) Project, Dhoti of district Baran (2008-09 to 2013-14). Concurrent and post project impact assessment studies of these projects had been taken up and results were discussed in previous section of this publication. With successful demonstration of soil and water conservation technologies on watershed basis by IISWC, Dehradun and its Centers leads this approach to grow to the extent that presently, it has emerged as single flagship programme for rural poor in the region. Various soil and water conservation works integrated with other developmental activities are now extensively being taken up by various Government and Non-Government Organizations.

3.2.6.3.1 Lab to land programme

The Indian Council of Agricultural Research launched the Lab to Land Programme (LLP) in 1979 to disseminate viable and economical technologies for increasing and stabilizing agricultural production and improving socio-economic status of the agrarian community. The aim of the programme was to take the proven technologies to the door steps of the farmers with active involvement and participation of the scientists working in the institutions. The programme was taken up in three phases spread over seven villages covering 50 farm families. The families in phase III and their fields were different from families adopted in Phase I and II. Following aspects were given major emphasis in the technology transferred to the adopted families:

- Proper land use following the principles of soil conservation.
- Reclamation of marginal lands and shallow gullies for agriculture.
- Adoption of improved cropping technology and efficient water management.
- Farm forestry and orchard plantation.

During phase I and II, average increase in crop yields was 275, 106 and 54% for sorghum, wheat and gram as compared to past yields (Verma, 1986). Farmers in their usual practice were using local varieties in most of the areas and the fertilizer use was extremely limited. Highly increased yields in this programme proved that use of improved varieties and judicious quantities of fertilizers could pay back many times the additional cost (Table 3.90). The figures indicate considerable increase in crop yields. Intercropping systems sorghum + pigeonpea, sorghum + green gram and maize + green gram were introduced in the demonstrations. These systems proved very successful and deserved to be further encouraged. The crop yields under phase III are presented in Table 3.91.

Table 3.90: Grain yield of crops in programme phase I and II

Crop and variety	Yield under lab to land demonstrations (kg/ha)						Past average yield (kg/ha)	Increase in yield (%)
	1979-80	1980-81	1981-82	1982-83	1983-84	Average		
Sorghum (*CSH-5*)	2850	2960	2088	2400	2770	2814	750*	275.2
Maize (*Ganga-5*)	-	2020	1900	2600	-	2173	-	-
Green gram (*Pusa Baisakhi*)	-	-	700	-	-	700	-	-
Black gram (*T-9*)	-	916	1050	1100	-	1022	-	-
Sesame (*Pratap*)	-	-	-	-	330	330	240	37.5
Soybean (*T-1*)	-	-	-	-	800	800	-	-

Sorghum + pigeonpea (*CSH-5*) (Local)	1600 (360)	2020 (220)	-	-	-	1810 (290)	-	-
Sorghum + greengram (*CSH-5*) (*Pusabaishaki*)	-	-	-	-	2755 (135)	2755 (135)	-	-
Maize + green gram (*ganga-5) (Pusabaishaki)*	-	-	-	-	2100 (278)	2100 (278)	-	-
Irrigated wheat (*K.Sona*)	2890	2540	2820	2380	2780	2682	1300	106.3
Irrigated gram (*C-235*)	1850	2050	1200	1650	1740	1698	1100*	54.4
Rainfed wheat (*A-9-30-1*)	1060	1040	900	-	-	1000	650*	53.8
Rainfed gram (*RS-10*)	450	750	600	920	-	680	400*	70.0

*Local varieties were used figures in parenthesis are yields of subsidiary crops.

Table 3.91: Grain yield of crops (kg/ha) in phased III

Crops and variety	Yield under lab-to-land demonstrations			Past average yield	Increase in yield (%)
	1984-85	1985-86	Average		
Sorghum (*CSH-5*)	2200	3560	2780	1100	152.8
Maize (*Ganga-5*)	1800	-	1800	950	89.4
Irrgigated wheat (*K.Sona*)	2954	3370	3167	1300	143.6
Irrigated gram (*C-235*)	1025	1210	1118	700	59.7

3.2.6.3.2 Farmers participatory action research programme (FPARP)

Farmer Participatory action research programme sponsored by Ministry of Water Resources, Govt. of India with a slogan of "more crop and income per drop of water" was implemented in eight villages of Kota and Baran districts of South-Eastern Rajasthan during 2008-09 to 2010-11. Technology considered for evaluation on 10 farmers' fields were namely contour furrow (CF), Contour Bench terrace (CBT), intercropping andagri-horticulture.

The data presented in Table 3.92 revealed that improved technology could increase the water use efficiency (WUE) over conventional farmer practices ranged from1.19 to1.97 kg/ha.The increase in crop in response to adoption of improved technology ranged from 29 to 55% over farmers practice (control) while net returns were highest (183%) in intercropping of soybean + maize followed by soybean-mustard (166%) cropping system under CBT technology. The negative net returns under agri-horti system were due to additional cost of Guava plantation which could not be compensated by soybean yield enhancement.

The income from the plantation was expected only after five years.

3.2.6.4 Field Evaluation of Technologies under Transfer of Technology Programme

Contour furrow technology recommended for deep black soils with 1-3% land slopes by the Centre based on experiment conducted during 2004-08 was transferred to farmers field (during 2012-16) under transfer of technology programme for evaluation in 30 villages of Baran, Bundi and Kota districts of South-Eastern Rajasthan.

Contour furrow is a low cost alternative to bunding and shall be preferred where sorghum, soybean or maize is cultivated. Year wise results of soybean crop with and without contour furrow technology during *Kharif* season at farmers' fields are summarized in Table 3.93. It was observed that imposition of contour furrow technology in Soybean crop increases yield from 17 to 57% over the years (Kumar *et. al.*, 2018).

Table 3.92: Impact of technologies on water use efficiency, yield and net returns under FPARP

Technology	Crop	WUE(kg /ha-mm)			Grain yield (kg/ha)			Net returns(Rs./ha)		
		FP	Improved Technology	% increase	FP	Improved Technology	% increase	FP	Improved Technology	% increase
Contour Furrow (CF)	Soybean	0.797	1.194	50	650 (845)	957 (1219)	50 (44)	11551	17306	50
CBT**	Soybean-mustard	1.051	1.630	58	750 (450)	1086* (501)	55 (11)	2755	7327	166
Inter-cropping	Soybean+maize	1.167	1.499	28.5	850 (1105)	1099* (1140)	29 (3.1)	1705	4821	183
Agri-horticulture	Soybean + guava	1.508	1.947	31	1200 (1450)	1575 (1725)	31 (19)	8780	-41	-99

**CBT= Contour Bench Terraces *Soybean grain equivalent, FP =Farmer Practice Figures in parenthesis indicates yield of by product

Table 3.93: Impact of Contour Furrow (CF) on soybean yield on farmers' fields

Year	District	No. of villages	No. of farmers	Mean yield (kg/ha)		% increase with CF
				Without CF	With CF	
2012	Kota	2	3	1719	2187	27.22
	Baran	3	3	1725	2023	17.28
2013	Kota	4	5	1412	1718	21.67
	Baran	4	5	812	1275	56.96
2014	Bundi	3	4	960	1273	32.60
2015	Bundi	4	5	822	1121	36.50
2016	Bundi	5	10	1593	2046	28.43
	Baran	5	10	1702	2187	28.47

3.3 Technologies Developed/Refined and Adopted by Other R&D Organizations

Among several recommendations emerging from Agricultural Universities and ICAR institutions located in the Chambal ravine region, some selected soil and water conservation technologies are listed here which have relevance with the current challenges for sustainable management of land and water resources in the region.

3.3.1 Technologies from Dryland Farming Research Station, Arjia (Bhilwara)

As a constituent of MPUAT, the Dryland Farming Research Station located at Arjia (Bhilwara, Rajasthan) has been working under All India Coordinated Research Project for Dryland Agriculture (AICRPDA) with network of 27 centers located in arid, semi-arid, sub-humid, humid and per-humid climates represent diverse bio-physical and socio-economic settings of the rainfed production systems (rice, maize, sorghum, pearl millet, finger millet, cotton, groundnut and soybean) of the country. The project has the mandate to generate location specific technologies through on-station research in thematic areas of rainwater management, cropping systems, nutrient management, energy management, evaluation of improved varieties of rainfed crops, and alternate land use/integrated farming systems. This research station has contributed following recommendations:

3.3.1.1 Efficient Management of Harvested Rainwater

Small water harvesting structures known as '*Nadi*' are common in South-Eastern Rajasthan. Traditionally, farmers practice mixed cropping of wheat, barley and chickpea in submerged area with receding moisture condition after releasing the harvested water of *Nadi* for pre-sowing irrigation to *rabi* crops or life saving irrigation of *kharif* crops in the downstream area. Recycling of harvested water from the *Nadi* ensured double cropping in this predominant maize based production system by taking chickpea in the *rabi* season that enhanced the overall water and land productivity.

3.3.1.2 Chiseling for Promoting *In-situ* Moisture Conservation

In the region, the primary tillage in black soils is done by cultivator or MB plough or disc plough for creating a rough soil surface. However, disturbing the land at a particular depth results in formation of hard plough pan which eventually restricts infiltration rates and rain water, receptivity. Chisel plough helps to break the plough pan, ridging (30 DAS) with country plough after sowing and peripheral bunding or compartmental bunding help in improving the infiltration opportunity time for *in-situ* rainwater conser-vation. Chisel plough improves around 50% of infiltration of runoff water and improves the soil quality as well. The chiseling is effective in breaking of the plough pan and peripheral bunding further increases the *in-situ* rainwater conser-vation. This technology gives an increase in maize grain yield by 20% B: C ratio of 3.68 as compared to the farmers' of no *in-situ* moisture conservation measures (2297 kg/ha; B: C ratio 3.41). The *in-situ* moisture conservation practices are effective in mitigating the initial and intermittent dry spells during crop growth period. Now, the technology is being adopted in 22% maize cultivated area with the availability of chisel plough.

3.3.1.3 Improved Varieties of Rainfed Crops

Farmers generally grow traditional cultivars of crops, which are low yielding, late maturing, susceptible to drought, insect and pests. These cultivars generally face terminal/late season drought at maturity and grain filling stages resulting in crop failure or low yields. This is a common feature of rainfed areas of Rajasthan, where drought occurs frequently. Improved cultivars of major crops have been evaluated at the research station and those, with distinct superiority over traditional ones have been recommended for the region. These varieties are of short duration and less susceptible to drought. Some of the improved varieties of different crops namely maize (Navjot, PEHM 2, PM-3), groundnut (TAG-24), sesame (RT-46), black gram (RBU-38), green gram (RMG-62), horse gram (AK-21) have excelled in performance over their traditional cultivars. Farmers observed 42 % higher economic benefit in maize (Navjot), 78% in groundnut (TAG-24), 28% in green gram (RMG-62), 56% in black gram (RBU-38), 71% in sesame, 60% in horse gram (AK-42*)* and 34% in chickpea (ICCV-10). Due to higher productivity, the adoption of these varieties went up to 55% in maize, 64% in groundnut, 30% in green gram, 40% in black gram, 55% in sesame, 10% in horse gram and 37% in chickpea. Timely availability of good quality seed of these varieties may increase the seed replacement ratio in the region further and help in upscaling to adjoining areas.

3.3.1.4 Profitable Intercropping Systems

Farmers grow mixture of two or more crops as insurance against drought and to meet their food requirement. Mixed seeding of maize with black gram and green gram is most common in this region. In groundnut, farmers broadcast sesame seed followed by planking. The proportion of crops is arbitrarily decided by farmers, which results in low productivity. Farmers also constrained to take up intercultural and weed control operations. Intercropping of maize (Navjot/PEHM-2/PM-3) +black gram (T-9) (2:2) and groundnut (JL-24/ TAG-24) +sesame (RT-46*)* (6:2) are recommended for the region in place of farmers' practice of mixed cropping. Intercropping of maize+black gram (2:2) gives yield advantage between 54 to 142% and groundnut + sesame (6:2) gives yield advantage of 17 to 34% over farmers' practice of mixed cropping of maize with short duration pulses.

3.3.1.5 Nutrient Management

Foliar spray of soluble NPK (18:18:18) @ 2% at flower initiation and pod filling stages of black gram produced higher seed yield (1407 kg/ha) compared to water spray (1089 kg/ha), with higher net returns (Rs.74277/ha) and RWUE (1.60 kg/ha-mm). In an another study at the Newariya Village, Chittorgarh district, Rajasthan, two sprays of KNO_3 (25 and 40 DAS) @ 1% along with RDF (50:30 kg NP/ha) gave the highest maize grain and stover yield (2283 and 3767 kg/ha), net returns (Rs.30900/ha), B: C ratio (3.17) and RWUE (3.60 kg/ha-mm) followed by RDF + water spray (2023 and 3433 kg/ha) as compared to RDF + no spray (1950 and 3250 kg/ha). Application of RDF (50 kg N + 30 kg P_2O_5 / ha) + 25 kg $ZnSO_4$ /ha gave the highest maize grain yield of 2350 kg/ha, net returns of Rs.31333/ha, B: C ratio of 3.23 and RWUE 3.70 kg/ha-mm as compared to farmers' practice of RDF alone (1917 kg/ha). In an another study, spray of $ZnSO_4$ @ 0.5% + NPK (soluble) @ 2% before tasseling and at grain filling stage, gave significantly higher maize grain yield (2510 kg/ha), net returns (Rs.30507/ha) and B: C ratio (2.85) compared to other treatments.

3.3.2 Conservation Technologies for Arable Lands Recommended by CTE, Udaipur

3.3.2.1 PuertorecanTerraces for Arable Lands

It is very common practices in the area that farmers used to cultivate such sloping lands which is having slope more than 6% and where contour bunding is not suitable. To check soil erosion and for better moisture conservation the College of Technology and Engineering (CTE), Maharana Pratap University of Agriculture & Technology (MPUAT), Udaipur has recommended Puerto ricanterraces which are formed using dry stone barriers placed along the contours with cross section of 0.60 m x 0.45 m (Singh *et. al.*, 1992 a & b). It is very popular and cost effective soil and water conservation measures in Southern Rajasthan as stones are easily and locally available in the area. These are time tested and very stable terraces.

3.3.3 Technologies Developed by Central Arid Zone Research Institute, Jodhpur

The Central Arid Zone Research Institute (CAZRI) is a major research establishment in western arid zone of Rajasthan. It is also one of the first institutes in the world exclusively devoted to arid zone research and development. Over a period of about 65 years of its establishment, CAZRI has developed series of packages for reversing the land degradation due to wind erosion and sustainable management of severely stressed arid zone ecosystem.

3.3.3.1 Rehabilitation of Shifting Sand Dunes

Rajasthan is the state witnessing the advanced stage of wind erosion. Sand dunes and their movement is a problem which seriously affects the production of agricultural lands, roadways, railway tracks, water courses and other economic establishments in many parts of arid western Rajasthan. About 68% area of Western Rajasthan is affected by this problem. Technological packages for rehabilitation of shifting sand dues are developed and field-tested by CAZRI (Bhimaya and Ganguli, 1961; Kaul, 1968) are grouped into three major steps.

(i) Protection from biotic interferences.

(ii) Erection or development of physical barriers to minimize surface sand drift.

(iii) Re-vegetation or afforestation of the treated dunes.

Protection from biotic interferences: Most parts of arid lands especially in Indian sub-continent suffer from acute biotic stress as a result of ever increasing human and livestock populations and associated demands. Therefore, it is very essential to fence the area to be stabilized by angle iron posts with three linings of barbed wires. In sandy tract ditch fencing is not feasible because of high wind velocity and with very high degree of sand movement, the ditches are often filled with eroded soil. Barbed wire fencing in Beechwal area of Bikaner for 25 years checked the biotic activity resulting in the development of a permanent cover of grasses like *Lasiurus sindicus, Cenchrus ciliaris, Panicum turgidum, Cenchrus biflorus*etc. These grasses by their extensive root system fixed the sand and checked its movement besides being a perennial source of fodder.

Sand dune fixation by establishment of artificial barriers: Sand dune fixation is essential to check the movement of sand and protect the young planted seedlings from abrasive action of the moving sand. It can be achieved by constructing checker boards or parallel hedge system depending upon the direction of the wind. Locally available materials like *Leptadenia pyrotechnica, Zizyphus nummularia, Calligonum polygonoides, Lasiurus sindicus, Panicum turgidum* and *Erianthus munja* are used for this purpose by burying them vertically downwards across the wind direction in rows 2-3 m apart particularly at the crest of the dunes. It should be 5-10 m towards the base.

Afforestation of sand dunes: After fixation, sand dunes can be permanently stabilized with vegetation. It can be done by direct seedling, transplanting seedling or cuttings of indigenous or exotic but adopted species. The seedlings are planted in pits of 50 cm^3 at 3m x 3m or 5 m x 5m distance in between the rows could be used for planting grass slips or sowing grass seed. The success of sand dune stabilization depends upon choosing the right type of species, planting healthy seedlings, timely and deep planting, timely replacement of casualties and proper care of plantation. Kaul (1985) reported that *Prosopis juliflora (Syn. P. juliflora), Zizyphus* tree species, *Calligonum polydonoides, Crotalaria burhia, Aerva javanica, Zyzyphus nummularia* (shrub), and *Lasiurus sindicus, Panicum turgidum. Panicum antidotale* grasses are most suitable plant species for sand dune stabilization in the arid zone of Western Rajasthan. *Calligonum polygonoides* with extensive root system was found to be excellent and binder. Though *Prosopis cineraria* is a very deep rooted and hardy tree, it grows slowly and provides complete cover after a long time. Fast growing *Khejri* is developed by CAZRI could be used for this purpose. Tree and grass species suitable for different rainfall conditions are presented in Table 3.94.

Table 3.94: Suitable tree and grass species for sand dune afforestation

Rainfall zone (mm)	Tree species	Grass species
150	*Acacia tortilis, Prosopis juliflora, Acacia nubica, Calligonum polygonoides*	*Lasiurus indicus*
150-250	*A. tortilis, P. juliflora, Calligonum polygonoides, Acacia senegal, Prosopis cineraria, Acacia bivenosa*	*Cenchrus ciliaris, Cenchrus setigerus*
250	*A. torotilois, P. juliflora, C. polygonoides, A. senegal, P. cineraria, C. mopane, A. bivenosa, C. nutan.*	*Cenchrus ciliaris, Cenchrus setigerus*

Source: Gupta (1990)

Planting techniques: About 6-8 months old plants raised in polytheylene bags in the nursery are used for planting. For successful establishment these are planted with onset of monsoon at 30-50 cm depth by removing polythene bag but without disturbing the block of soil and exposing the root. If water is available a shallow watering is provided for the establishment of roots. Costin *et. al.* (1974) reported better results by deep planting (upto 1.5 m) of long cuttings of *Tamarix aphylla* with a diameter not less than 1.5-2.6 cm. Shallow planting (50-70 cm) in depressions, deep planting (80-120 cm) on slopes and further deep planting (150 cm) on the top of the dunes was generally found economical by them. Planting in pits or bored holes was found better than planting by digging with a spade as in the latter case there was more loss of moisture. Gupta and Muthana (1985), however, reported higher survivability and better growth and establishment of seedlings of *Acacia tortilis* planted in the sandy plains. The previously made pits were used by placing pond sediments as subsurface moisture barrier at 60 cm depth in 5 mm thickness and refilled by mixing manure at the rate of 5 kg/pit. The higher seedling survivability and better growth and establishment is attributed to reduction in percolation loss and more availability of water to the young seedlings. In the absence of adequate rainfall, post planting irrigations help in the establishment of seedlings. Ten liters of water per seedling per irrigation has generally been found adequate for the first two years. Spreading a thin layer of sand around the seedling after each irrigation helps in conserving moisture by reducing evaporation loss.

Economics of sand dune afforestation: Sand dune fixation by checkerboard method is labour intensive and is not economical in the countries where manpower is expensive. In such countries use of chemicals has been found quite economical. In India, however, checkerboard technique was found quite effective and economical. Afforestation of sand dunes with *Prosopis juliflora* could yield fuel wood of about 38 t/ha after 10 years taking average yield of 95 kg per tree with a tree spacing of 5m (Bhimaya *et. al.*, 1967). *Calligonum polygonoides* plantation at a spacing of 3m^2 was found to yield about 21 t/ha (an average of about 19 kg/plant) after six year (Kaul, 1985). The plantation of *Acacia tortilis* at 5m spacing has been reported to yield fuel wood of about 30 t/ha after a period of 10 years. The cost of sand dune afforestation including fencing has been reported to be about Rs. 1000/ha (Kaul, 1985). However with the increase in inflation it could be even twice this amount.

Aerial seeding of sand dunes: Though the success rate is much higher in case of seedling transplant technique, yet it is not possible to cover large areas in short period of time due to many cost inhibitive factors. Improved techniques of direct seedlings seem to be the only answer for large scale sand dune stabilization. One such technique is aerial seeding of a mixture of pelletized (clay+ sand+cow dung in 1:3:1 proportion) seeds of *Acacia tortilis, C. mopane, D. nutans, Prosopis juliflora, Z. rotundifolia, Citrullus colocyathis* and *Lasiurus sindicus* at the rate of 14 kg/ha with onset of monsoon. The technique was found viable. However, in case of some failures repeated sowing may be necessary. After stabilization, the sand dunes should not be allowed for grazing. The biotic activity should not be permitted for 10-15 years. After 10th year the trees could be lopped for either fodder or fuel wood or both depending upon the species.

3.3.3.2 Moisture Conservation Techniques

Rainfall in the arid region is low and scanty. The annual average rainfall varies from 150 to 400 mm and its annual coefficient of variation being 37 to >50% (Rao and Singh, 1998). The annual estimated potential evapo-transpiration values range from 1600 mm in eastern part to >1800 mm in western part. The soils of the region are generally coarse textured with sand content varying from 90% in dunes to 60% in comparatively heavy soils and are deficient in organic matter as well (Joshi, 1993). The availability of surface water is very limited. Underground water is very deep, limited and mostly brackish in nature. Under such situations, the only option available is to harness the precipitation to its fullest.

3.3.3.1.1 Increasing water storage in the soil

A significant cause of low production and crop failure in rainfed agriculture is lack of water in the soil. Soil moisture management is, therefore, a key factor when trying to enhance agricultural production. Technological interventions of CAZRI for increasing the amount of water stored in the soil are as follow:

3.3.3.1.2 Bunding and vegetative barriers

Bunding has been the age old practice to reduce runoff and improve moisture storage in the soil. At Pali, bunding prevented runoff, increased infiltration and improved the availability of moisture to *Rabi* crops *i.e.,* mustard, *taramira* and chickpea by 11.4 mm in a soil core of 100 cm (CAZRI, 1998; Regar *et. al.,* 2007). Contour bunding is extensively recommended for controlling soil erosion and moisture conservation in arable areas on slopes ranging from 1 to 6%. In an early study, Kanitkar (1944) proposed bunds of 0.30-0.60 m height to be sufficient for sandy soils. The bunds must be placed in series from ridge to bottom of a valley to form terraced slopes. It was observed that 25 mm of rain water can store upto 13-15 cm soil depth for future use of growing crops. Wasi Ulah *et. al.* (1972) conducted an exhaustive study on the performance of contour furrows and contour bunds and observed that contour furrows alone stored more soil moisture (39%) than the contour bunds alone (27%) and the combination of contour bunds and furrows (26-32%). Singh (1984) recommended contour bunding of 75 cm height and 80 cm vertical spacing combined with contour furrowing of 10-15 cm depth and 100-125 cm vertical spacing. Moisture pattern of the system was studied and highest soil moisture was recorded at the Centre of furrow and middle of ridges throughout the season (Verma *et. al.,* 1977; Sharma *et. al.,* 1980; Sharma, 1983). Hence, the middle of ridge recorded highest population, dry matter production and precipitation use efficiency (Sharma *et al.,* 1983) in partial modification to conventional water conservation measures like contour bunds, Sharma *et. al.* (1997) designed contour vegetative barriers (CVB). Under this technique locally available fast growing perennial grasses with extensive root system such as *Cymbopogon jwarancusa, Cenchrus ciliaris* and *Cenchrus setigerus* are transplanted 0.3 m apart on contours at 0.6-1.0 m vertical interval forming a dense hedge. In a four year study of this system, it was found that the runoff volume was reduced by 28 to 97%. The CVB plots stored about 2.5 times more soil moisture than control and improved cluster bean and pearl millet yield by 37-51% and 19-40% over control, respectively. In another study vegetative barriers of different grasses were established at a horizontal interval of 30 m and pearl millet was sown in between. For the cumulative rainfall of 105 mm only, about 36.5, 72.1 and 54.2% higher moisture storage as compared to control (36.9 mm every 60 cm) was recorded under the alleys of *Cenchrus anguistifolia, Lasirus sindicus and Saccharum munja,* respectively. The average yield of pearl millet improved by 39.1% over control (CAZRI, 1998). Combination of bunding and vegetative barriers of *Cenchrus ciliaris* improved profile moisture in a field having 1-2% slope and resulted in 40% increase in yield of mungbean and mothbean (CAZRI 2000). These barriers being easy to raise, less expensive and provide fodder during lean period are readily adopted by the farmers.

3.3.3.1.3 *In-situ* moisture conservation

Systematic studies on *in-situ* moisture conservation were initiated during the year 1969. Since then inter-plot, micro-catchment and inter-row techniques are evolved and perfected for different soil, topographic and rainfall situations. Two *in-situ* water harvesting systems were devised at CAZRI, Jodhpur during seventies and eighties (Singh, 1988b). In inter-plot water harvesting, micro-catchment is prepared in one or both sides of cropped area and 2/3rd of area is cropped, leaving 1/3rd as catchment (1.5 m or 0.75 m area is used as catchment on both sides, respectively) with a slope of 5% towards the cultivated area increase soil moisture and yield of many crops (Singh *et. al.,* 1973, Singh 1988a, Singh 1985). It has also resulted in saving of 1/3rd of inputs. In semi-arid part (Pali) catchments with 4-8% slope provided 50-80% runoff to the cultivated area and enhanced the yield of crops like castor, sunflower and mung bean (Jain and Singh, 1982). Ridge and furrow system (inter row system) was designed in modification of inter plot water harvesting (Singh 1988b). In this no land is wasted for catchment purposes. The furrows of about 30-40 cm width and 15-20 cm depth are made. Distance of 60-90 cm is kept between two ridges. This system is particularly suitable for medium to heavy textured and deep to moderately deep soils (Faroda *et. al.,* 2007). In light soils, the crops are sown in furrows whereas in heavy soils, planting may be done on ridges to eliminate water logging hazards. Under this system, pearl millet yield improved by 210% over regular flat planting, whereas comparative value for micro catchment was 120% (Singh and Saxena, 1998). Laying out of ridge-furrow configuration against the prevailing wind direction of South-West to North-West was found effective for increasing moisture availability in the arid region (Singh and Bhati, 1998).

Another approach developed to conserve rain water is to adjust row spacing and make conservation furrows at the time of inter-cultivation. Planting of pearl millet at 60 cm and making ridge-furrow after interculture (30 DAS) in wider row spacing (60 cm) with 50% N through FYM recorded significantly higher grain (49.7 and 53.41%) and fodder yield (40.36 and 43.14%), respectively in Jodhpur and Barmer districts over farmers' practice (30 cm sowing). Plants maintained higher relative water content (RWC) and stomata' conductance at grain formation stage (Makkhan Lal *et. al.,* 2007). In sorghum, Inter pair row conservation furrow improved grain yield by 63.0% over Control (Regar *et. al.*, 2006). In henna, inter row and inter paired row water harvesting (conservation furrow) provided 8.6 and 7.0% higher leaf yield over inter triplet row water harvesting and control (Regar *et. al.*, 2005).

3.3.3.1.4 Sub-surface moisture barriers

A vast area of arid region is occupied with sandy soils. These soils being coarse textured have high infiltrability. High percolation rates not only affect moisture retention but also cause nutrient leaching. Such soils can be made productive by the use of sub-surface barriers. A systematic study on sub-surface moisture barrier was initiated in 1971 at CAZRI. As it is a costly input and cannot be applied over larger areas, the trials were initiated on vegetable crop *i.e.* round gourd (*Citrullus vulgaris*). Pits of 50 cm diameter were dug by tractor augur and bentonite was placed at a depth of 75 cm and pit walls were also thoroughly dusted with bentonite. The results showed that this technique yielded 49% higher yield than for conventional system (Singh *et. al.*, 1975; Singh, 1980). Other materials like pond sediments, 'asphalt and vermiculite were also tried. Bentonite clay and pond sediments at 60 cm depth in 5 mm thickness were 60-70% and 50-60% effective in retaining total rainfall in the root zone, respectively (Singh *et. al.*, 1979). Use of Asphalt as a sub-surface barrier (2 mm thick at 60 cm depth) restricted deep percolation loss to 24 mm compared to 120 mm from unbarriered soil profile and increased pearl millet yield by 40-50% (Gupta and Aggarwal, 1978, 1980). Large scale use of these barriers is limited due to cost of barriers and non-availability of machinery to incorporate them.

3.3.3.1.5 Soil amendments

In arid regions where the organic matter level of soil is very low and soil structure is very weak, soil amendments like pond sediments, vermiculite, FYM *etc.* were found very promising in improving moisture retention capacity of soil. Pond sediments available from widely scattered ponds are commonly utilized for improving soil productivity. The mixing of pond silt upto 30-40 cm soil depth @ 76 t/ha increased available water storage capacity from 6.5-6.9%, reduced infiltration rate from 15 to 13.2 cm/ha and hence increased the yield of pearl millet by 40-50% and mungbean by 35-40% over control.

3.3.3.3 Watershed Atlas of Rajasthan

As a valuable contribution to state watershed programmes, the State Remote Sensing Application Centre (SRSAC), Department of Science and Technology, Government of Rajasthan has prepared a Watershed Atlas demarcating micro watersheds on 1:50000 scale (SRAC and DWDSC, 1999). Using aerial photographs, latest satellite imageries and other sources of information, land use and drainage density have been shown on these maps. All the watersheds are codified in the catchment, watershed macro and micro watershed levels and prioritization has been done on the basis of vegetation cover, status of land degradation, physiographic features and current land use.

4.0 INDIGENOUS TECHNICAL KNOWLEDGE, THUMB RULES AND PRACTICES ADOPTED BY STATE AGENCIES

The resource constraint communities of Rajasthan have developed and maintained a rich tradition of conserving every single drop of rain water with their highly skilled indigenous methods. Despite lowest per capita availability of rain water, by and large, people of Rajasthan have been self-reliant until very recently when Indira Gandhi Canal network and excessive exploitation of groundwater changed socio-ecological equilibrium maintained for the centuries in the region. Severe water shortage experienced in rural and urban areas during recent drought years has drawn attention to re-examine the relevance of these age-old conservation practices in present context. The indigenous techniques / practices adopted in the region are listed below. These practices have also been adopted by the various state agencies with suitable modifications / refinements.

4.1 ITKs on *in-situ* Moisture Conservation Techniques

Summer ploughing: Summer ploughing is popular practice in South-Eastern Rajasthan to promote *in-situ* moisture conservation, control the weeds and increase infiltration and water holding capacity. It is generally done in the months of April and May across the general slope. Sometimes slope direction is ignored and tillage direction is as per the convenience of the farmer.

Kulying: *Kuly* is specially a blade harrow with blade of 75 to 90 cm in length and operated by a pair of bullock and a man which is hitched to yoke by beam and rope. It is made by village artisans and weight of *kuly* ranges from 35 to 40 kg. The cost of implement varies from Rs. 300 to 400 and annual maintenance is about Rs. 50-100. It can cover 1.5 ha land per day and rate of *kuly*ing is about Rs. 99/ha. The service life of a *kuly* is 8 to 10 years. It consists of: (1) *Pass* (blade), (2) *Danta* (iron rod for fixing blade with body), (3) *Runda* (body), (4) *Dandia* (beam) and (5) *Nijuna* (handle). *Kulying* is done in *Kharif* fallow during dry spells in monsoon and after the recession of monsoon at 8-10 days interval. The depth of *kuly* operation is kept 5-7 cm to create dust mulch. The intended functions of this practice are to enhance moisture availability for *Rabi* sowing and maintain the soil moisture level during cropping period. This practice is also quite prevalent in South-Eastern Rajasthan.

Kulphaing: *Kulpha* is a smaller size blade harrow compared to *kuly* and operated by a pair of bullocks and a man and hitched to yoke by beam and rope. The working depth varies from 3 to 5 cm depending upon the soil condition at the time of operation. It is made by village artisans and weight of *kulpha* ranges from 15 to 20 kg. The cost of implement varies from Rs. 200 to 300 and annual maintenance cost is about Rs. 50-100. Approximately, 0.8 ha area is covered per day @ Rs 100/ha. The service life of a *kulpha* is around 4 to 5 years. It consists of : (1) *Kulpha*ni (Blade), (2) Danta, (3) Runda (body), (4) Dandia (beam) and (5) Nijuna (handle). This is a popular practice for interculture operation in *Kharif* crops like sorghum, soybean, maize *etc*., in South-Eastern Rajasthan. *Kulpha* operation across the slope in between the rows of *Kharif* crops helps in controlling weeds and improving water availability to crops by way of reducing evaporation and runoff.

Criss-cross ploughing: Criss-cross ploughing is a very old indigenous tillage practice in the region. In criss-cross system, ploughing is carried out along as well as across the slope. It has been observed that unidirectional ploughing often leaves some unploughed land between two adjacent furrows. Hence, ploughing is done two times firstly along the slope and secondly across the slope. It requires more energy and time as compared to single ploughing. At the time of ploughing farmer divides whole field into a number of small blocks. The number and size depend upon the size of field and number of ploughs working in the field. The ploughing is started from the border of field and goes towards center till a block/field is covered. This practice thoroughly pulverizes the soil which helps better intake and retention of rainwater.

Bandhi: (Earthen embankment): These are heavy cross section earthen bunds constructed across the slope at the lowest end of the field by individual farmer with or without a provision of *nikas (*waste weir) to dispose of excess runoff from one field to another or tableland to nalla bed. These structures are generally used to retain upslope silt and water. With time undulating piece of land is converted into a level land if *bandhi* is intact. The yield of crops in bunded area increases due to improved moisture regimes and fertility status.

Contour bunding: This is the most popular conservation activity on arable lands to reduce length of run of runoff water. These are recommended to be employed on the land slope in < 6% with sufficient soil depth. The bunds vertical interval is calculated as follows:

$$VI = 0.305(XS + Y)$$

Where, X= Rainfall factor which range from 0.4 (for annual rainfall > 875 mm) to 0.8 (< 625 mm)

VI = Vertical interval (m)

Y =Factor for soil infiltration and crop cover which range between 1.0 (for clay soils and low cover) and 2.0 (for lighter soil and good cover).

S = Percent slope.

A deviation upto 20% of vertical interval is permitted to accommodate bunds on the field boundaries falling near designed contour.

The impounding height of bund is calculated by following formula.

$$H_e = \sqrt{\frac{R_e VI}{50}}$$

Where, VI = Vertical interval (m)

H_e = Impounding depth (m)

R_e = 24 hours rainfall excess (cm) for 10 years.

Top width of the bund should be 30 cm. Side slopes vary from 1:1 in red gravelly soil to 2:1 in sandy soils.

Graded bunding: These are constructed in areas having annual rainfall of more than 800 mm, where stagnation of water may damage the standing crops and excess water is to be removed safely out of the fields. The cross section of graded bund is similar to that of contour bund. A longitudinal grade of 0.1 to 0.5% depending on soil type is adequate. For strengthening the bunds fortification with vegetation is desirable.

Bench terracing: Bench terraces are provided in the fields with slope of more than 6% and having adequate soil depth. In Rajasthan the rainfall is low; therefore, in most of the areas inward sloping bench terraces are prepared. Terrace width is fixed according to slope and depth of soil available for cutting.

$$W = \frac{200d}{S}$$

$$VI = \frac{2WS}{100 - S}$$

For riser with side slope 1:1

and

$$VI = \frac{2WS}{200 - S}$$

For riser with side slope 0.5:1

Where, W= Horizontal width (m)

VI= Vertical interval (m)

d= Maximum admissible cut depth of soil (m)

S= Desired land slope (%)

Puertorican terrace (PRT): Outright construction of bench terraces may be costly and may result in reduction of productive soil depth until the fertility is rebuilt by use of manure and fertilizers. Puertorican types of terraces are recommended to avoid these problems. In these, mechanical or vegetative barriers are kept on original hill slope at convenient distances and the terraces are formed gradually. With each ploughing soil is pushed downwards thus gradually building the terrace over years. Cultivation along the slope is recommended between the barriers to induce the terrace formation at faster rate.

Stone wall terrace: Where stone is locally available at the site and potential productivity of site justifies expenses, stone wall terrace can be erected. The following cross section of stone wall is successful:

Top width	= 0.4 m (not less than 0.4 m)
Base width	= 1.4 m
Depth of foundation	= 0.4 m
Height	= as per site conditions.

Bandha **(Stone masonry):** Bandha is a stone masonry drop structure with very long and heavy earthen embankment or masonry wall (extension wall) in different shapes and sizes. These structures are made of limestone masonry and constructed by about 20% resourceful farmers. It is adopted in Chambal ravines of South- eastern Rajasthan. These structures are generally used to retain silt, and conserve water in upstream and dispose of excess runoff from the field. Over the time, undulating piece of land is converted into a level land if *bandha* is intact. The yield of crops increases due to retention of fertile soil and improvement in soil moisture regime.

4.2 Runoff Management Practices

Talab/Talai/Nadi/Toba **(Pond):** *Talab* is embankment type or dug out pond and more common in the rural as well as urban areas of the region owned by community. There are various sizes of ponds, the smaller ponds are generally called as *Talai*, while bigger are known as *Talab*. *Talab/Talai* is generally called in Eastern part of Rajasthan while *Nadis* in Western and Southern Rajasthan. The motivation of construction of these ponds was to meet the irrigation demand of agricultural crops, domestic and animal consumption in one hand and to reduce surface runoff and to recharge ground water level on the other. *Talab/Talai/Nadi* is runoff-harvesting structures constructed near the human settlements or depression sites of village by a large and huge cross section embankment around three sides of *talab* with a provision of *nikas* (sluice gate) to remove the excess water for protecting the embankments from over topping and breaching, and use for drawing irrigation water. In some *talabs* different types of mechanism is provided to withdraw water for irrigation. A straight tunnel across the base of embankment has been constructed using stones. A gate of wooden/mild steel is provided at the inlet of tunnel to get water whenever required. Most of *talabs* have *ghat* (solidly constructed steps) leading to water level, *chabootras* (pavilion) and a small temple or chatterries. There is no evidence of any established tradition of water distribution or management body in the village. The length of *talab* varies from 200 to 500m, height from 5 to 7m, top width from 5 to 8 m and bottom width from 20 to 40m. Catchment area of these ponds ranged from 25 to 700 ha, the submerged area from 5 to 100 ha and ratio of catchment to capacity from 7 to 51.

Johad: Popularly known as tank in other parts of the country is a well-known traditional water storage system in several parts of Rajasthan. *Johads* are simple embankments of mud and rubble is constructed across the slope to arrest rainwater. Sometimes a series of these are constructed depending upon the type of terrain. These structures have high embankments on three sides while the fourth side is left open for entry of water. The *Johads* in most cases are concurs with crescent shape. The height of the embankment is kept in such way that the capacity of *Johad* is more than the volume of runoff received from the catchment. Therefore, the height varies from one *Johad* to other. The water storage area of *Johad* varies from 2 ha to maximum of 100 ha. In some cases, a masonry structure is made as outlet for disposal of excess water. The water collected in the *Johad* during monsoon is directly used for irrigation, drinking and other domestic purposes. *Johads* need annual repair too. Every year before monsoon, pitching of soil on the cracks of the bund is very necessary.

Sagar (Submergence bunds): The submergence bunds are unique system in some parts of Kota and Bundi districts of South-Eastern Rajasthan. Basically, it is a water and soil conservation practice. Runoff water is conserved by constructing a large bund as a barrier across the slope of catchment with a provision of *nikas* (sluice) to remove the excess water for protecting the bund from over topping and breaching. The size of bund is designed on the basis of rainfall, soil type and watershed characteristics. The minimum command to catchments area is 1: 20 to 25. The harvested runoff from catchments is retained during the monsoon season in upward side of the bund to recharge the profile.

The harvested water is either lost through seepage and evaporation or it is drained by mid-September for sowing of *Rabi* crops like mustard, chickpea, wheat *etc*.

Khadin: *Khadins* are essentially natural depressions with earthen embankment in Agricultural field. There are more than 500 *Khadins* in Jaisalmer districts, which received average rainfall of 160 mm. It is a runoff based agriculture system which depends on water harvesting at the low lying flood plain or valley floor. A mud core wall in the way of runoff water is constructed in a sloping area to store it in the field for the moisture conservation for longer period. Because of ample moisture availability inside and around *khadin* area including bund the tall and dense natural vegetation comes up. The land under submergence in *khadins* is cultivable, both in *Rab*i and *Kharif* depending upon the quantity of runoff received. If rainfall is low and less water is received, only *Kharif* crops are taken but if the land is submerged during rainy season, cultivation of wheat or gram is done after the water is released. There exists overflow device to let off excess flow. This system widely practiced in Western Rajasthan to store large quantities of rainwater for the crop cultivation.

Anicut: Anicuts are very popular water harvesting structure in Rajasthan. It is constructed across the perennial/ seasonal stream or *nalla* to harvest surface as well as subsurface runoff during or off monsoon season and to recharge ground water to meet animal, domestic and irrigation demands. *Anicuts* are also a masonry drop structure with very long and heavy stonewalls. These structures are made of stone masonry. The recharged aquifer and improved soil moisture regime are used for *Rabi* cultivation.

Tanka: *Tanka* is the underground tank (cistern) constructed for collection and storage of surface runoff from natural catchment, artificially prepared catchment or from rooftops. The artificial catchments are generally circular and sloping towards the centrally located *tanka*. The catchment area is clean and protected. The shape and size of *tanka* vary, mostly either square / rectangular or circular or 3m x 1.2m in size with depth varying between 2.5-5 m. The circular shaped is preferred from safety point of view. The mouth is covered with stone slab and cement plaster lid. On one side a hole is made for collecting the runoff from catchment. An opening of 45-60 cm is provided for withdrawal of water. The storage capacity of *tanka* is generally enough to meet the demand of a family for whole year. This practice is widespread in Western Rajasthan to store rainwater for drinking purpose.

Kund: *Kunds* or *Kundis* (circular pits with dome like covering) have long been used as storage reservoirs in Barmer, Nagaur, Bikaner and Churu districts of Western Rajasthan. Kund is covered underground tank to serve the drinking water problems and is made of using local materials and cement. In the absence of sufficient rainfall, water is brought from different places and stored in the *kunds*. There are several hundreds of *kund* in Western Rajasthan.

Baori: *Baories* are wells with steps. These *Baories* are mainly used for drinking water. Most of the *baories* are very old and built by erstwhile ruler of the state. Unfortunately, most of these *baories* are now filled up with soil and garbage and are on the verge of extinction. *Baories* are generally in rectangular in shape with very beautiful architecture. A small temple is usually found near it. Many *baories* are located near human settlements and some few on the pathways away of the villages. The *baoris* are found in all parts of Rajasthan for drinking water and some of them are still in use.The age-old traditional water harvesting and conservation techniques have helped people of Rajasthan in maintaining productivity without disturbing ecological balance. With increased access to ground water reserves through intensive installation of bore wells and to surface water through canal networking these traditional methods have been grossly neglected and ecological balance has been dangerously disturbed. Communities are more vulnerable to frequently occurring droughts in the region than era before. Traditional small water harvesting systems and *in-situ* moisture conservation techniques have very important role to play in empowering local communities, promoting integrated village ecosystems management and creating economic wealth in poor villages.

5.0 PHYSICAL AND FINANCIAL ACHIEVEMENTS OF THE STATE AGENCIES

Rajasthan is known for its age old traditional methods of efficient rain water harvesting and their management. Government initiated soil conservation works in Rajasthan way back in 1957 under the agriculture department and most of the works has been taken up under Desert Development Programme (DDP) and Drought Prone Area Programmes (DPAP). For stabilizing production in dry land areas, soil and water conservation programmes were initiated in early eighties on watershed basis. Recognizing the need of soil and water conservation activities in the state, a separate department namely; Watershed Development and Soil Conservation was established during 1990-91 for effective execution of watershed development projects and to support the implementing agencies for effective planning based on watershed approach. The State Remote Sensing Application Centre, Jodhpur subsequently developed a uniform delineation, codification, prioritization procedure of the watersheds and documented in the form of "Watershed Atlas of Rajasthan".The area of catchments, sub catchments, watersheds and sub-watersheds has been delineated. The macro watersheds have been classified on the basis of areas coverage ranging from 1000 to 10,000 ha and micro watersheds on area ranging between100 to 1000 ha.

5.1 Watershed Programmes in the State of Rajasthan

Watershed delineation: The State Remote Sensing Application Centre has delineated 2858 macro watersheds and 15465 micro watersheds in all the districts of Rajasthan except Jaisalmer, Bikaner, Churu and Hanumangarh. However, the developmental activities in all the districts of the state are being carried out on watershed basis since 1995-96.

Selection criteria of watersheds: The percentage cultivated area of watershed and its drainage density are taken together as variables in assigning the priority of the watershed for soil conservation works. Apart from these socio-economic factors as indicated in the guidelines are also taken in to account for priority watershed.

Major watershed activities: The major developmental activities taken up in state watershed programmes are as under:

- **Agronomic measures:** Summer ploughing, contour farming, tillage practices, intercropping, vegetative barrier.
- **Forestry:** Agro-forestry, horticulture, agrisilvipasture, alley cropping.
- **Soil and water conservation:** Construction of *tanka, khadins*, percolation tanks, small farm ponds, renovation of existing water structures, different types of check dams, bunding, contour vegetative hedges, vegetative filter strips, ditch cum bunds, *etc.*
- **Livestock management:** Castration of scrub bulls, Camps and Medicines, distribution of Bulls/Rams, cultivated fodder development, Pasture development.

Watershed treatment: The geographical area of Rajasthan state is 342 Lakh ha and out of which 245 lakh ha is considered as available for treatment. As per record about 60 lakh ha has been treated under various watershed development schemes carried out so far against 66 Lakh ha area sanctioned. Therefore, 179 Lakh ha area of the state still remained untreated. For the development of rainfed and degraded waste lands the following major programmes were implemented prior to merge of all the scheme under one umbrella namely; Integrated Watershed Management Program (IWMP) in the year 2008 with the financial assistance of Ministry of Agriculture (M.O.A.), Ministry of Rural Development (M.O.R.D.) and the Ministry of Environment and Forest (M.O.E.F.), Government of India apart from various overseas agencies.

1. **RVP:** The centrally sponsored scheme of soil conservation in the catchment of river, River Valley Projects (RVP) was launched during the III Five Year Plan (1962-63). The scheme was primarily aimed at treating degraded arable and non-arable lands on watershed basis extending over more than one state with appropriate soil and water conservation measures. The total treated catchments area under RVP in Rajasthan state; which falls under high and very high priority was reported to be 3.52 lakh ha with total expenditure of Rs. 97.37 Crores.

2. **NWDPRA:** National Watershed Development Programme for Rainfed Areas (NWDPRA) was a programme of Department of Agriculture & Cooperation and launched in the year 1985-86 with the objective to restore ecological balance and improve production and productivity in the vast rainfed areas. From 2008-09 onwards all the schemes of watershed development governed by government merged and come under one umbrella namely Integrated Watershed Management Program (IWMP). The cumulative area treated under NWDPRA and IWMP up to February, 2017 was reported to be 30.92 lakh ha with an investment of Rs.2912.78 Crores.

3. **Drought Prone Area Programme (DPAP):** To combat the frequent recurrence of droughts in the state, DPAP was introduced during the year 1975, as a Centrally Sponsored Scheme (CSS) with a matching state share of 50:50 and adopted the watershed approach in 1987. While DPAP concentrates on non-arable lands, drainage lines for *in-situ* soil and moisture conservation, agro-forestry, pasture development, horticulture and alternate land use were its main components. The basic objective of the programme was to minimize the adverse effects of drought on the production of crops and livestock and productivity of land, water and human resources thereby ultimately leading to the drought proofing of the areas. The scheme covered 11 districts of the state and was implemented on cluster basis prior to conversion on watershed basis from 1995-96. The area treated so far under this programme was reported to be 3.3 lakh ha with an investment of Rs. 143 Crore.

4. **Desert Development Programme (DDP):** This programme was launched in 1977-78 for hot desert areas of Rajasthan. The programme aims to mitigate the adverse effects of desertification and adverse climatic conditions on crops, human and livestock population, and combating desertification through shelter-belt plantation, pastures development, soil moisture conservation and water resources development with ecological balance. This programme covered 85 blocks of 16 districts in the state. The area treated under this scheme since 1995-96 was 13.46 lakh ha with an investment of Rs. 600 Crores.

5. **Integrated Wastelands Development Programme (IWDP):** This program was introduced during 1991 with 100% central assistance. IWDP included silvi-culture and soil and moisture conservation in lands under government or community or private control as its predominant activity, without any regard for the complete micro watershed principle or with people's participation. IWDP was transferred to the department of land resources along with the NWDB in July, 1992. From 1st April, 1995 the scheme was implemented on a watershed basis under the common guidelines for watershed development. The Programme was expected to promote employment generation in the rural areas besides enhancing people's participation at all stages in the development of wastelands leading to sustainable development and equitable sharing of the benefits. The area treated under this programme was 3.98 lakh ha with total cost of Rs. 958.73 Crores.

6. **Combating Desertification Project (CDP):** Combating Desertification Project was a special project sanctioned by GOI under DDP. CDP was implemented in 10 desert districts *viz*., Barmer, Bikaner, Churu, Jodhpur, Jaisalmer, Jalore, Jhunjhunu, Nagaur, Pali and Sikar. The programme was funded by the GOI and Government of Rajasthan (GOR) on sharing basis in the ratio of 75:25. Nearly 2.34 lakh ha area was treated during the project period with an expenditure of Rs. 310.92 Crores.

7. **Peoples Action for Watershed Development Initiatives (PAWDI)**: The project was sanctioned in collaboration with Swiss Development Co-operation (SDC) in December 1995 and completed in June 1999. This was a GO-NGO partnership project. The project was executed in Pratapgarh & Thanagazi blocks of Chittorgarh and Alwar districts, respectively. The emphasis was given on

people's participation, awareness creation, capacity building for sustainable development & socio-economic upliftment of beneficiaries. Nearly 1980 ha area was treated during the project period with an expenditure of Rs. 4.30 Crores.

8. **Non-Governmental Organizations (NGOs):** A large number of NGOs are also involved in soil and water conservation activities in the state. N. M. Sadguru Foundation, Tarun Bharat Sangh, (TBS) Bhartiya Agro-Industry Foundation (BAIF), Association for Sarva Seva Farms (ASSEFA), Seva Mandir andAssociation for Rural Advancement through Voluntary Action and Local Involvement (ARAVALI) are some of the prominent NGOs in the state. Johad project of Tarun Bharat Sangh (TBS) in Alwar district for water conservation and availability of water has been well recognized. As per their records Rs.1500 lakh have been incurred on construction of *Johads* up to 1997-98 in which Rs.1100 lakh were contributed by the villagers.

5.2 Physical and Financial Achievements of the State under Watershed Programmes

As per the records available from various agencies, total area treated with soil and water conservation measures under different schemes is about 59.68 lakh ha with total cost of Rs. 4848.50 Crores (Table 5.1 through 5.5). District maps of Bundi, Jhalawar, Karauli and Kota depicting area covered under different watershed development schemes are given (Fig. 5.1 through 5.4). Overall status of watershed projects in Rajasthan state as a whole is presented in Fig. 5.5. Apart from above mentioned major schemes implemented on watershed basis, soil and water conservation works are also being carried out under externally funded schemes/ projects run by the NGOs and other central agencies in the state. The NGOs have covered extensive areas and their achievements are appreciable, however, accurate figures of physical and financial achievements were not available.

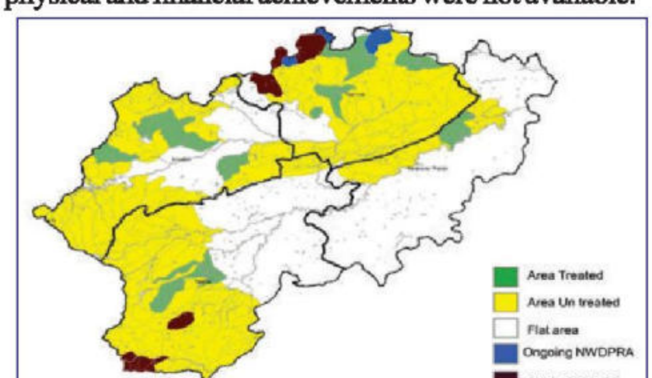

Fig.5.1: Watershed Status in Bundi

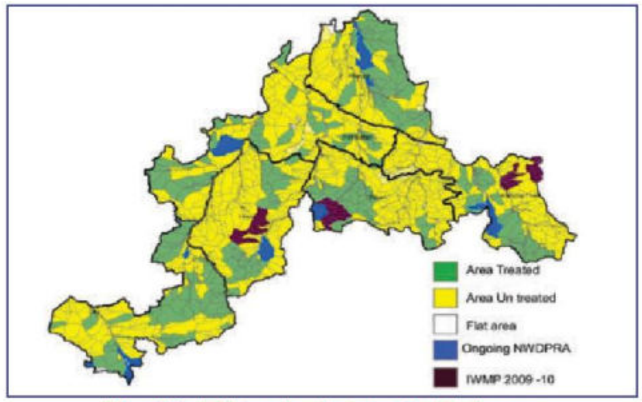

Fig. 5.2: Watershed status in Jhalawar

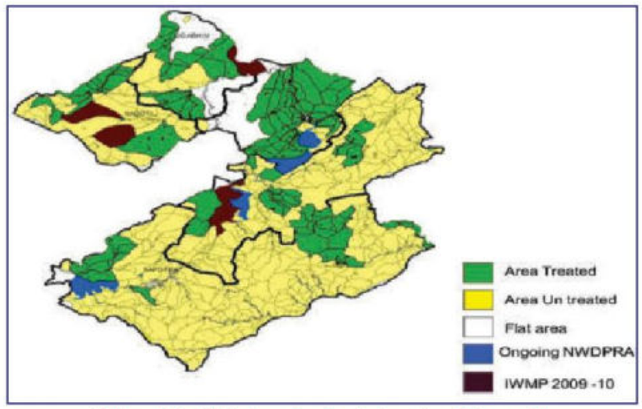

Fig. 5.3: Watershed status in Karauli

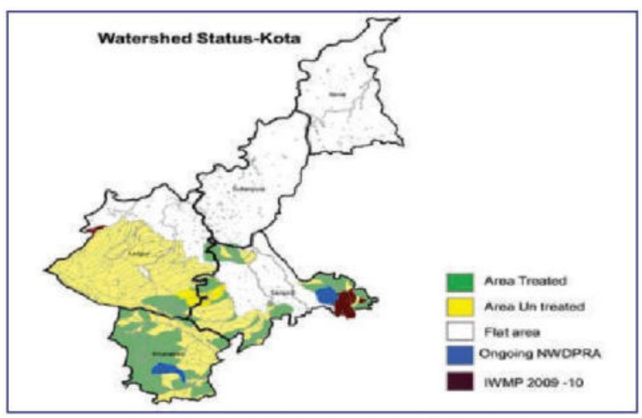

Fig. 5.4: Watershed status in Kota

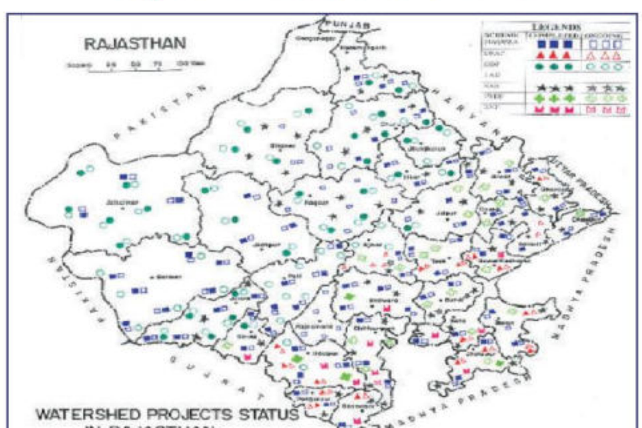

Fig. 5.5: Status of watershed projects in Rajasthan

Table 5.1: Programme wise details of micro-watersheds in Rajasthan

Scheme	Nos. of MWS*	Area (lakh ha)	Cost (₹. in Crore)
NWDPRA	12149	22.14	786.55
DPAP	1072	4.80	245.0
CDP	3098	6.96	696.0
DDP	4320	21.08	1080
IWDP	557	6.81	274.0
EAS	1803	4.59	536.0
RVP	187	2.89	37.22
Total	**13186**	**69.27**	**3629.77**

*MWS-Micro-watersheds

Table 5.2: Details of area treated, under treatment and available for treatment in future in Rajasthan state (Lakh ha)

District	Geo. area of district	watershed area	Cluster area	Treatable area)	Area treated/ sanctioned	Area yet to be treated
Ajmer	8.42	7.97	0.00	7.97	3.83	4.14
Alwar	7.82	4.63	0.0	4.63	0.79	3.84
Banswara	5.06	3.15	0.0	3.15	2.10	1.05
Baran	6.99	5.82	0.0	5.82	1.44	4.38
Barmer	28.17	2.69	20.13	22.82	3.58	19.23
Bharatpur	5.07	1.22	0.0	1.22	0.63	0.58
Bhilwara	10.47	10.13	0.0	10.13	2.13	8.00
Bikaner	30.38	0.0	22.04	22.04	2.66	19.38
Bundi	5.81	3.32	0.0	3.32	0.75	2.57
Chittorgarh	10.35	10.18	0.0	10.18	2.99	7.19
Churu	13.85	0.0	9.16	9.16	2.50	6.66
Dausa	3.40	2.71	0.0	2.71	0.93	1.78
Dholpur	3.00	2.08	0.0	2.08	0.56	1.53
Dungarpur	3.85	3.63	0.0	3.63	1.33	2.30
Hanumangarh	9.70	0.0	0.37	0.37	0.93	0.50
Jaipur	11.05	6.82	0.0	6.82	1.61	5.21
Jaisalmer	38.39	0.0	23.92	23.92	4.81	19.12
Jalore	10.56	3.89	5.80	9.69	2.32	7.37
Jhalawar	6.32	5.89	0.0	5.89	1.80	4.09
Jhunjhunu	5.91	1.55	2.52	4.07	2.41	1.66
Jodhpur	22.56	6.03	12.75	18.78	3.45	15.32
Karouli	5.05	4.30	0.0	4.30	0.56	3.74
Kota	5.21	2.31	0.0	2.31	0.71	1.60
Nagour	17.64	3.43	9.10	12.53	5.69	6.84
Pali	12.33	9.78	1.78	11.56	3.02	8.54
Rajsamand	4.55	4.13	0.0	4.13	2.05	2.08
Sawai Madhopur	4.98	4.06	0.0	4.06	1.36	2.69
Sikar	7.74	1.93	3.70	5.63	3.33	2.30
Sirohi	5.17	4.65	0.0	4.65	1.10	3.56
Tonk	7.17	5.60	0.0	5.60	1.79	3.80
Udaipur	14.62	12.33	0.0	12.33	3.20	9.13
Total	**333**	**134.23**	**111.27**	**245.50**	**66.39**	**179.12**

SoS Source: Perspective & Strategic Plan For Development of Rain fed and Watershed areas in Rajasthan for 18 Year Period: Commissionerate of Watershed Development & Soil Conservation Pant KrishiBhawan, Janpath, Jaipur.

Table 5.3: Physical and financial progress of soil conservation & watershed development programmes in Rajasthan by state soil conservation department

Year	National watershed development programme		Special scheme (DDP, DPAP, EAS,etc.)		Externally aided scheme		Total	
	Area (ha)	Expenditure (Rs. in lakh)	Area (ha)	Expenditure (Rs. in lakh)	Area (ha)	Expenditure (Rs. in lakh)	Area (ha)	Expenditure (Rs. in lakh)
1974-75	-	-	59681	6	-	-	59681	6
1975-76	-	-	54582	49	-	-	54582	49
1976-77	-	-	18248	1	-	-	18248	1
1977-78	-	-	8299	7	-	-	8299	7
1978-79	-	-	16303	67	-	-	16303	67
1979-80	-	-	35649	93	-	-	35649	93
1980-81	-	-	32356	236	-	-	32356	236
1981-82	-	-	4653	219	-	-	4653	220
1982-83	-	-	41840	316	-	-	41840	316
1983-84	-	-	36086	375	-	-	36086	375
1984-85	-	-	17368	124	-	-	17368	124
1985-86	-	-	29677	581	-	-	29677	581
1986-87	1329	8	66249	1669	-	-	65578	1678
1987-88	11597	91	30870	878	-	-	42467	969
1988-89	9645	90	26638	1024	-	-	36283	1114
1989-90	11763	121	31460	1091	-	-	43223	1212
1990-91	9000	834	24057	1421	-	71	33057	2325
1991-92	24633	751	22485	1110	1407	365	48525	2226
1992-93	95555	1464	28281	1379	5431	872	129267	3715
1993-94	104882	2087	46942	1285	14146	1272	165970	4644
1994-95	77879	2452	38581	2431	25568	1398	142028	6281
1995-96	96087	3501	97468	2361	25614	2516	219169	8377
1996-97	116015	3548	36355	1184	29700	2906	182070	7638
1997-98	75950	2579	26459	2667	36105	2400	138514	7646
1998-99	89459	3814	79872	4080	13500	1474	182831	9369
1999-2000	85792	3933	69910	4262	1102	182	156804	8377
2000-01	119518	3896	51463	5749	247	82	17228	9727
001-02	60783	3655	25576	4324	-	-	86359	7979
2002-03	38960	3108	111954	5414	-	-	150914	8522
2003-04	84424	3527	106560	5288	-	-	190984	8815
2004-05	81714	3382	119096	11802	-	-	200810	15184
2005-06	111570	4938	302263	23982	-	-	413833	28920
2006-07	87947	4300	414095	35424	10259	521	512301	40245
2007-08	34091	1521	373648	25873	10622	566	418361	27960
2008-09	0	688	367189	31819	5497	357	372686	32864
2009-10	0	0	0	-	-	-	0	0
2010-11	0	3624	0	-	-	-	0	3624
2011-12	10918	8672	0	-	-	-	10918	8672
2012-13	136813	21782	0	-	-	-	136813	21782
2013-14	363063	50952	0	-	-	-	363063	50952
2014-15	491597	70904	0	-	-	-	491597	70904

20115-16	253771	36197	0	-	-	-	253771	36197
2016-17*	408010	44860	0	-	-	-	408010	44860
Total	**3092765**	**291279**	**2852213**	**178589**	**179198**	**14982**	**5968176**	**484850**

*Up to February, 2017
Source: Annual report 2012-13: Commissionerate of Watershed Development & Soil Conservation
Pant Krishi Bhawan, Janpath, Jaipur and website searched on 20th July, 2014 & 20th November, 2017

Table 5.4: Financial progress of soil conservation programmes under Chambal river valley projects

S. No.	Year	Budget allocated (Rs. in lakh)	Expenditure (Rs. in lakh)	S. No.	Year	Budget allocated (Rs. in lakh)	Expenditure (Rs. in lakh)
1	1961-62	0.91	0.91	23	1983-84	96.20	82.31
2	1962-63	4.42	4.87	24	1984-85	98.00	96.00
3	1963-64	6.38	5.79	25	1985-86	126.75	120.31
4	1664-65	6.77	6.69	26	1986-87	125.00	122.00
5	1965-66	13.55	11.14	27	1987-88	159.60	148.26
6	1966-67	14.92	11.53	28	1988-89	188.00	186.62
7	1967-68	11.46	8.91	29	1989-90	214.00	213.64
8	1968-69	11.00	10.40	30	1990-91	275.00	274.48
9	1969-70	12.00	10.77	31	1991-92	616.00	473.98
10	1970-71	25.00	23.37	32	1992-93	616.00	588.11
11	1971-72	36.00	36.41	33	1993-94	562.00	437.05
12	1972-73	42.80	40.69	34	1994-95	761.68	678.24
13	1973-74	46.00	44.16	35	1995-96	801.02	718.54
14	1974-75	39.45	38.70	36	1996-97	839.99	793.83
15	1975-76	48.98	45.19	37	1997-98	909.30	824.40
16	1976-77	46.05	46.01	38	1998-99	941.14	806.41
17	1977-78	50.135	49.75	39	1999-2000	1039.01	931.54
18	1978-79	69.52	69.89	40	2000-2001	842.34	613.50
19	1979-80	96.627	97.44	41	2001-02	644.34	593.34
20	1980-81	105.02	105.18	-	-	-	-
21	1981-82	118.00	90.74	-	-	-	-
22	1982-83	75.00	76.13	-	-	-	-
	Grand Total					**10737.762**	**9737.209**

Table 5.5: Physical progress of soil conservation works in Rajasthan under river valley projects

Name of River valley projects	Total watersheds	Area in Rajasthan state	Total very high and high priority WS*	Area in very high and high priority watersheds	Nos. of treated watershed	Area under treated watershed (ha)
Chambal	225	392897	88	150217	79	140890
Mahi	558	1577062	137	362985	37	112516
Dantiwada	170	263560	76	123185	43	98249
Total	**953**	**2233519**	**301**	**636387**	**159**	**351655**

*WS-watershed

6.0 CRITICAL ISSUES RELATED TO SOIL AND WATER CONSERVATION IN RAJASTHAN

Rajasthan, with its diverse agroeco-systems, is richly endowed in the cultivation of a variety of cereals, oilseeds, pulses, seed spices, vegetables and fruit crops. The state has strong animal husbandry sector supported with vast stretches of grazing lands and forest vegetation. Overall, agriculture in Rajasthan is expected to contribute 25.56% of state's total GSDP in the year 2019-20, in which crops, livestock, forestry and fisheries contribute in a ratio of 48:42:11:0.4. Rajasthan has net cropped area of 183.49 lakh ha, out of this, approximately 75% of area is rainfed (116.88 lakh ha) and only 25% is irrigated area (66.61 lakh ha). However, this 25% irrigated area contributes more than 50 % of agricultural output. Main sources of irrigation in Rajasthan are Open Wells (31.62%), Tube-wells (41.91%), Canals (24.45%) and Tanks (0.84%). About 73% of irrigation is through tube-wells and wells placing enormous stress on groundwater. It is particularly alarming that share of tube-wells over the last four decades has shot up from 1% in 1967-68 to 39%.

With extreme variations in rainfall, soil, landscape features and water availability the state is classified into ten agro climatic zones which offer a unique set of opportunities and challenges as listed below (Table 6.1). The ICAR-IISWC, Research Centre, Kota is situated in Humid South-eastern plain and primary focus has been on tackling gully erosion problem, nevertheless, the Centre has been taking initiatives to address resource conservation issues for other agro-climatic zones of the state as well. Some of the pressing issues common to all ecosystems of the state are listed below.

Table 6.1: Agro-climatic zone of Rajasthan

Zone	Name of the zone (Covering districts)	Key features (Annual rainfall / Soil type)	Major land uses / Livelihood	Major issues
I A	Arid Western Plains (Barmer& parts of Jodhpur)	200-370 mm/ Desert soils and sand dunes aeolian soil,	Pearlmillet, mothbean /livestock based livelihood	Frequent drought, groundwater deep and saline, impermeable gypsum layer
I B	Irrigated North Western Plain (Sriganganagar, Hanumangarh)	100-350 mm/ Alluvial soils	Cotton-wheat/Canal irrigated intensive agriculture	Water is supply driven, waterlogging, high soluble salts and exchangeable sodium
I C	Hyper Arid Partial Irrigated Zone. (Bikaner, Jaisalmer, Churu)	100-350 mm/ sand dunes and aeolian soil,	Pearlmillet, mothbean, clusterbean /livestock based livelihood	Frequent drought in unirrigated area, groundwater deep and saline, impermeable gypsum layer
II A	Internal Drainage Dry Zone (Nagaur, Sikar, Jhunjhunu, Part of Churu)	300-500 mm/ Sandy loam	Pearlmillet, clusterbean and dry pulses/livestock based livelihood	Shallow depth of soil, red soils in depressions, frequent drought
II B	Transitional Plain of Luni Basin. (Jalore, Pali, Part of Sirohi, Jodhpur)	300-500 mm/ red desert soil	Pearlmillet, clusterbean and dry pulses/livestock based livelihood	Frequent drought, groundwater deep and saline, low fertility soils
III A	Semi-arid Eastern Plains (Jaipur, Ajmer, Dausa, Tonk)	500-600 mm/ Sierozens, lithosols, and brown soils	Sorghum, pearlmillet and pulses in Kharif and mustard, chickpea in Rabi	Low soil fertility, ground water deep and saline
III B	Flood Prone Eastern Plain (Alwar, Dholpur, Bharatpur, Karoli, S.Madhopur)	500-700 mm/ Alluvial soils	Sorghum, and pulses in Kharif and mustard, barley chickpea in rabi	Flood prone zone, Alluvial soil prone to water logging, alluvial calcareous

IV A	Sub-humid Southern Plains (Bhilwara, Sirohi, Udaipur, Chittorgarh)	500-900 mm/Soil are lithosols at foot hills &alluvials in plains	Maize, sorghum, pulses in Kharif and wheat and gram in Rabi	High variability in soil types and rainfall
IV B	Humid Southern Plains (Dungarpur, Udaipur, Banswara, Chittorgarh)	500-1100 mm/medium texture, well drained calcareous	Maize, paddy, sorghum, pulses in Kharif wheat and gram in Rabi	Shallow soil depth, calcareous soil, High variability in rainfall distribution
V	Humid South-eastern Plain (Kota, Jhalawar, Bundi, Baran)	650-1000 mm/Black of alluvial origin, clay loam	Horticultural crops/Soybean, blackgram, in Kharif and wheat, mustard, chickpea in Rabi	Heavy soils, narrow window of soil workability, waterlogging, heavy incidence of disease and pests

6.1 Immediate Challenges

Unstable crop productivity and profitability: Vulnerability of agricultural production systems to different types of biotic and abiotic stresses arising due climatic aberrations, disease and pest infestations, unscientific management, stray cattle or wildlife *etc.* leads to uncertainties in crop productivity. Agriculture production has severely suffered due to unfriendly monsoon behaviour in the region during recent years. Apart from amount of rainfall, early or late onset and recession of monsoon and patterns of intermittent dry spells have caused serious concerns. There is an urgent need to identify technological solutions specific to aberrant monsoon patterns leading to drought or flood situations, and strategies to manage pre-harvest and post-harvest challenges faced by the farmer due unfriendly weather and market conditions.

Water scarcity: Fresh water availability is emerging as a most pressing problem in India. There is an urgent need for a comprehensive water policy to insure perpetual supply of quality water to rural as well as urban areas for agricultural, industrial and domestic purposes. Emphasis is needed on adopting river basin and watershed approach integrating all aspects of water management including water availability and its allocation, pollution control, protection of water resources, rain water harvesting and recycling. Eco-region specific multiple use models need to be developed for enhancing water productivity.

Rajasthan has only 1.15% of water resources, supporting 5.67% human population and 10.5% cattle population of the country. As the groundwater exploitation increasingly exceeds the recharge several areas are turning into dark zones in respect of ground water reserves. The draft of groundwater for irrigation purpose has increased more than three times in last two and a half decade from 1984 to 2009. The worsening water balance in the state, has resulted in the ever increasing numbers of blocks under the categories of over-exploited as on March, 2009, the per cent of total blocks, under over-exploited category has gone up to around 70% that were only 36% in 1984. Concerted efforts are needed to assess the impact of conservation measures on ground water recharge. Hydro-meteorological monitoring for crop production, monitoring of ground water recharge and designing of water harvesting and recharging structures for replenishing ground water reserves are the major issues of concern for the researchers.

Unemployment and livelihood insecurity: Despite launching of several mega projects such as MGNREGA, National Rural Livelihood Mission (NRLM), Deendayal Antyodaya Yojana at national and state levels, livelihood insecurity and lack of employment opportunities is a primary concern which need immediate attention to address growing distress in rural communities. Effective research, development and policy initiatives are needed to induce the social mobilization, institution building and empowerment process through facilitating knowledge dissemination, skill building, access to credit, access to marketing, and access to other livelihoods services underpins this upward mobility.

6.2 Long-Term Challenges

Preparedness for climate change impacts: Climate change is an upcoming global threat which requires careful impact assessment investigations to formulate strategies to address this issue at national and regional levels. The year 2019 was the second-hottest year on record and current temperatures are believed to be roughly 1°C above pre-industrial levels due to human activity. Temperatures are now poised to reach 1.5°C above pre-industrial levels - with terrible consequences for millions of people in the form of agricultural impact and natural disasters.

Increased CO_2 levels, temperature extremes, increased drought and flood frequency and severity, loss of biodiversity are climate change impact forecasts which are likely to hit agriculture base livelihoods harder unless timely initiatives taken for climate risk mitigation and innovative solutions are worked out for sustaining agricultural production levels under foreseeable climate change scenario.

Sustainable development of natural resources: With the continuing decline in per capita land availability, the need for economic utilization of waste or degraded lands assumes importance. The region has vast area of degraded lands in the form of ravines, salt affected soils, sand dunes and degraded community lands. Suitable techniques for economic utilization of these lands need to be identified. Land use options need to be developed to ensure sustained fuel and fodder supply during drought years. This may include improving planting stock with drought tolerant species, refining the planting techniques and taking other necessary steps for regulating biotic and biophysical stresses.

Development of technologies for value addition in the multi-strata production systems in the non-arable lands needs priority attention. Introduction of more valuable vegetation including horticultural crops and less exploited medicinal and aromatic plants should be explored. Development of technologies for introduction of intensively managed higher value vegetation with introduction of capital intensive management in non-arable lands may be attempted.

Enhance resource use efficiency of agriculture production systems: There will be increasing greater emphasis for developing technologies and management systems to enhance land, water and energy use efficiency of production systems. This would be a priority for not only meeting increased food and fiber needs of growing population, but also to remain competitive in the global market. Strategies to achieve this shall include developing and disseminating site specific soil and water conservation measures, scientific land use planning, adopting efficient and stress tolerant genotypes, adoption of efficient irrigation systems, and synergistic integration of production systems.

The adoption of soil and water conservation technologies by the farmers is far from satisfactory and dissemination of these techniques has been slow in the region largely due to high cost of conservation technology offered to them. The situation calls for concerted efforts for refining the technologies as per need of clientele. Strategies for improving the acceptance of technologies related to soil and water conservation shall include reduced gestation period, reduced cost and better site suitability. The long gestation period and lower rates of survival and growth of the natural grasses and vegetation enhances the cost of measures. This contributes to the diminishing of farmer's interest in the adoption of these measures leaving overall negative impact on eco-restoration of degraded areas. Though suitable tree, grass and shrub species have been identified for amelioration of degraded lands, further research is needed for development of stress tolerant planting stock, efficient utilization of soil moisture and nutrients by the planted vegetation and improving microclimatic conditions for improving out planting success. Designing cost effective mechanical measures and exploring other low cost alternative is desirable for achieving better acceptance in the farmer's field. For example replacement of masonry component in the structures with dry stone or gabion component may help. Conservation technologies also need to be examined for their suitability to soil type and intended land use. In south-eastern Rajasthan refinement of design of mechanical measures is needed to avoid cracking of structures due to shrinking and swelling of clay soils.

Management of common property resources: The management of CPRs' is an area of concern for all related to soil and water conservation and watershed management. Apart from other socio-economic problems the presence of large livestock population, nomadic tribes and open grazing system practiced in most part of state are the major constraints. Strategies for proper upkeep of the CPRs' shall include developing effective and self-sustaining community development and conflict resolution mechanism and ensure equitable distribution of benefits. Resolution of conflicts becomes a major area of socioeconomic research and there is need to develop strategies for the proper upkeep of CPRs. Region specific problems need to be identified and solutions should base on the prevailing socioeconomic conditions. Equitable distribution of benefits should focus on gender equity, social equity and shall aim at creation of economically viable self-reliant systems of development.

7.0 PRIORITIZATION OF PROBLEMS AND A VISION STATEMENT FOR THE STATE

As the average annual rainfall vary from less than 100 mm to over 1000 mm, the state has wide range of variation in agro-ecological and socio-economical settings and therefore prioritization of problems and issues may change accordingly. However, all the major regional issues and problems emanate from the harsh climatic and prevailing poor socio-economic conditions in the rural areas of Rajasthan. Under hot and arid to semi-arid climate region receives low and erratic rainfall. High evapotranspiration and temperature extremes result in subsistence cropping and scarce natural vegetation. Large chunks of lands are degraded due to water or wind erosion in the rainfed areas while in the command areas development of soil salinity is a severe problem. Large number of low yielding livestock, nomadic tribes, and open grazing system aggravate the problem of land degradation by removing the scarce vegetative cover.

7.1 Major Problems in the State

The current major regional problems and issues prioritized as follows:

1. Low and unstable agriculture productivity from rainfed areas due to low and erratic rainfall, frequent droughts, high evapotranspiration requirements of crops and lack of contingency plans and alternate land use options for farmers.
2. Severe water scarcity evidenced by rapidly depleting ground water due to over exploitation of ground water, poor ground water recharge and lack of effective rainwater management strategy.
3. Livelihood insecurity, under-utilized man power, and lack of education and employment opportunities in rural areas are the issues which need to be stressed upon in all the rural development programmes.
4. Extensive areas are under various forms of land degradation. Shifting sand dunes, ravine lands, rocky land forms with shallow depth of soil and mine spoils in rainfed areas; and water logging and salinization in command areas are major forms of land degradation.
5. Status of natural vegetation is extremely poor due to high biotic pressure. Eco-restoration of forest and community lands is a pre-requisite for improving livestock productivity and sustainable development of natural resources.
6. Developing sustainable soil management strategies for medium deep black soils of South-Eastern Rajasthan and sandy plains of Western Rajasthan is also a priority concern. Excessive surface runoff, poor permeability, development of cracks, formation of pot holes, salinity and water logging in black soil region and low water holding capacity, organic carbon and fertility status in sandy soils are major issues.
7. Low adoption of farm technology is evidenced by subsistence cropping particularly in rainfed areas. This calls for an urgent action to identify the constraints and take up necessary modifications accommodating farmers' priorities.

7.2 Vision

Rajasthan state has abundance of land and natural resources, huge human and livestock base and wide spread minerals, oil and natural gas base. In spite of sever water scarcity due to arid or semiarid climate with deficient or ill distributed rainfall patterns, the definite monsoon cycles and rich traditional wisdom of efficient rain water management offer plenty of scope for rigorously implementing watershed management programmes in the state. The long term strategic planning shall be prepared in the background of current trends of economic growth and globalization of market forces. Investment in watershed management programmes could be highly rewarding in this region. Adoption of conservation measures will not only rehabilitate cultivable wastelands, this will also promote replenishment of rapidly depleting ground water resources and reduce erosion hazards. Implementation of watershed development projects on river basin scale is expected to mitigate problems of droughts and floods. To ensure sustainability of the benefits achieved from these programmes, it would be necessary to inculcate a sense of belonging for the developmental activities among the beneficiaries. Previous experiences suggest that peoples' participation at every stage of project planning and execution is the best strategy to achieve this goal.

Greater emphasis is needed to improve and stabilize crop yields from rainfed production systems. Efficient rain water management must be complemented with prudent crop planning and integrated nutrient and pest management. Intercropping with drought resistant crops and contingency crop planning for aberrant monsoon situations can bring stability in crop production. Diversification of land use system is also desirable to minimize the risk of total crop failure.

Agroforestry and agri-horti-system with low cost micro-irrigation systems have good potential to improve and stabilize farm income. There is a need to explore production potential and marketability of drought resistance seasonal and perennial species which have commercial value. The identified site-specific species shall be properly integrated with the prevalent land uses.

Pasture, community lands and other community owned resources are generally underutilized and in degraded status. Sincere efforts are needed to tackle the problems of stray cattle and illegal occupancy before the productivity of these lands is restored. Effective social campaign for generating general awareness, developing effective mechanism for benefit sharing and disseminating improved livestock management skills shall be integral part of watershed programmes. This will bring ecological as well as economic benefits to the local community.

Rural communities in Rajasthan heavily depend on livestock rearing for their livelihood support. There is excellent scope of improving animal productivity through a) breed improvement programmes, b) improving and managing fodder availability and c) educating migratory tribal communities and farmers about modern concept of animal husbandry and dairying.

Status of natural resource base is also closely linked with poverty and livelihood insecurity. Every possible effort is needed to promote agricultural and non-agricultural income generating activities especially for land less and women. There are complementary relationships among different production systems. Therefore, inter-sectorial linkages should be explored and strengthened. Establishing bio-industries, cottage industries and other income generating activities would enhance farmers risk bearing capacity and farm input levels, which in turn contribute to improved resource use efficiency and crop yield.

While research, training, extension and developmental agencies will have to collaborate for extending effective technical and infrastructural support, financial and policy institution need to come forward with adequate credit, incentives and market policies to safeguard the interest of small farmers.

8.0 RESEARCH GAPS AND VISION STATEMENT FOR NEXT 50 YEARS

Concurrent growth in human and animal population increased biotic pressure on land and water resources of the regions restricting the wholesome advantages of developmental projects. Also, rapidly changing socio-political climate has reshuffled the priorities and added several issues (Table 8.1). In view of present realities and foreseeable challenges there is a need to re-examine short term and long-term research targets. An effective well focused strategy needs to be developed based on the feedback and experiences of previous research and extension projects. Major issues and research gaps have been identified for major thrust areas as listed below:

Table 8.1: Two way table of goals and prioritization of problem.

Research goals	Problems and issues of the region						
	Low production from rainfed areas	Water scarcity	Livelihood insecurity	Wastelands restoration	Underutilized CPRs	Sustainable soil management	Poor adoption of farm technology
Assessment of land use impact on soil	X	X	X	XXX	-	X	-
Technology for rainfed farming	XXX	XX	XX	-	-	XXX	X
Technology for non-arable lands	-	XX	XX	X	XXX	XX	X
Efficient rain water management	XXX	XXX	X	X	X	X	X
Restoration of degraded lands	-	XX	XX	XXX	XX	XX	X
Impact assessment of watershed projects	XX	XX	XX	XX	X	X	X
Intangible benefits and post project sustainability	X	X	XX	X	XXX	-	XX
Dissemination of watershed technology	XX	XX	XX	XX	X	-	XXX

XXX, XX and X –high, medium and normal priorities, respectively

8.1 Research Gaps

1. There is inadequate understanding about the impact of different land uses and conservation measures on soil quality, erosion losses and land degradation.
2. Strategies for improving productivity of rainfed system need to be developed along with drought proofing techniques.
3. There is need to identify cost effective land use options for ensuring optimum productivity of non-arable marginal lands and community lands.
4. Site specific recommendations are needed for efficient rain water harvesting, recycling and promoting ground water recharge.
5. Rehabilitation and productive utilization of severely degraded ravines and mine spoils and challenging task in the state region for which suitable technologies options need to be developed and evaluated.
6. Developing bio-physical and socio-economic indicators for monitoring and evaluating the impact of watershed development projects.
7. Assessment of intangible benefits and post

project sustainability of the benefits.

8. Assessment of constraints and success in dissemination of watershed technologies.

8.2 Role of the Centre to Periodically Address the Research Gaps

Over a period of sixty years this Centre has developed and field-tested technological package of practices for production and sustainable utilization of ravine and adjoining marginal lands. The research achievements have been very well disseminated to the farmers and concerned governmental agencies and NGOs by way of training, lab-to-land programmes, operational research projects and other pilot projects taken up from time to time. Based on the technical recommendations made by the Centre extensive eco-restoration and soil conservation works were taken up through river valley projects and watershed development projects by state agencies. In the background of past experiences and present realities the Centre has assigned a strategy to address identified research gaps on critical issues (Table 8.2).

Table 8.2: Vision statement of the prioritized problems/issues for the region

	Research programmes	2020-2025	2026-2030	2031-2035	2036-2045	2046-2055
1.0	**Assessment of land use impact on soil**					
1.1	Identification and characterization of soil quality parameters for specific land uses and develop cumulative land quality indices.					
1.2	Selection and validation of erosion predictions models for upgrading erosion prediction capabilities.					
1.3	Studies for updating the extent and severity of gully erosion along the river Chambal and its tributaries.					
1.4	Studies on quantification of nutrient losses and erosion-productivity relationship.					
1.5	Develop methodologies for quantification of off-site impact of erosion.					
1.6	Developing a centralized repository of high resolution digital maps of Chambal ravine region.					
2.0	**Technology for rain fed farming**					
2.1	Evaluate cropping systems for reducing the risk of crop failure under aberrant monsoon conditions.					
2.2	Developing sustainable soil management for major rainfed production systems (SSNM, surface cracks and other soil related physico-chemical constraints).					
2.3	Studies on *in-situ* and inter-plot water harvesting and increasing water use efficiency of major rainfed crops.					
2.4	Develop organic farming and conservation agriculture suitable for agro-climatic zone - V					
3.0	**Technology for non-arable lands**					
3.1	Evaluation of compatible agri-horticulture, horti-pastoral and other land use options for productive utilization of non-arable marginal lands.					
3.2	To develop management techniques for reducing gestation period and improving resource use efficiency.					
3.3	Studies on synergistic integration of multiple production systems such as horticulture + fisheries + dairying etc.					
3.4	Development and refinement of low cost mechanical and bio-engineering conservation measures for erosion control.					

4.0	**Efficient rain water management**
4.1	Hydro-meteorological data analysis for climate change impact assessment and designing water harvesting structures and crop planning.
4.2	Water budget studies on major land uses and surface hydrology of micro-watersheds.
4.3	Developing low cost micro-irrigation techniques suitable for small and marginal farmers.
4.4	Enhancing water productivity through short duration fish farming in the harvested rainwater.
4.5	Development of design procedures and DSS for the recharge filter, recharge pond and conservation trench for artificial groundwater recharging
4.6	Studies on sub-surface hydrology and techniques for promoting ground water recharge.
5.0	**Restoration of degraded lands**
5.1	Evaluation of cost effective measures for rehabilitation and productive utilization of severely degraded deep ravines.
5.2	Studies on identification of suitable tree and grass species and their establishment on mine spoils
5.3	Establishment of benchmark ravine cluster for field evaluation of rehabilitation technology and synergistic integration of production systems.
6.0	**Impact assessment of watershed projects**
6.1	To develop methodological framework for assessing bio-physical impact of watershed projects.
6.2	Identification of measurable socio-economic indicator. Ascertaining their relative importance and quantification procedures.
6.3	Develop framework for quantification of ecosystem services in response to soil and water conservation activities.
7.0	**Intangible benefits and post project sustainability**
7.1	Vulnerability analysis of livelihood support systems..
7.2	Economic analysis of sustainability of technological interventions after field implementation /post project period
8.0	**Dissemination of watershed technology**
8.1	Watershed evaluation studies for constraint analysis in technology dissemination.
8.2	Identifying suitable methods and strategies for effective dissemination of watershed technologies.
8.3	Developing specialized training modules for field functionaries and members for implementing agencies of watershed project

8.2.1 Research Gaps

8.2.1.1 Inadequate Understanding about the Impact of Different Land Uses and Conservation Measures on Soil Quality, Erosion Losses and Land Degradation.

8.2.1.1.1 Research strategies

i. Identification and characterization of soil quality parameters, structural and functional biodiversity of soil micro-organisms, and C-sequestration potential for specific land uses.

ii. Selection and validation of erosion predictions models for upgrading erosion prediction capabilities.

iii. Studies for updating the extent and severity of gully erosion along the river Chambal and its tributaries.

iv. Studies on quantification of nutrient losses and erosion-productivity relationship.

v. Develop methodologies for quantification of off-site impact of erosion.

vi. Developing a centralized repository of high resolution digital maps of Chambal ravine region.

8.2.1.2 To Develop Drought Proofing Techniques and Strategies for Improving Productivity of Rainfed System.

8.2.1.2.1 Research strategies

i. Evaluate cropping systems for reducing the risk of crop failure under aberrant monsoon conditions.

ii. Develop sustainable soil management systems for major rainfed production systems. This includes studies on site specific nutrient management (SSNM), managing surface cracks and other soil related physico-chemical constraints.

iii. Studies on *in-situ* and inter-plot water harvesting and increasing water use efficiency of major rainfed crops.

iv. Develop organic farming and conservation farming models suitable for agro-climatic zone-V.

8.2.1.3 To Identify Cost Effective Land Use Options for Ensuring Optimum Productivity of Non-arable Marginal Lands and Community Lands.

8.2.1.3.1 Research strategies

i. Evaluation of compatible agri-horticulture, horti-pastoral and other alternate land use options for productive utilization of non-arable marginal lands.

ii. To develop soil and plant management techniques for reducing gestation period and improving resource use efficiency.

iii. Studies on synergistic integration of multiple production systems such as horticulture + fisheries + dairying, etc.

iv. Development and refinement of low cost mechanical and bio-engineering conservation measures for erosion control.

8.2.1.4 To Develop Site Specific Recommendations for Efficient Rainwater Harvesting, Recycling and Promoting Groundwater Recharge.

8.2.1.4.1 Research strategies

i. Assessment and database generation of climate change impacts on runoff and hydro-meteorological data analysis for designing water harvesting structures and crop planning.

ii. Water budget studies on major land uses and surface hydrology of micro-watersheds.

iii. Developing low cost micro-irrigation techniques suitable for small and marginal farmers.

iv. Enhancing water productivity through short duration fish farming in the harvested rainwater.

v. Development of design procedures and DSS for the recharge filter, recharge pond and conservation trench for artificial groundwater recharging.

vi. Studies on sub-surface hydrology and techniques for promoting ground water recharge.

8.2.1.5 To Develop and Evaluate Suitable Technological Options for Rehabilitation and Productive Utilization of Severely Degraded Ravines and Mine Spoils.

8.2.1.5.1 Research strategies

i. Evaluation of cost effective measures for rehabilitating and productive utilization of severely degraded deep ravines including medicinal plants, energy plantation, softwood & plywood spp., and pasture legumes.

ii. Studies on identification of suitable tree and grass species and their establishment techniques for rehabilitation and productive utilization of the areas degraded due to mining activities.

iii. Establishment of benchmark ravine cluster for field evaluation of rehabilitation technology and synergistic integration of production systems.

8.2.1.6 To Develop Bio-physical and Socio-economic Indicators for Monitoring and Evaluating the Impact of Ravine Restoration and Watershed Development Projects.

8.2.1.6.1 Research strategies

i. Develop methodological framework for assessing bio-physical impact of watershed projects considering indicators such as soil quality parameters, soil loss and runoff reduction, land quality improvement, surface and ground water quality and availability, biodiversity and green cover, crop and animal productivity parameters, etc.

ii. Identification of measurable socio-economic indicator assessing awareness levels, peoples' participation, conflicts and cooperation levels, performance of community institutions, CPRs, social and gender equity, education, employment, health and other life quality parameters, etc.

iii. Develop framework for quantification of ecosystem services in response to soil and water conservation activities.

8.2.1.7 Assessment of Intangible Benefits and Post Project Sustainability of the Benefits.

8.2.1.7.1 Research strategies

i. Impact assessment on vulnerability of livelihood support systems under changing climate scenario.

ii. Economic analysis of sustainability of technological interventions after field implementation /post project period.

8.2.1.8 Assessment of Constraints and Success in Dissemination of Watershed Technologies.

8.2.1.8.1 Research strategies

i. Watershed evaluation studies for constraint analysis in technology dissemination.

ii. Identifying suitable methods and strategies for effective dissemination of watershed technologies.

iii. Developing specialized training modules for field functionaries and members for implementing agencies of watershed project.

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