Soil and Water Conservation Techniques in Rainfed Areas

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This e-book is a compilation of resource text obtained from various subject experts for MANAGE – WALAMTARI collaborative online training program on “Soil and Water Conservation Techniques in Rainfed Areas” Conducted from 10-12 May, 2022. This e-book is designed for researchers, academicians, extension workers, research scholars and students engaged in Natural Resource Management, Horticulture, Dry Land Agriculture, etc. Neither the publisher nor the contributors, authors and editors assume any liability for any damage or injury to persons or property from any use of methods, instructions, or ideas contained in the e-book. No part of this publication may be reproduced or transmitted without prior permission of the publisher/editor/authors. Publisher and editor do not give warranty for any error or omissions regarding the materials in this e-book.

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FOREWORD

WALAMTARI is a pioneer in imparting technical knowledge in water and land management issues, soil and water conservation, on farm water management, micro irrigation etc to stake holders viz officials of Agriculture department and I & CAD dept., farmers, students, engineers, researchers and faculty. It has conducted many national and international trainings in collaboration with ICAR institutes and MANAGE and projects with Norwegian embassy and NWM etc.

Land and water management plays a key role in rainfed agriculture especially in climate change scenario. Wide scale implementation of soil and water conservation measures in rainfed areas not only conserve the rainwater and minimise soil erosion but also improves yield of crops.

It takes immense pleasure to conduct a MANAGE – WALAMTARI collaborative national level online training programme on soil and water management techniques in rainfed areas. The lecture notes of this training programme were compiled and e-book was prepared. This e-book will help to equip the trainees of different states with sustainable land and water management practices in rainfed areas.

The efforts of the training organisers and resource persons deserve appreciation in compiling the latest information and technological interventions on soil and water management practices in rainfed areas. This publication would be useful for extension personnel, researchers who are involved in soil and water management activities to effectively harvest and manage the rainwater for higher crop productivity in rainfed areas.

With best compliments

V.RAMESH
Director General
WALAMTARI

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Indigenous & Local Knowledge (ILK) or Indigenous Technical Knowledge (ITK) on Soil and Water Conservation

Dr Prasanta Kumar Mishra
Consultant, ICRISAT

Introduction

Soil and water are the basic resources and these must be conserved as carefully as possible. The pressure of increasing population neutralizes all efforts to raise the standard of living, while loss of fertility in the soil itself nullifies the value of any improvements made. This calls for more systematic resource conservation efforts. It is well known to every farmer that it is the top soil layer, which sustains agricultural production. Once this layer is lost or eroded, nothing can be done to replace it within a short period of time. Climate and hydrology, soil topography, soil surface conditions and their interactions are major factors affecting erosion-sedimentation processes. The semi–arid regions with few intense rainfall events and poor soil cover condition produce more sediment per unit area. But the man's intervention has disturbed the natural equilibrium and intensive and extensive agriculture has become a dominant factor in accelerating land degradation. The ever-increasing population pressure has brought intensive cultivation of land to the forefront through irrigated agriculture. No doubt these practices have resulted in a great increase in productivity, but they have resulted in large-scale water logging. Cultivable wastelands are increasing in the agricultural fields due to improper land management. The obvious remedy for this is to follow appropriate soil and moisture conservation practices along with integrated nutrient supply system for improvement of soil fertility as well as crop productivity on sustained basis. Soil and water conservation in any form is the only known way to protect the productive lands. In a predominantly agricultural country like India, where droughts and floods cause chronic food scarcity, adequate soil conservation programme, not only increases crop yield, it also prevents further deterioration of land. Methods to control surface runoff and soil associated erosion have been practiced in India from times immemorial.

Traditional/local knowledge is gathered over a period of time and transferred from generation to generation. It is synonymous to local knowledge and is defined as "A sum total of knowledge based on acquired knowledge and experience of people in dealing with problems and typical situation in different walks of life". For the term indigenous technical knowledge (ITK)/ or Indigenous and Local Knowledge (ILK), "local knowledge'' and "Traditional knowledge" have been used in the literature inter–changeably. It is the knowledge, which has been accumulated by the people over generations by observation, by experimentation and by handling on old peoples' experiences and wisdom in any particular area of human behavior.

Indigenous technical knowledge is the local knowledge that people have gained through inheritance from their ancestors. It is a people derived science and represents people's creativity, innovations and skills. Indigenous technological knowledge pertains to various cultural norms, social roles or physical conditions. Such knowledge is not a static body of wisdom, but instead consists of dynamic insights and techniques, which are changed over time through experimentation and adoption to environmental and socio-economic changes. This knowledge has backgrounds of hundreds and sometimes thousands of years of adoption, while bearing odds and evens of the time.

This knowledge is not possessed by only one sector of society, for example, in many cultures women and elders have passive insights into certain aspects of culture. Sometimes researchers have been unaware of such perceptiveness among rural people due to their biased focus on land-owning male farmers, neglecting other members of society. Traditional knowledge and practices have their own importance as they have stood the test of time and have proved to be efficacious to the local people. Some of these traditional practices are in the fields of agriculture – crop production, mixed farming, water harvesting, conservation of forage, combined production system, biodiversity conservation, forestry and domestic energy etc.

Fortunately, we have many indigenous techniques for conserving natural resources. There is a need to enmesh these practices along with conventional soil and water conservation measures for promoting sustainable development of agriculture. It may not be out of place to mention that some of these ITKs/ILKs may need minor modifications in different watershed situations as well as socio-economic fabrics across the country. Inclusion of these ITKs would ensure sustainability of different eco-systems, befitting the man-animal-plant-land-water complex in each watershed. The documentation of ITKs on soil and water conservation will form a basis for formulating coordinated research programme for validation and refinement of the ITKs on soil and water conservation. Although farmers practice many indigenous technologies relating to soil and water conservation, there is a lack of documentation for identifying the constraints for possible refinements to make them Modern Technical Knowledge (MTK) with scientific validation.

In India, a detail study of Indigenous Technical Knowledge (ITK) on soil and water conservation in rainfed areas was taken up through a National Agricultural Technology Project (NATP) entitled "Documentation & Analysis of Indigenous Methods of In-situ Moisture

Conservation and Runoff Management” at Central Research Institute for Dryland Agriculture (CRIDA) in early 2000.

Methodology

In order to obtain the feedback of the farmers regarding soil and water conservation measures the survey using developed proforma (Table 1) was initiated in treated and untreated villages in different agro-ecological regions of India through the AICRPDA project centers.

Table 1. Sample ITK Proforma

<table>
<tr><td>1</td><td>Title (Local name, if any)</td><td colspan="2"></td></tr>
<tr><td>2</td><td>Purpose / Objective / Rationale</td><td colspan="2"></td></tr>
<tr><td>3</td><td>Location – Village, Block / Mandal, Dist, State</td><td colspan="2"></td></tr>
<tr><td rowspan="4">4</td><td rowspan="4">Agro-Ecology</td><td colspan="2"></td></tr>
<tr><td>Agro-eco. Region:</td><td>Soil:</td></tr>
<tr><td>Rainfall (mm):</td><td></td></tr>
<tr><td>Crops</td><td></td></tr>
<tr><td>5</td><td>Percentage of problematic area covered (Farmers having similar problems)</td><td colspan="2"></td></tr>
<tr><td>6</td><td>Description
· Category of farmer (small medium/big)
· Individual / community basis
· How the practice evolved
· Since how long this ITK is in use
· In case of crop planting & gap filling method and time with seed rate
· Maintenance
· Farm implements used (if any)
· Cost/ha (or cost/structure) & labour involved
· Methods of implementation / ITK specification</td><td colspan="2"></td></tr>
<tr><td>7</td><td>Advantages</td><td colspan="2"></td></tr>
<tr><td>8</td><td>Constraint (for adoption, implementation, maintenance, replication, etc.</td><td colspan="2"></td></tr>
<tr><td>9</td><td>Improvement (for wider adoption, of the system etc.) or simplification Whether any external support needed</td><td colspan="2"></td></tr>
<tr><td>10</td><td>Replicability / Feasibility (other places in India where this can be adopted)</td><td colspan="2"></td></tr>
<tr><td>11</td><td>Photographs / slides / Map / Videograph</td><td colspan="2"></td></tr>
<tr><td>12</td><td>Additional information</td><td colspan="2"></td></tr>
</table>

Documented ITKs

The ITKs were documented under following specific categories **(Table 2).**

Table 2. A list of some documented ITKs on soil and water conservation measures under different categories

S. No	Categories	Name of ITK
1	**Agronomic Measures**	i. Intercropping ii. Cultivation and sowing across the slope iii. Wider row spacing and deep interculturing iv. Mixed cropping v. Cover cropping vi. Criss –cross ploughing vii. Hoeing with local hoes viii. Set furrow cultivation ix. Application of Farm Yard Manure (FYM) x. Strip cropping xi. Green capping xii. Green manuring xiii. Pre-emergence soil stirring xiv. Ridge and furrow planting
2	**Tillage**	i. Conservation furrows with traditional plough ii. Deep pluoghing iii. Summer ploughing/ Off-season tillage iv. Repeated tillage during monsoon season
3	**Bunding & Terracing (Mech. & Vegetative barrier)**	i. Vegetative barrier ii. Stone bunding iii. Nala check with soil filled in cement bags iv. Compartmental bunding v. Peripheral bunding/ Field bunding vi. Ipomea as vegetative barrier vii. Conservation bench terrace viii. Loose stone surplus ix. Stabilization of field boundary bund with *Vitex negundo* x. Strengthening bunds by growing grasses xi. Bund farming of pulse crops in *kharif* under rainfed situation xii. Earthen bunds xiii. Stone-cum-earthen bunding xiv. Live bunding by raising Cactus xv. Grass Plantation on field boundaries (filter strip)

S. No	Categories	Name of ITK
		xvi. Growing of Saccharum
4	**Land Configuration**	i. Use of indigenous plough for formation of broad bed & furrows ii. Furrow opening in standing crops local implement hoe (Dawara) for moisture conservation iii. Levelling the plots by local leveler iv. Opening up set furrow v. Conservation furrow : *Gurr*
5	**Soil Amendment / Mulching**	i. Application of tank silt ii. Application of ground nut shells iii. Sand mulching iv. Gravel sand mulching v. Retention of pebbles on the soil surface vi. Retention of sunflower stalks vii. Mulching of *Sal leaf* in turmeric viii. Crop residue application in the field
6	**Erosion Control & Runoff Diversion Structures**	i. Sand bags as gully check ii. Loose boulder checks iii. Stone waste weir iv. Waste weir (stone / sorghum stubbles) at the outlet of the field v. Brushwood structure across the bund vi. Grassed waterways vii. Spur structure viii. Nala plugging
7	**Water Harvesting, Seepage Control & Ground Water Recharge**	i. Seepage control by lining farm ponds with white soil ii. Harvesting of seepage water *iii.* Wells as runoff storage structures iv. Rain water management using indigenous rain gauge (*Role*) v. Farm pond vi. Percolation pond / tank vii. Ground water recharging through ditches and percolation pits viii. Well recharging through runoff collection pits ix. Dug wells x. Haveli / Bharel system xi. Bandh system of cultivation xii. Earthen check dams xiii. Field water harvesting

S. No	Categories	Name of ITK
		xiv. Nadi farming system xv. Collection of sub-surface runoff water and recycling in Diara land xvi. Rain water harvesting from roof top and

Refinement of ITKs for Promotion of the Technologies

Some potential ITKs/ILKs identified for further study, research and development of new projects is presented in **Table 3.** A scientific study may change this Indigenous Technical Knowledge to Modern Technical Knowledge (MTK).

Table 3. Identification of researchable Issues of some selected ITKs

Name of ITK	Purpose	Researchable Issues
Furrow opening in standing crops	Rainwater conservation	♦ Modification of implement with different serrated blades and introducing additional tines ♦ Effectiveness in conserving soil moisture
Nadi farming system	To collect runoff during *kharif* for life saving irrigation during drought spell or presowing irrigation (*Palewa*) for *rabi* crops	♦ Documentation and analysis of socioeconomic aspect of present *nadi* system for its sustainability ♦ Evaluation of present *nadi* farming system
Mixed pulses as vegetative barrier Stabilization of gullies using sand bags	Resource conservation Gully control and runoff management	♦ Proportion of pulses as vegetative barrier ♦ Cost effectiveness of the system ♦ Soil conservation efficiency ♦ Strengthening of sand bags structure with different vegetative barriers
Application of white soil as lining material in farm pond	To work as a sealant material for lining dugout farm pond	♦ Standardization of application technique and economic feasibility for wider application ♦ Study on the seepage losses at different hydraulic heads
Wider row spacing in pearl millet	Rainwater conservation and weed control	♦ Plant geometry and population research in different rainfall situations
Rainwater harvesting in *kund/tanka*	The harvested water in kund / tanka is used for	♦ Research should be done on the use of stored water for arid horticulture

Name of ITK	Purpose	Researchable Issues
	drinking and establishment of tree	♦ Design of *tankas* for different geo-hydrologic conditions
Crop stubbles and residue management	Improve the organic matter and water holding capacity of soil	♦ Quantification of soil and water conserved and yield advantage ♦ Better or improved implements for crop residue incorporation ♦ Alternate ways of composting and application
Brush wood waste weir	Safe disposal of excess runoff	♦ Design and stabilization of structure
Mulching in turmeric	To conserve rainwater	♦ Quantification of soil loss, improvement of soil quality and water availability ♦ Use of alternative organic material to *Sal* leaves as mulch
Indigenous stone / brush wood structure across the slope	To check soil loss	♦ Shape and size of brush wood structure depending on the runoff and site conditions
Agave sp. as vegetative barrier	To reduce runoff velocity and to increase infiltration opportunity time	♦ Different species of Agave can be evaluated ♦ Cost-benefits analysis.
Broad bed and furrow practice	To harvest rain water and dispose of runoff	♦ Width of broad bed needs to be evaluated for different crops and rainfall situations ♦ Identification of suitable low cost tractor/bullock drawn implement for layout of BBF
Water harvesting and recycling	Rain water harvesting and recycling to crop field as supplemental irrigation	♦ Recharging of water table ♦ Cost effectiveness ♦ Improvement in crop yield
Standardization of recharging technique	Augmentation of ground water	♦ Design of filter and improvement in filtering efficiency with better filtering material. ♦ Effect of geology/soil formation on recharge
Set-row cultivation	For harvesting rain water and maintaining soil structure	♦ Quantification of rainwater conservation and water use efficiency (WUE) of the crops

Name of ITK	Purpose	Researchable Issues
		♦ Improvement in soil health and crop yield over years
Summer / premonsoon tillage	Conservation tillage-to harvest early showers, facilitate timely seeding and weed control	♦ Identification of appropriate tillage implements for soil and water conservation ♦ Evaluation of root: shoot ratio and quantification of WUE of crops
Ridge & furrow planting for modulation of overland flow	Conservation of rain water, modulating excess water, control soil loss and boosting productivity	♦ Fabrication and development of ridge former accommodating required row spacings and ridge cross- section
Formation of *Gurr*	Reduction of runoff and soil moisture conservation	♦ Effect of bullock and tractor made *Gurr* onrunoff reduction, soil water conservation and crop productivity
Green manuring practice	To conserve soil water and improve soil health	♦ Growing of green manure crop and its management in improving soil health and crop productivity ♦ Economic evaluation of the system by addressing sustainability issues
Application of tank silt	To increase the fertility and water holding capacity of soil	♦ Method and quantity of tank silt application in different soils ♦ Improvement in soil water and fertility with tank silt application and its effect on crop productivity ♦ Cost effectiveness of silt application especially with Government programme of tank desiltation.

Conclusions

Many ITKs on in-situ soil and moisture conservation are not adopted everywhere throughout India because of constraints in adoption and unawareness of the effectiveness of such practices. The present documentation process has definite bearing on the future course of action in framing new projects. This short-term documentation project may lead to the following future activities:

1. Similar exercise can be undertaken to document the ITKs/ILKs from all the Agroecological regions of the country.
2. The potential ITKs may be tested for their suitability and adoption in other Agroecological regions as a dissemination strategy.
3. The documented ITKs may be published/translated in all regional languages for the benefit of the farming communities.
4. Validation of the ITKs is a logical step to qualify and quantify the effectiveness of these practices. Suitable modifications of the traditional practices through on-farm research would help in developing appropriate and acceptable technologies for different local environments.
5. The effect of conservation measures on resource losses can be studied in detail through experimentation and use of stimulation model.
6. As a policy matter the local ITKs should be in built in the resource conservation

Rain Water Management Technologies for Climate Resilience in SAT Regions of Peninsular India

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Rain water is the primary constraint defining the semi-arid tropics (SAT) and is a limiting resource for sustainable agriculture in the SAT. If not managed properly, it affects crop productivity significantly and causes land degradation through runoff and associated soil loss. Out of 140.30 m ha net cropped area in India, nearly 83.90 m ha is the net rain-fed area and the remaining 56.40 m ha is the irrigated area. The SAT is characterized by high water demand with a mean annual temperature greater than 18 °C where rainfall exceeds evapotranspiration for only 2 to 4.5 months in the dry and 4.5 to 7 months in the wet-dry semi-arid tropics (Troll, 1965). The coefficient of variation for the annual rainfall ranges between 20 and 30 per cent in these dry regions. Along with the erratic rainfall, increasing population, rising demand of water for non-agricultural uses is proportionally reducing the water availability for agriculture, which is the lifeline for rural poor. Thus efficient management of rainwater through water harvesting and efficient water use technologies is the solution for increasing productivity, reducing poverty, and maintaining the natural resource base in the SAT.

The average annual rainfall in India is about 1170 mm. Most rain falls in the monsoon season (June-September), necessitating the creation of large storages for maximum utilisation of the surface run-off. Within any given year, it is possible to have both situations of drought and floods in the same region. Regional variations are also extreme, ranging from a low value of 100 mm in Western Rajasthan to over 11,000 mm in Meghalaya in North-Eastern India. Possible changes in rainfall patterns in the coming decade, global warming and climate change could affect India's water resources.

The peninsular India consists of four agri based important states namely Andhra Pradesh, Tamil Nadu, Karnataka and Kerala representing the different topograpy and climate. Andhra Pradesh receives its rainfall both from South-West (SW) and North-East (NE) monsoons. There is a wide variation of the rainfall between the different districts of the State. The six north coastal districts and three north telangana districts receive more than 1,000 mm per annum, while a scanty rainfall below 700 mm is registered in Kurnool, Anantapur and Kadapa Districts. The lowest is recorded in Anantapur District (568 mm),while Vizianagaram District has the highest rainfall (1,159 mm) on an average.

The average annual rainfall of Tamil Nadu is 912mm. Tamil Nadu occupies 4% of India's geographical area while it has only 3% of the water resources at all India level. The occurrence and distribution of rainfall in the Karnataka is highly erratic. The annual normal rainfall is 1138 mm received over 55 rainy days. It varies from as low as 569 mm in the east to as high as 4029 mm in the west. About 2/3rd of the geographical area of the state receives less than 750 mm of rainfall. Even assured rainfall areas of the state experience scarcity of water in some years. Kerala gets on an average of 307 cm rainfall, the bulk of which (70%) is received during the South-West monsoon which sets in by June and extends upto September. The state also get rains from the North-East monsoons during October to December. The state experience severe summer from January to May when the rainfall is minimum. The two monsoons have a direct bearing on the ground water potential of the state which also follows the same seasonal trends.

In-situ Rain water management practices in Peninsular India

Conservation furrows:

Castor is an important non-edible oilseed crops grown by the rainfed farmers in Alfisols of southern Telangana . The productivity of this crop in the region is very low due to shallow soils and frequent dry spells. The dry spells occur at early (0-45 DAS), mid (45-90 DAS) and terminal (90-120 DAS) growth stages of the crop and reduce potential yields considerably. This involves management of drought through a package of practices covering (i) sowing of drought tolerant cultivars of castor like Jyothi, Kranti during June 15th to July 7th week across the slope (ii) formation of conservation furrows for every 2 rows planted at 90 cm apart (iii) operation of blade harrow in between castor rows during early growth stage of the crop and iv) additional nitrogen application 10 kg N/ ha after the relief of the dry spells either at early (up to 45 DAS) or mid (45-90 DAS) growth stages of the crop.

Conservation furrows for drought mitigation

Nitrogen application after the relief of dry spell

The adoption of drought management practices as a package gives 35-50% higher yields of castor over farmers practice with a B:C ratio of 1.8. The technology is prevalent in the districts of Mahaboobnagar, Ranga Reddy, Nalgonda and parts of Medak districts in Telengana region.

Compartmental bunding for moisture conservation

In northern dry zone of Karnataka, kharif cropping is not possible due to workability and tillage related constraints in medium to deep black soils. Further, infiltration rate is low resulting in more runoff. It involves making square compartments on the field to retain rainwater and arrest soil erosion. After receipt of early rains in June and July, land is harrowed to remove germinating weeds. Then compartmental bunds (0.15 m height) are formed using bullock drawn bund former. The size of the bunds varies from 3 m x 3 m to 4.5 m x 4.5 m depending on the slope. The cost of compartmental bunding is Rs.150/ha. These bunds are retained till the sowing of rabi crops, which are sown with seed cum ferti drill during second fortnight of September to first fortnight of October. Compartmental bunds provide more opportunity time for water to infiltrate into the soil andhelp in conserving soil moisture.

Gravel and sand mulching in sodic soils for moisture conservation

Sodic medium and deep black soils exist on an extent of 2.5 lakh ha in Koppal and Gadag districts in northern Karnataka. The infiltration rate is low and most of the rainwater is lost as runoff in these soils. However, traditionally, some farmers in this region apply locally available gravel and sand mixture as mulch and successfully produce better crops and get more income.

The technology involves sand application during summer to sodic vertisols. Before application of sand, perennial weeds like Cynodon dactylon, Cyperus rotundus etc.,

are removed. FYM @ 5 t/ha is applied followed by deep ploughing. After bringing the soil to fine tilth, nearly 275- 300 tractor loads/ha of gravel and sand mixture is uniformly applied and spread manually using spades to ensure uniform thickness of 10 to 15 cm on soil surface. The cost of application of gravel sand is Rs.77500/ha (Rs.2500 for labour cost spreading + Rs.75, 000/- for transportation @Rs 250/tractor loads).

Cover cropping for in-situ moisture conservation in black soils

Farmers keep land fallow during kharif in medium to deep black soils of northern dry zone of Karnataka and cultivate sorghum, sunflower and chickpea during rabi. This results in splash

erosion and high runoff in kharif, which leads to loss of topsoil, decline insoil fertility and crop yields over time.

In order to reduce runoff and splash erosion, cover cropping with quick growing species have been used. These crops include sunhemp, greengram, cucumber, ridge gourd in kharif. These species quickly cover the ground surface in 45 days and reduce run off, conserve rainwater in-situ. Legume cover crops improve soil fertility by adding nitrogen and benefitting succeeding crops when incorporated at harvest or during vegetative stage as in case of sunhemp (at 45 days).

Ridge furrow and Broad Bed furrow systems for moisture conservation

In South Tamilnadu region, where the black cotton soils are predominant, were tried with land configuration systems like ridge furrow and broad bed furrow systems. The spacing of furrows was 45 cm and 1.2 m width broad bed was found suitable in black soils. When the systems are grown with sorghum, the BBF gave the maximum yields followed by ridge furrow and flat bed systems. These systems improved therainwater use efficiency as well as controls the erosion within the field and provides efficient drainage to the crop for proper growth and yield. The above technology is very useful to the farmers of the rainfed black soils for improving the productivity and profitability.

Farm Pond Technology in Peninsular India as Ex situ runoff water harvesting from farm fields

Andhra Pradesh

CRIDA has optimized the size of farm ponds and catchment command ratios for different runoff co efficients. 500 m^3 capacity farm pond of size 17x17 x 3 m and 750 m^3 with size 20 x 20 x 3 m have been suggested to implement in medium to high rainfall regions. The minimum catchment requred for such farm ponds varies from 2 to 10 ha depending upon the slope , crops and other multiple uses of water. However, there is a scope for increasing the capacity of the farm ponds in high rainfall regions when planned with cropping sytem and fish culture. Oil seed crops (ground nut, sunflower, sesamum, soybean, castor and cotton), pulses(redgram, chick pea, blackgram, green gram) and cereals(sorghum, maize) are popularly grown in rainfed areas of AP like Anantapur, mahaboobnagar, Adilabad, Medak, Nizamabad, Kurnool, Prakasam , Chittor and YSR kadapa districts. In addition to the above crops, vegetables can also be planned under farm ponds . Lining of farm ponds is required in reed soils regions to arrest seepage and blacvk soils have good potential for water harvesting. The cost of the excavation is estimated to be Rs Rs25-30/m^3 of storage. The lining cost of the film(500 micron HDPE/300gsm silpulin) is Rs 80-100/ m^2. Supplemental irrigation at critical stages of flowering and pod filling with 50 mm water has improved the yield of groundnut by 65% over the rainfed.

 

After the establishment he cultivated groundnut in half acre of land. The water stored in the farm pond was sufficient to irrigate and sustain the crop and he was able to harvest 14 bags of ground nut worth of Rs. 15400 (Rs. 1100 per bag). The net income after deducting all the input and cultivation expenses was Rs. 9400.

Conclusions

The paper deals with different in situ and ex situ rain water harvesting technologies adopted in different regions of peninsular India. Farm pond technology would serve the purpose of climate resilence in rainfed agriculture and found more profitable in black soil regions. The technology will help the farmers to reap multiple benefits from the localised storage of water like fish farming, growing vegetables apart from their traditional crops ensuring both water and food security in the rainfed regions.

Drought Assessment and Management-A Case Study on undivided AP

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Consultant, ICRISAT

In a study on drought by ICAR-Central Research Institute for Dryland Agriculture (CRIDA), twenty-two districts of undivided Andhra Pradesh have been considered except Hyderabad for assessing drought based on various bio-physical and socio-economic parameters. Data were collected from primary and secondary sources. Handbook of statistics of each district and published literature were referred. Primary survey was conducted in 66 villages, three villages per district to assess the impact of drought on socio-economic aspect of various sections of the society. The various parameters studied are rainfall and its variation, frequency of drought of various types (meteorological, hydrological, agricultural), status of groundwater, drinking water, feed and fodder availability and use of remote sensing for assessing drought. Software has been developed for assessing drought, while procedure for data collection and proformae have been reviewed and modified suitably.

RAINFALL AND CO-EFFICIENT OF VARIATION (CV)

Andhra Pradesh represents a transition from tropical to sub tropical India. The climate is predominantly semi arid to arid, except for the coastal belt, which has semi-arid to sub humid climate. Occurrence of rainfall in Andhra Pradesh is influenced by South West and North East monsoon. The South West monsoon establishes over Andhra Pradesh during the second week of June, normally by June 10. The withdrawal of South West monsoon begins from last week of September and it retreats South of Andhra Pradesh by the end of October. At about the same time, the North East monsoon sets in and the activity of North East monsoon is generally experienced over Coastal and Rayalaseema regions of Andhra Pradesh. Region-wise rainfall analysis indicates that Telangana, Coastal Andhra and Rayalaseema regions of the state receive 82, 59 and 55 per cent of the annual rainfall, respectively during South West monsoon. The North East monsoon contributes only 11 per cent in Telangana region while the Coastal and Rayalaseema region receive over 30 per cent of the annual rainfall during this period.

The analysis of available rainfall data at mandal level indicates an average annual rainfall of 911 mm for Andhra Pradesh. The coefficient of variation of rainfall varies between 25 to 35%. The rainfall of 10 districts falls below the average annual rainfall of AP. Anantapur district receives the lowest amount of rainfall and Visakhapatnam receives the highest. Of all the districts, Prakasam, Nellore and Chittoor receive major amount of rainfall from October to December through North-East monsoon, while other districts receive through South–West monsoon. The contribution of off-season rainfall during the hot summer and winter is little. Similar analysis has been carried out for all the mandals.

DROUGHT FREQUENCY

Frequency of meteorological, hydrological and agricultural droughts was analyzed to assess the vulnerability of mandals to different types of drought. Mandals having daily rainfall data of more than 20 years were considered for the analysis of agricultural drought.

Meteorological Drought

Meteorological drought may be defined as the deficiency of rainfall from the normal over a given period of time. Different mandals were categorized as drought prone considering normal rainfall and the tolerable deficiency in rainfall as followed by GoAP (1995) **(Table 1)**

Table 1 Categorization of meteorological drought on the basis of rainfall and its deficiencies

Rainfall	Range of normal rainfall (mm)	Rainfall deficiency and frequency for drought categorization	
		Rainfall deficiency (%)	Frequency (%)
Low	< 750	15	≥20
Medium	≥ 750 < 1000	20	≥20
High	≥1000	25	≥20

Frequency of droughts was analyzed for all the mandals using historical rainfall data. Drought prone mandals with respect to meteorological drought for each district were identified **(Fig. 1)**. It is evident all the districts, except Vizianagaram, experience drought once in five years and Anantapur once in three years. Other districts drought frequencies are in between.

Software for real time assessment

Software has been developed to assess the meteorological drought in a real time mode. Daily rainfall is the input for the model. The output gives up-to date report of rainfall status and its deviation on daily, weekly, monthly, seasonal and annual time scales. The cumulative rainfall is compared with respective normal values of weekly, monthly, seasonal and annual rainfall. Further, the cumulative rainfall is compared with the threshold value to estimate the per cent deviation of the rainfall from threshold and the time of crossing the threshold. Non-achieving of threshold value indicates drought situation, which is also presented graphically using the same software.

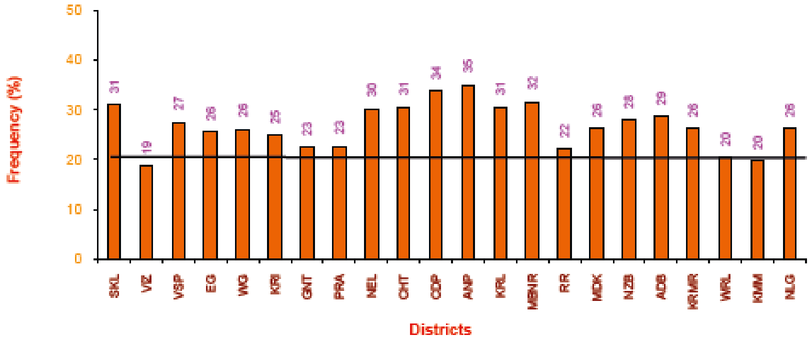


Fig. 1 Meteorological drought frequency of different Districts

Hydrological Drought

Prolonged meteorological drought results in a marked depletion of water resources and consequent drying up of reservoirs, lakes, streams and rivers, cessation of spring flows and also a fall in ground water level. Hydrological drought, thus, refers to the deficiencies in surface and subsurface water supplies in streams, surface reservoirs and groundwater. Runoff from rainfall is the major source for flow of water in streams and replenishing reserves in reservoir and ground water. Runoff-producing rainfall is considered for evaluating the hydrological drought for different mandals (as the data on rainfall is mostly available). The runoff-producing rainfall is estimated using widely accepted SCS curve number (CN) method taking into account soil type, land use, antecedent moisture condition and average slope of the area.

Runoff Estimation Using Curve Number Technique

The CN method defines a retention parameter S (mm), which varies with time because of changes in soil moisture content. The parameter S is related to CN by the following relationship:

$$S = ((1000/CN) - 10) \times 25.4 \quad \ldots\ldots (1)$$

The values of the CN vary with antecedent moisture condition (AMC). In the original procedure of USDA and its Indian adaptation, three such conditions are defined as AMCI, AMCII, and AMCIII, corresponding to dry, average, and wet catchment conditions, respectively (USDA,1972). These conditions are identified empirically based on the cumulative rainfall in the 5 days preceding the current rainfall event during the rainy season. Limiting values of the cumulative rainfall of the previous 5 days are defined for identifying the AMC. If the rainfall is <35 mm, then AMCI applies; if it is more than 52.5 mm, AMCIII applies; and if it is in between 35 and 52.5mm, AMCII applies.

The values of the CN for average AMC (CN for AMCII i.e.CNII) are taken from standard table for various soil, land use, and management conditions. The corresponding values of CN for dry (CNI) and wet (CNIII) catchments conditions are given by:

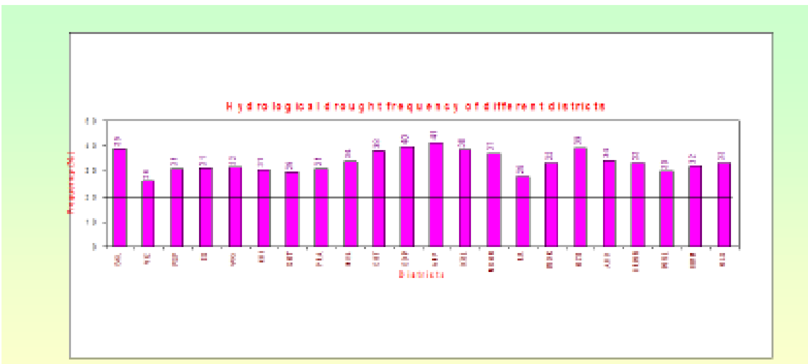
$$CNI = (4.2xCNII)/(10-0.058CNII) \ldots\ldots (2)$$

$$CNIII = (23xCNII)/(10+0.13CNII) \ldots\ldots (3)$$

The average condition CN (CNII) was decided on the basis of hydrologic soil group and land use pattern considering the standard land use data available with the Chief Planning Officer (CPO) of the respective district (GoAP 1995-2000). Weighted CN was calculated considering the proportion of area under different types of land uses. The slope factor is considered for upgrading the CN value for final use. The average slope is interpolated from slope map. The soil types are extracted from the map prepared by NBSS & LUP (ICAR), Nagpur. The CNI and CNIII were calculated from equations 2&3 respectively . Corresponding S1, S2, and S3 values were calculated from eq.1 using the CN1, CN2, and CN3 values. The runoff (R) for corresponding rainfall (P) where rainfall is greater than 0.2S was calculated using equation (4). For this, available daily rainfall and land use data (mandalwise) were collected from Planning Department, GoAP.

$$R = (P-0.2S)^2/(P+0.8S) \ldots\ldots (4)$$

Knowledge of the extent of water resources availability in the district is of vital importance in identifying the hydrological drought. As per the definition of Central Water Commission, a particular year may be considered as hydrological drought year if the runoff is less than 75% of the normal runoff (IWRS, 2001). With the above techniques, the runoff –producing rainfall, corresponding to the individual runoff events for each mandal, was calculated. In the present study, 80% of the runoff-producing rainfall is considered as threshold value for assessing hydrological drought. In other-words, if the runoff is less than 20% of the normal runoff, then, it is considered as hydrological drought year. The analysis of data indicates that all the districts are prone to hydrological drought once in five years (**Fig.2)**. The severity of hydrological drought is more than the meteorological drought. Mandal-wise information on hydrological drought for each district is presented in the software.



Most districts are prone to hydrological drought once in three years

Fig. 2. Hydrological drought frequency of different districts

Software for real time assessment of Hydrological drought

Runoff-producing rainfall

Software has been developed for assessing the hydrological drought on real time and to get first-hand information on the runoff-producing rainfall events. An average value of the amount of daily rainfall, which is causing runoff, has been estimated for each district for using it in the software. The input to this model is daily rainfall. A threshold value of runoff producing rainfall for each mandal was estimated considering the long-term average values. The output produces up-to-date report on the occurrence of runoff-producing rainfall showing deviations from the threshold value for the mandal. When the runoff-producing rainfall is less than 80% of the normal (threshold value), it is considered as hydrological drought year. The report is also displayed graphically using the same software. The daily and monthly cumulative values are compared with the threshold to estimate the percentage deviation andthe time of crossing the threshold. Non-crossing of threshold value indicates hydrological drought situation, which is presented graphically in daily and monthly graphs**.**

Storage Water Levels in Reservoirs

State Governments collect data on the levels of stored water inimportant reservoirs through its Irrigation Department. Reservoir storage level is an useful in dictator of water shortages. As data on reservoir storage area vailable on are gular basis, thes ecould provide accurate Information on water shortages. The Central Water Commission maintains data on water levels, where the water storage is compared with the Full Reservoir Level (FRL). State Governments need to plan the use of reservoir storage as per their reservoir operation rules, Which lay down the priority for the use of available water: drinking water, urban and industrial use and irrigation for agriculture. Reservoir water levels may fall below the expected level even when the reservoir operation rules are not followed and the usage of water is not adequately regulated.

Surface Water and Groundwater Level

Natural discharge from shallow aquifers provides base flow to streams and sustains the water in lakes and ponds, particularly during periods of dry weather. Similarly, ground water levels are also affected due to poor recharge, either due to lack of adequate rain fall or poor water conservation practices. As a result, water availability in deep bore wells and open wells diminishes substantially. Declining ground water level sare Important indicators of drought conditions, though these are often attributed too verextr action of water. Anannual decline in the water table of up to 2metres is considered normal and can tolerate even a deficient rainfall the following year. A decline of up to4 metres is acause for concern and above 4metres is as tress situation. Most of the State Governments have similar ground water boards or agencies for surveying groundwater levels and their periodical reports provide information upon declining ground water levels.

Agricultural Drought

Andhra Pradesh is basically an agricultural State, with 34% of its GDP contributed by agriculture. Agriculture is the major source of employment to the people. Droughts during the season affect the agricultural production and agricultural droughts of high severity cripple the economy of the State. To assess the agricultural drought, it is necessary to measure the extent to which rainfall and soil moisture are falling short of the water requirement of crops during the cropping season. Moisture Adequacy Index (MAI) is a better measure for assessing the degree of adequacy of rainfall and soil moisture to meet the potential water requirement of crops. Hence, to identify the mandals that can be vulnerable to agricultural drought, weekly MAI was worked out for the mandals having more than 20 years of rainfall data.

Methodology for calculating MAI

Moisture Adequacy Index (MAI) is the ratio of actual evapotranspiration (AET) to the potential evapotranspiration (PET). AET can be obtained as an output parameter from water balance calculations. Thornth wait and Mather (1955) weekly water balance model was used for estimating water balance of mandals. In each district, mandals with more than 20 years of data were selected and water balance of those mandals was worked out. The weekly water balance parameters like weekly AET, surplus, deficit etc. for weeks 1 to 52 were worked out for such mandals. Weekly MAI for weeks 1 to 52 were worked out as ratio of weekly AET and PET values. As Agricultural droughts occur during the cropping season only, average MAI during the cropping season has been taken as the yard stick for assessing the intensity of agricultural droughts. The available information has been used for determining the average MAI during the cropping season (rainy season). Agricultural droughts during different seasons (years) were classified into four groups based on average MAI during the season

(Table 2).

Table 2. Drought classification based on MAI

Drought severity	**MAI**
No drought	MAI > 0.75
Mild drought	MAI <0.75 and >0.50
Moderate drought	MAI <0.50 and >0.25
Severe drought	MAI <0.25

Frequencies of all the categories of agricultural drought like mild, moderate and severe were added to work out the drought frequency of a mandal. Districts having drought frequency less than or equal to 20% were classified as safe, more than 20 or less than or equal to 40% as moderate and more than 40% as severe. Based on the above classification, districts were categorized as safe, moderate and severe.

Drought Severity Index (DSI): Considering the agricultural drought frequency (number of years of different types of drought like mild, moderate and severe) and the severity based on MAI, an index called drought severity index has been devised (Eqn.5). The formula for working out drought severity index (DSI) is as follows:

$$DSI = \frac{(0.0 * \text{No drought} + 0.25 * \text{Mild droughts} + 0.50 * \text{Moderate droughts} + 0.75 * \text{severe droughts})}{\text{Total number of years}} \times 100 \ldots\ldots (5)$$

As these indices like drought intensity and drought frequency were estimated for mandals having more than 20 years of rainfall, the need for extrapolating the indices to all 1099 mandals arose. A novel methodology has been developed for extrapolating these indices for the rest of the mandals of the district. First of all, regression equations between DSI and mean rainfall of the mandals (with >20 years data) were developed. Later, in the equations so developed, mean rainfall of each mandal was incorporated to workout the DSI of all mandals in a district. This type of exercise was done separately for each district of the State. A similar approach was adopted for the drought frequency also. Data of drought intensity and drought frequency of all the 1099 mandals of 22 districts (Hyderabad excluded due to total urban area) are presented district-wise in the software. The data show that intensity and frequency of agricultural droughts are not uniform across the mandals of district and some are more vulnerable and some are less vulnerable. Based on drought severity index, mandals were classified into 4 categories viz. safe, less vulnerable, moderately vulnerable and highly vulnerable. This categorization was made using the mean (M) and standard deviation (σ) of drought severity index over all the mandals of the state. The methodology for categorization of mandals and the limits of DSI are presented in (**Table 3**). Accordingly, mandals with DSI $\leq$ 3 were marked as safe (SF); DSI > 3 and $\leq$ 13.5 as less vulnerable (LV); DSI > 13.5 and $\leq$ 24 as moderately vulnerable (MV) and DSI > 24 as highly vulnerable (HV).

Table 3. Drought classification based on DSI

Category	DSI
Safe (SF)	$\leq (M - \sigma)$
Less vulnerable (LV)	$> (M - \sigma)$ and $\leq$ Mean
Moderately vulnerable (MV)	> Mean and $< (M + \sigma)$
Highly vulnerable (HV)	$> (M + \sigma)$

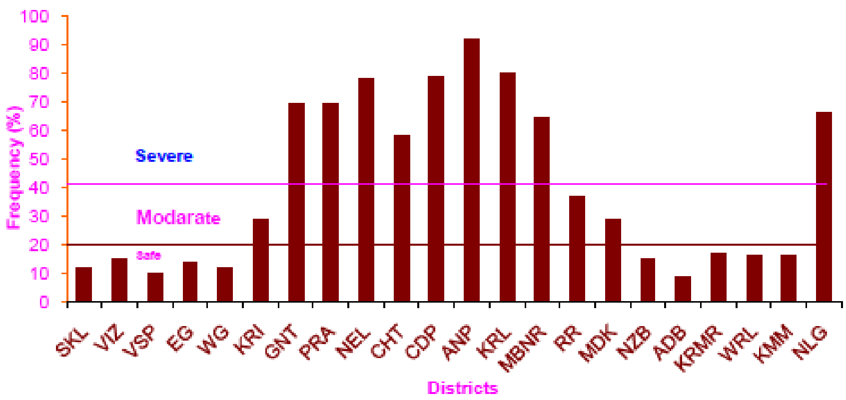


Fig 3. ricultural Drought Frequency of different districts

Integration of Meteorological, Hydrological and Agricultural Droughts

The mandals having all the three types of drought (frequency >20%) were analyzed and presented in **Fig.4**. The figure indicates that 12 districts covering 33% mandals are prone to all the three types of drought.

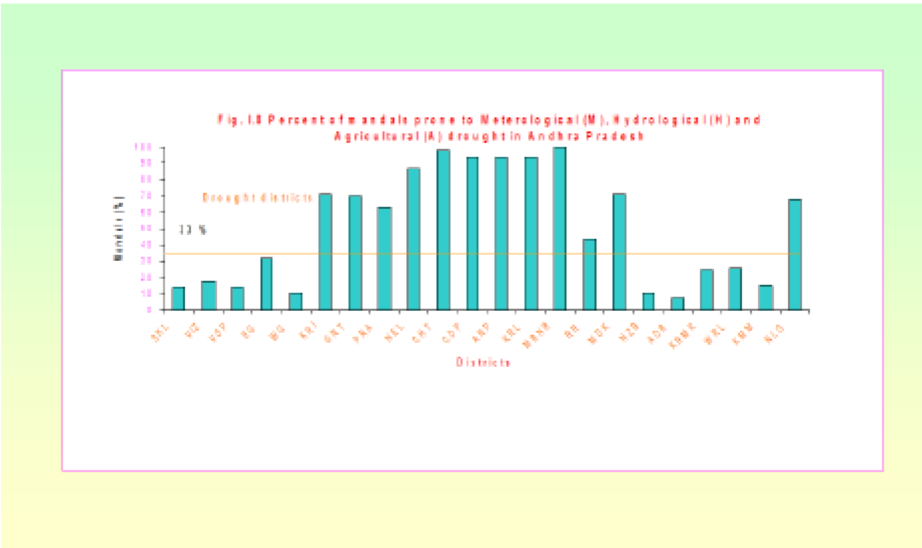
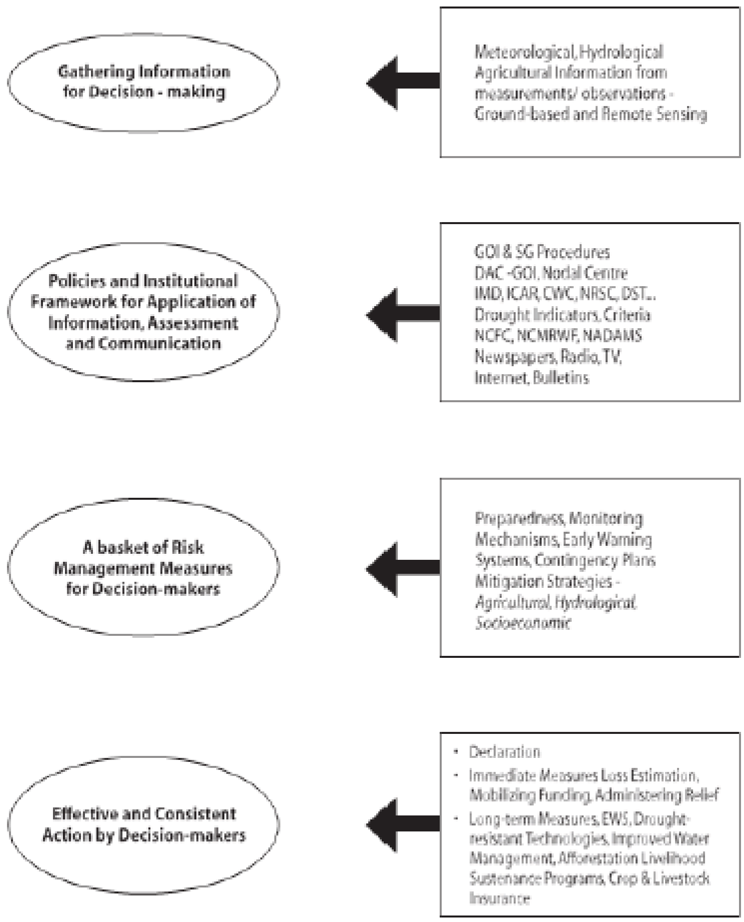


Fig. 4. Percent mandals prone to meteorological, hydrological and agricultural drought

Socio-Economic Drought

The impact of drought was assessed for all the four categories of vulnerable sections of a rural society, namely farmers, women, artisans and landless. The groups were interviewed using a structured schedule separately in three villages of 22 districts. Villages prone to drought in different revenue zones of a district were identified with the help of revenue officials. These groups were interviewed using a structured schedule in three villages of 22 districts of Andhra Pradesh, except Hyderabad. An attempt was made to record the farmers' perceptions for identifying drought prior to its occurrence taking into consideration their indigenous knowledge and wisdom. People in all the districts of Andhra Pradesh have reported recurring phenomenon of drought in the past decade. Chittoor and Cuddapah were the major affected districts which suffered continuously for the last one-decade followed by Anantapur, Rangareddy, Mahbubnagar, Nalgonda, Warangal, Medak and Nellore (8 years). They suggested that the departments of agriculture, meteorology, and revenue and agricultural research institutes, etc should do the drought assessment jointly. However, the year 2002 was recorded as the most severe drought year in all the districts of the State. Erratic distribution of rainfall and poor amount of rainfall were considered as the main reasons of occurrence of severe drought. Media (Radio, T.V. and Newspapers) played a minor role in creating awareness about drought and there was no effective mechanism at the district level. However, the farmers have their own wisdom of identifying drought prior to its occurrence.

Drought Management Strategy



Vegetative and Agronomic Measures for Soil & Water Conservation

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The mechanical/engineering soil and water conservation measures are effective in controlling runoff and soil loss and enhace the productivity of rainfed lands. These measures have been implementing by various Governmental schemes to control soil erosion in arable lands. But cost of construction of these measures is very high and farmers are not able to implement these measures without support of any schemes/programmes. The vegetative and agronomic measures control the soil erosion and conserve the rainwater some extent and these are cost effective and easily implemented by the farmers.

Vegetative Measures for Soil & Water Conservation

The various vegetative measures for reducing the sediments and nutrients losses are vegetative filter Strips, Riparian Forest Buffer, Conservation Cover, Contour Buffer Strips, Alley Cropping, and Grassed Waterways. Live-bunds or vegetative barriers are the alternative biological measures, which have been shown to effectively conserve soil and water by moderating the surface runoff and allowing them increased infiltration time.

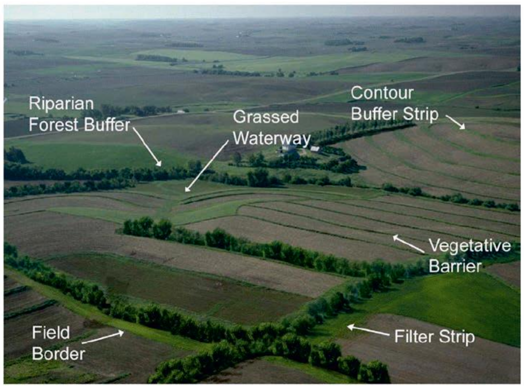

Figure Vegetative measures (photo courtesy of USDA-NRCS)

Vegetative filter strips:

A Vegetative filter strip is the dense, planted vegetation (typically grass of short height up to 45 cm) across the slope to remove sediment and other pollutants from runoff coming directly from the crop land. Vegetative filter strips are only intended to provide runoff treatment and are therefore situated between the table land and a surface water collection system, pond, tanks, reservoirs, rivers etc. Vegetative filter strips (VFS) can able to capture soil and nutrients from runoff coming from agricultural lands. The VFS as sheet flow reducing the chances of rills and gully formation and captures sediments along the path and allowing sediment free runoff to gully bed.

A vegetative filter strip is a defined area of vegetation next to a waterway designed to remove pollutants and sediment from runoff water via particle settling, water infiltration, and nutrient uptake. A filter strip's purpose is to filter and capture nutrients, sediment and pathogens in surface runoff coming from grazing areas (manure, cropland, etc.) before the contaminated runoff reaches any surface water. A filter strip's most important function is to help keep fecal coliform bacteria and other pathogens contained in livestock manure out of streams, ditches and seasonal drainages. Filter strips can be managed to produce feed and reduce pollution. Pastures and haylands that are already established next to sensitive areas can make excellent filter strips.

Vegetative barriers

The grass barriers are narrow strips (approximately 1.2 m wide) of tall, erect, stiff-stemmed, native perennial grasses planted on the contours to reduce the sediment yield, retard and disperse the runoff and facilitate benching of the slopes. Whereas, the vegetative filter-strips are typically much wider (more than 5 m) established between field borders and water ways. Vegetative barriers are considered relatively cheaper, ecofriendly and pro-farmer. Their usefulness is increasingly realized either for supplementing or substituting earthen bunds.

Grassed waterways

A grassed waterway is a vegetated channel that carries runoff at a nonerosive velocity to a stable outlet. Grassed waterways can be enhanced by including filter strips to filter runoff and to trap sediment outside of the waterway. Vegetation in the channel should be lay down to convey water while vegetation in the filter strips should be tall and stiff to avoid submergence and to filter sediment from runoff. If properly sized and constructed, grassed waterways safely transport water down natural draws through fields. Waterways also provide outlet channels for constructed terrace systems, contour cropping layouts and diversion channels. Grassed waterways are a good solution to the erosion caused by concentrated water flows when the watershed area generating the runoff water is relatively large Grassed waterways are broad, shallow and typically saucer-shaped channels designed to move surface water across farmland without causing soil erosion. The vegetative cover in the waterway slows the water flow and protects the channel surface from the eroding forces of runoff water. Left alone, runoff and snowmelt water will drain toward a field's natural draws or drainage ways. Itis in these areas that grassed waterways are often established.

Agronomical Measures for Soil & Water Conservation

Soil conservation is a preservation technique, in which deterioration of soil and its losses are eliminated or minimized by using it within its capabilities and applying conservation techniques for protection as well as improvement of soil. In soil and water conservation, the agronomical measure is a more economical, long lasting and effective technique. Agronomic conservation measures function by reducing the impact of raindrops through interception and thus reducing soil erosion. They also increase infiltration rates and thereby reduce surface runoff. Widely used agronomic measures for water erosion control are given below.

Contour Cropping:

Contour Cropping is a conservation farming method that is used on slopes to control soil losses due to water erosion. Contour cropping involves planting crops across the slope instead of up and down the slope. Use of contour cropping protects the valuable top soil by reducing the velocity of runoff water and inducing more infiltration. On long and smooth slope, contour cropping is more effective as the velocity of flow is high under such situation and contour cropping shortens the slope length to reduce the flow velocity. Contour cropping is most effective on slopes between 2 and 10 percent.

Strip Cropping

Strip cropping is the practice of growing strip of crops having poor potential for erosion control, such as root crop (intertilled crops), cereals, etc., alternated with strips of crops having good potentials for erosion control, such as fodder crops, grasses, etc., which are close growing crops . Strip cropping is a more intensive farming practice than contour farming. The farming practices that are included in this type of farming are contour strip farming, cover cropping, farming with conservation tillage and suitable crop rotation. A crop rotation with a combination of intertilled and close growing crops, farmed on contours, provides food, fodder and conserves soil moisture. Close growing crops act as barriers to flow and reduce the runoff velocity generated from the strips of intertilled crops, and eventually reduce soil erosion. Strip cropping is laid out by using the following three methods:

Mulching

Mulches are used to minimize rain splash, reduce evaporation, control weeds, reduce temperature of soil in hot climates, and moderate the temperature to a level conducive to microbial activity. Mulches help in breaking the energy of raindrops, prevent splash and dissipation of soil structure, obstruct the flow of runoff to reduce their velocity and prevent sheet and rill erosion (Fig.). They also help in improving the infiltration capacity by maintaining a conductive soil structure at the top surface of land.

Conservation/contour furrow

A conservation furrow at 45 days after sowing can be opened with bullock drawn implements in between crop rows to conserve the rainwater and reduce the soil and nutrient losses from the crop fields..Contour-furrow irrigation can save irrigation water, reduce erosion, and mean better crops on sloping fields. You waste little water by surface runoff or by over irrigation at the upper end of the furrows. In comparison with down -slope irrigation, water in contour furrows moves more slowly across the field and, therefore, does not erode or wash the soil. You get a more even distribution of water over the field, making good growing conditions for all of the plants. This pays off in better yields and in higher quality products. Irrigation water flowing down sloping fields is wasting our basic soil and water resources at a very serious rate.


Ridge-furrow system

The ridge-furrow system with alternate ridges and furrows is one of the innovative water-saving technologies which aim to drastically increase the precipitation use efficiency in rain-fed farming systems of arid and semi-arid areas. Ridges and furrows are made with bullock drawn plough across the slope in June at the onset of monsoon. The width of furrow is 45 cm and height is 20 cm. The ridge and furrow system performed better in medium as well as high rainfall areas. In high rainfall regions, this system serves as drainage as well as moisture conservation measures.


Broad bed and furrow system

Broad bed and furrow system involves preparation of broad bed of 90-120 cm, furrow of 45 cm and sowing of crop at row spacing of 30 cm. In medium rainfall regions, the broad bed and furrow (BBF) system significantly increased the crop yields, particularly the soyabeen yields in Vertisols of Maharasthra and Madhya Pradesh upto 83% over the farmer's practice. During high rainfall events BFB drains the runoff through furrows, while also acts storage which moisture availability during scarcity period.

Water Harvesting Ponds in Farmlands

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The water harvesting tern1 was firstly used in Australia by H.J. Geddes, to denote the collection and storage of any farn1 water either runoff or creek flow for irrigation use. This nomenclature has since then used very commonly, for expressing the meaning as collection of rainfall and all other water amounted to the same things. In the above definition, water harvesting includes stream flow in creeks and gullies, not just rainfall at point where it falls, therefore water harvesting tern1 is used to indicate the collection of any kind of water.

Importance

It is well known that, the land pressure is increasing day by day due to population growth, causing the more and more marginal lands are being used for agriculture. The agriculture is only possible when there is availability of water. Although at every places, there is ground water, but its exploration needs money, as a result it becomes a constraint. However, by water harvesting during rainy season, the water availability can be formed, investing least cost. In arid, semi-arid and sub-humid areas where rainfall pattern is irregular, ranges from heavy slower to less storm and much of these rainfall is lost as surface runoff, as a result there is scare of water and results into the risk of human being. Although, in this situation artificial supply of water to fulfil the demand may provide an obvious response to the water scare but it is proved more costly. Under such condition the water harvesting is a substitute and is most important. The sources of water that are to be harvested are the roof water, sheet flow or intern1ittent and even perennial water. The harvested water can be used for various productive purposes such as domestic water supply, creating stock of water for irrigation of the crops, trees and also for fish farming.

Harvesting Principles

The design principle of water harvesting structures is similar to the other hydraulic structures requiring a wide range of input. In many regions local thumb rules are used for designing the structures. For hydrological design a more or less universal criterion is followed which is basically "the ratio of the catchment area to the cultivated area." Where this ratio is known or assumed, the possible size of field to be irrigated by harvested water can easily be determined. The size of catchment can be assessed either by conducting field survey to estimate in the field or measured from the topographic map of the catchment, provided that the map is available. In several parts of world, the value of thumb rule varies from 1:5 to 1:40, depending on rainfall magnitudes and its distribution; watershed characteristics, runoff coefficient and water requirements of the existing crops to be irrigated.

Water Harvesting Ponds

Ponds are small tank or reservoir like constructions, are constructed for the purpose of storing the surface runoff, generated from the catchment area. The Farm ponds are water harvesting structures, solve several purposes of farm needs such as supply of the water for irrigation, cattle feed, fish production etc. Farm ponds also playa key role in flood control by constructing them in large numbers in the area. In addition, the farm ponds are also used for storing the monsoon water, which is used for irrigation of crops, and several other purposes, according to the need. A farm pond also has significant role in rainfed fanning cultivation.

Type of ponds

Depending upon the sources of water and their location with respect to the land surface, farm ponds are grouped into three types.

1. Earthen embankment pond.
2. Embankment cum dugout farm pond.
3. Dugout pond.

Site selection

Selection of suitable site for the pond is important as the cost of construction as well as the utility of the pond depend upon the site.

- The site for the pond is to be selected keeping in view of the following conditions.
- The site should be such that largest forage volume is available with least amount of earth fill; a narrow section of the valley with steep side slope is preferable.
- Large area of shallow water should be avoided as these will cause excessive evaporation losses and also cause watersheds to grow.
- The site should not cause excessive seepage losses.
- The pond should be located as near as possible to the area, where the water will be used. When water is to be used for irrigation, gravity flow to the areas to be irrigated is preferable.
- Pollution of the farm pond water should be avoided from drainage, from farmsteads, sewage lines and mine dumps.

Capacity of ponds

The capacity of the pond is determined from contour survey of the site at which pond is to be located. From the contour plan of the site, the capacity is calculated for different stages.

For the purpose, the area enclosed by each contour is measured using planimeter, the volume between two contours at an internal of contour (d) and having areas A1 and A2 is given by

$$V = \frac{d}{2}(A1 + A2)$$

Example :

Calculate the capacity of a pond given the area enclosed by different contours at the site as follows :

S.No Area enclosed (Sq.m)	Contour	v a l u e s (m)
1	250	220
2	251	290
3	252	340
4	253	370
5	254	480
6	255	550
7	256	620

Vol.(cm) = 1 x 100/2[2.2+ 2.9 + 3.4 + 3.7 + 4.8 + 5.5] = = 2450 cum

(b) the storage capacity of the pond can be roughly calculated from the formula.

Storage capacity (ha.m) = 0.4 D.A.

Where,

D = Maximum depth of water (m)

A = area of water spread behind bunds ha

Earth work computation

i. Embankment top width.

Normally the top width of the embankment is fixed by the equation

$$W = \frac{Z}{5} + 5$$

Where W = Width of crest (m)
Z = height of embankment above the stream bed (m)

Where the top of the embankment is to be used for roadway, the top width should be provided for a shoulder on each side of the traveled way to revent raveling. The top width in such cases should not be less than 4.5 m.

ii. Embankment side slope

The side slope of the dam depend primarily on the stability of the material in the embankment.

The greater the stability of the fill material, the steeper can be side slope.

The more unstable materials require flatter side slopes.

Table Recommended side slope for the earthen embankments

Soil classification	Slope	
	U/S	D/S
Well graded gravels, sand, gravel, mixtures little or no	Previous and hence not	
fines	suitable	
Clayey gravels, silty gravels sand clay mixtures and gravel sand silt mixtures	2.5 : 1	2 : 1
Sand clays, silty clays, lean clays inorganic silts and clays	3 : 1	2.5 : 1
Inorganic clays of high plasticity and inorganic silts	3.5 : 1	2.5 : 1

iii. Free board

Free board is the added height of the dam, provided as a safety factor to prevent haves or runoff from storms greater than the design frequency for over topping the embankment. It is the vertical distance between the elevation of the high flood level, after all settlement has taken places. Normally 15% is adopted as free board.

iv. Allowance for settlement

Settlement includes the consolidation of fill materials and the consolidation of the formation materials due to self weight to fill material and the increased moisture caused by the storage of water.

Settlement or consolidation depends on the character of the materials in the dam and foundation, and on the methods and speed of construction. The design height of earth dams should be increased by an amount equal to 5% of design height.

Earth work computation

To estimate the borrow required should include the dam, allowances for settlement, backfill for the cutoff trench, backfill for the existing stream channels and the holes in the foundation area etc. The common methods of estimating the volume of earth fill is the sum of end area method with the fill heights, side slopes and top width established, the end area of the X-section at each station along the center line is used for computation of earth work.

Example –: An earthen embankment with a top width of 2.0m is proposed for construction across a valley, whose fill heights at every 10m. The section has side slopes 2 : 1. A core trench having 0.75 m depth, bottom width of 1.75m and side slopes of 1:1 is also under consideration. Calculate the earth work needed for embankment. The fill heights at 10m interval are from one side area 1.45, 1.85, 2.30, 2.85, 4.2, 5.0, 4.4, 2.9, 2.0, 1.25m.

Solution

The area of cross-section at every 10m interval may be computed in the first instance.

A = BD + nD2

Where B = 2 m and n=2

Therefore A = 2 D + 2D2 = 2 (D+D2)

D	D2	D+D2	X –section area =2 (D+D2) (sq.m)
1.45	2.10	3.55	7.11
1.85	3.42	5.27	10.55
2.30	5.29	7.59	15.18
2.85	8.12	10.97	21.95
4.20	17.84	21.84	43.68
5.00	25.00	30.00	60.00
4.40	19.36	23.76	47.52
2.90	8.41	11.31	22.62
2.00	4.00	6.00	12.00
1.25	1.56	2.81	5.63

Using the principle of sum of end area method, the earth work needed can be computed. The sample calculations are presented below :

Fill ht. (m)	End area (sq.m)	Sum of end area (Sq.m)	Distance (m)	Double Volume (cum)	volume (cum)
0	0	7.11	10	71.10	35.50
1.45	7.11	17.65	10	176.50	128.62
1.85	10.55	26.73	10	257.30	128.62
2.30	15.18	37.12	10	371.20	185.60
2.85	21.94	65.62	10	656.20	185.60
4.20	43.68	103.68	10	1036.80	328.10
5.00	60.00	107.52	10	1075.20	537.60
4.40	47.52	70.14	10	701.40	350.70
2.90	22.62	34.62	10	346.20	173.10
2.90	12.00	17.62	10	176.20	88.10
1.25	5.62	5.62	10	56.20	28.10
0	0.00				
					Total 2462.09

The above computation should shows only the volume of earth work required to complete dam itself. An estimate of the volume of earth required to fill core trench etcshould be made and added to the estimate made for the dam.

Av. depth = 0.75m

Bottom width = 1.75m

Side slopes = 1: 1

Length = 110 m

Area of X-section

Z = 1.75 x 0.75 + 2 x 0.75 x 0.75

= 1.31 + 1.23 = 2.44

Volume of backfill = 2.44 x 110 = 268 cum

Total earth work needed for dam, works out to be

268 + 2462 = 2730 cum

Dug out farm pond

Where topography does not lend itself to embankments construction, dugout or excavated ponds can be constructed in relatively flat terrain. Since dugout ponds can be constructed to expose a minimum water surface area in proportion to volume, they areadvantageous where evaporation losses are high and water is scarce.

I. Selection of site

Some of the important physical features that must be considered in locating dugout sites are the watershed characteristics, silting possibilities, and topography and soil type. The watershed must be capable of furnishing the annual runoff sufficient to fill the dugout. Division ditches are often used in adding supplemental drainages. The low point of a natural depression is often a good location for a dugout pond. Location withfavorable discharge condition should be selected.

The soil type at the site should be thoroughly investigated to determine the permeability of the soil that will form the bottom and sites of the dugout, as well as to avoid cutting in very hard stuff. In case the seepage rates of farm ponds are excessive, suitable lining may have to be resorted to (ex. Puddling and compacting to the optimum bulk density, bitumen spray, etc.) Soils underlain by limestone containing crevices, sinks or channels should be avoided.

ii. Planning

Excavated ponds may be constructed to almost any shape desired; however a rectangular shape is usually convenient. The size of the pond depends on the extent of area draining into the pond, the extent of area that could be put under pond and its surrounding bund of excavated soil, the amount of money considered appropriate to invest, the nature and amount of rainfall, soil type and expected runoff into the pond. The length and width of an excavated pond will not ordinarily be limited, except that the type and size of the excavating equipment, if used, may become a factor for consideration. The side slopes of a dugout pond should not be steeper than the natural angle of repose of the material being excavated. In most cases, the side slopes should be flatter than 1 : 1.

iii) Design of pond

The storage capacity of the pond is calculated by USDA-NRCS curve number method.

Curve number method as follows

Q= (P-Ia)2/ (P-Ia+S)

Q= Runoff , P= Rainfall, Ia= Initial abstraction,

S= potential maximum retention, If Ia= 0.2S, then

Q= (P-0.2S) 2 / (P+0.8S)

S= (25400/CN)-254

CN: curve number

CN depends on, Rainfall characteristics, Watershed characteristics, Land use, Land treatment, Hydrologic soil group, Hydrological condition

Hydrological condition

Poor	Less than 50% land is covered by canopy Heavy runoff.
Fair	Medium runoff. 50-75% land is covered by canopy
Good	More than 75% land is covered by canopy Less runoff.

Soil group	Description
A	Lowest runoff potential includes deep sand with very little silt and clay, rapidly permeable laces(>25mm/hr)
B	Moderately low runoff potential: mostly sand soils less deep than A and loess less deep than A(12.5-25 mm/hr)
C	Moderately high runoff potential shallow soils and soils containing considerable clay and colloids though less than those of group.(2.5-12.5 mm/hr)
D	Highest runoff potential includes mostly clay of high swelling percent, but this group also includes some shallow soils with nearly impermeable sub horizons near the surface.(<2.5 mm/hr)

AMC I	Preceding 5-day rain<12mm (dormant season) <36mm (growing season)
AMC II	Preceding 5-day rain 12-28mm (dormant season) 36-53mm (growing season)
AMC III	Preceding 5-day rain>28mm (dormant season) >53mm (growing season)

SL No.	Landuse	Trestmen/Practice	Hydrological Condition	Hydrological Soil Group			
1.	Cultivated	Straight Road	……	76	86	90	93
		Contoured	Poor Good	70 65	79 75	84 82	88 86
		Contoured Terraced	Poor Good	66 62	74 71	80 77	82 81
		Bunded	Poor Good	67 59	75 69	81 769	83 79
		Paddy	……	95	95	5	95
2.	Orchards	with under stoney cover without under stoney cover	…… ……	39 41	53 55	67 69	71 73
3.	Forest	Dense	……	26	40	58	61
		Open		28	44	60	64
		Shrubs		33	47	64	67
4.	Pasture	………..	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
5.	water land	……….	…….	71	80	85	88
6.	head surface	……….	…….	77	86	91	93
7.	Pave with curbs and storm sewers			98	98	98	98
8.	Gravel			76	85	89	91
9.	Dirt			72	82	87	89

Based on the estimated runoff the pond size must be designed, the pond size lesser than or equal to estimated runoff volume from the pond catchment area.

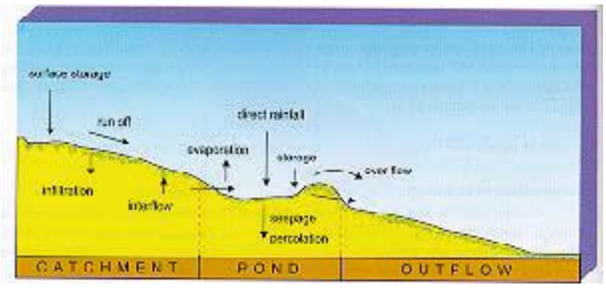
iv. Disposal of excavated material

Proper disposal with prolong useful life of the pond, improve its appearance and facilitate its maintenance and establishment of vegetation. The excavated material should be placed in a manner, that its weight will not endanger the stability of the pond, side slopes and the rainfall will not wash the material back into the pond. A berm with a width equal to depth of pond may be adapted.

v. Construction

The pond and waste areas should first be cleared of all vegetation. The limb of excavation and soil placement areas should be demarcated and excavated by step method using manual labour. Excavation and the placement of the excavated materialare the principal items of work required in the construction of this type of pond.

Experiences on water harvesting in dugout-cum-embankment type of pond in hilly region of North East India clearly indicate the feasibility of harvesting runoff from watersheds to an extent of 38% of monsoon rainfall. Contribution of subsurface flow from upper slopes accounts for 82-90% of the annual into the water harvesting pond located in the lower reaches and only 10-18% comes from direct interception of rainfall and collection of surface runoff. Stored water is used for crop, livestock and fishproduction (Satapathy, 1996 & 2000).



Plastic lining of ponds: Construction of small water harvesting structures in the lower reaches of micro-watersheds to store runoff and intercepted base flow for utilizing the stored water for pisciculture or to recycle back for life saving irrigation provides ample scope for water resources development in the NE Hills at a relatively low cost. This type of pond generally have high rate of seepage and percolation and cannot hold water during the crucial dry season. Two small ponds with storage capacity of 0.3 ham (AE pond) and 1.0 ham (FSRP pond) were created in the ICAR Research Farm at Barapani (Meghalaya). The pond were subsequently lined with LDPE Agri Film of 250 micron and covered with 30 cm soil on the bed as well as sides. The effect of lining and hydrological behaviour of ponds was studied. The maximum percolation rate through the AE pond under unlined condition was to be tune of 0.040 m3/m2 wetted perimeter/day. The percolation rate has remarkably reduced to 0.0029 m3/m2 wetted perimeter/day after lining pf the pond with Agri Film, showing average reduction of about 93% in the seepage loss (Rao and Satapathy 2005). Storage hydrographs of the pond after and before lining clearly shows the increase in water saving efficiency of the pond after lining in terms of both quantity and duration of storage.

Estimation of volume of a pond

The volume of excavation required can be estimated with sufficient accuracy by use of Primordial Formula.

$$V = \frac{A + AB + C}{6} \times D$$

Where V = Volume of excavation (m3)

B = area of excavation at the ground surface (m2)

C = area of the excavation at the bottom of pond (m2) ; and

D = average depth of the pond (m).

Example Compute the volume of excavation required to construct an excavated pond with an average depth (D) of 4.0m, a bottom width (W) of 12m, and a bottom length (L) of 30m the side slopes adopted are 2:1.

Solution : The volume of excavation required.

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Solution : The volume of excavation required.

$$V = \frac{A + AB + C}{6} \times D$$

Top length = 30 + (4x2)2 = 46m

Top width = 30 + (4x2)2 = 28 m

A = 46 m x 28 m = 1288m2

Mid-length = 30 + (2x 2)2 = 38m2

Mid-width = 12 + (2x 2) 2 = 20m2

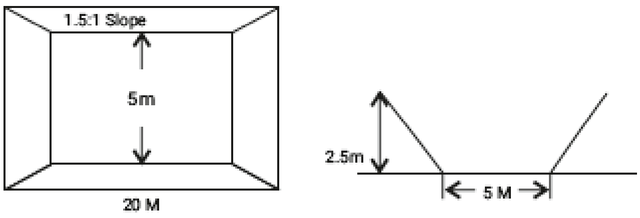
4B = (38 m x 20 m) x 4 = 3040 m2

C = 12 m x 30 m = 360 m

A + 4B + C = 4688 m2

$$V = \frac{4688}{6} \times 4 = 3124 \text{ m3 or } 0.3124 \text{ ham}$$

EXAMPLE Determine the volume of earthwork for the pond of following size.



Plan Elevation

Top dimensions = 20m x 12.5m

Bottom dimension= 15m x 5m

Depth = 2.5m

Side slope = 1.5:1

Solution-

Volume of earth work= ½(top dimension + bottom dimension) x depth

=1/2((20 x 12.5) + (15 x 5)) x 2.5

=390.62 m3

Design of Farm Pond

Catchment area = 10 ha

Mean annual rainfall = 500 mm

Runoff = 10% of 500 = 50 mm

50mm from 10 ha = 50/1000 x 10 x 10000

=5000 m3 = Expected volume of water

75% of probability 5000 = 75/100 x 5000 = 3750 Cum or 3800 Cum = Design Volume of water.

Side slope of the farm pond can be assumed 1 : 5 : 1

$$b = \left\{ \sqrt{\frac{3V - d^3 z^2}{3d}} \right\} - d\,z$$

Z = Side slope = 1.5

d = Depth = 3 m

$$b = \left\{ \sqrt{\frac{3 \times 3800 - 3^3 \times 1.5^2}{3 \times 3}} \right\} - 3 \times 1.5$$

= 31 + 2 x 3 x 1.5 = 40 m

Water Harvesting Check dams for Climate Resilient Agriculture in Rainfed Regions

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The rainfed regions of India are characterized by aberrant behaviour of monsoon rainfall, eroded and degraded soils with water and nutrient deficiencies, declining ground water table and poor resource base of the farmers. The major constraint is low and unstable yields in rainfed areas with large yield gap. In addition to these, climate variability including extreme weather events resulting from global climate change poses serious threat to rainfed agriculture. In rainfed regions, rainwater is the main source of water for agriculture but its use efficiency for crop production is low and varies from 30-45%. In monsoon dependent country like India, the rainfall is received in 100 days in 100 hours; therefore, there is a great need of storage of surplus runoff. The farm pond technology is one of the best technologies for climate resilient agriculture and is gaining of popularity, however, it is not feasible for marginal farmers due to area lost for cultivation and cost/unit of water harvested. In locations, where natural streams are available, the check dams can be an alternative for runoff harvesting and recycling to cope with climatic aberrations such as mid seasonal and terminal droughts and floods.

Check dams are constructed to store rain water and silt on the upstream side. Depending upon size of nala, its slope, watershed area and severity of the problem, suitable type of check dam can be selected. Temporary check dams made of locally available material like brushwood, log wood and planks are used in small gullies, mostly in the upper reaches where runoff is less. Semi permanent check dams made of loose boulder, and/or dry stone packing are recommended in small to medium gullies. Gabion check dams are preferred in medium gullies in the middle reaches. Permanent gullycontrol structures/water harvesting structures are used in medium to large gullies carrying more runoff especially in lower reaches. The effect of check dams on groundwater recharge, water availability, production, productivity, livelihoodimprovement were reported by several scholars (Wani et.al., 2007, Sharda et al.,2005 ,Joshi et. al., 2005, Kumar et. al., 2004; Dhyani et. al., 2016).

Temporary check dams

For stabilization of gullies through vegetation is a difficult task. Temporary mechanical measures are adopted to prevent washing away of the plantation by large volume of run-off that provides to establish the vegetation. Vegetations once established will be able to take care of the gully. Followings are some such mechanical measures / structures; a) Check Dams; - (i) Temporary check dams, (ii) Brush dam, (iii) Semi permanent check dams. b) Loose Rock Dam c) Log Wood Dam. Vegetative live check dams are constructed in upper reaches of the catchments or watershed. The grasses or baboo type of species can be used as live or vegetative check


Bamboo plantation as live check dams in degraded Mahi Ravines of Gujarat

Earthen check dams: Earthen check dams can be defined as small earthen embankments across gullies or streams to reduce the runoff velocity, stabilization of gullies and store the runoff water. The size of the gully plug/checkdam depends on width length and bed slope of the gully, anticipated runoff and proposed plantations in the gully. The height of the gully plug/earthen checkdam usually kept as 0.9 to 1.5 m, top width 1 m for small gullies and 2 m for medium gullies, side slopes 1:1, and length of the gully plug will be kept as equal to the channel width. The spacing depends upon the gradient of the channel bed. Usually for 3 % slope every 30 m distance gully plug can be constructed. These can be constructed at upper reaches of the catchment or watershed. The benefits of these check dams will be stabilization of gully beds and banks, deposition of sediments and nutrients, water storage thereby enhancing soil moisture and better plant growth. Reduced the runoff and soil loss by 80%.

Bori bund checkdam: Bori bunds is a type of embankment constructed across the gullies using polythene bags (empty cement or fertilizer bags) filled with the locally available sand or soil for blocking active and erosion-prone first-order streams. It is an effective method to slow down the speed of flowing water of the stream in any area. Usually where earthen gully plugs is not able to control the runoff flow these structures can be constructed. The size of the bori bund depends on width, length and bed slope of the gully, anticipated runoff and proposed plantations in the gully. The height of the bori bund usually kept as 0.9 to 1.5 m, top width 0.6 m, side slopes 1:1, and length of the gully plug will be kept as equal to the channel width. The spacing depends upon the gradient of the channel bed. Usually for 3 % slope every 30 m distance one bori bund can be constructed. For uniform distribution of soil moisture to the plantations, minimum spacing and minimum height can be maintained. Medium Gullies and deep gullies with complete sandy soils. The locations, where earthen gully plugs is not able to control the runoff flow (Rao et al., 2012). The benefits will be stabilization of gully beds and banks, deposition of sediments and nutrients, water storage thereby enhancing soil moisture and better plant growth. Reduced the runoff and soil loss by 80%.

 

Earthen and bori bunds/sand bag checkdams

Permanent gully control/water harvesting structures

Permanent Gully Control Structures are necessary where vegetative or temporary structures are not adequate. Permanent Structures such as masonry check dams, flumes or earth dams supplemented by vegetations are provided to convey the run-off over critical portion of the gully. Principal types of permanent structures are drop spillways, drop inlet spillways and chute spillways.

Drop spillway: The drop spill way is a weir structure. Flow passes through the weir opening, drops to an approximately level apron or stilling basin and the passes to the downstream channel Drop spillway may be constructed of reinforced concrete, plain concrete, rock masonry and concrete blocks with or without reinforcing or gabions. The spillway is an efficient structure for controlling relatively low heads, normally up to 3.0 meters.

Drop inlet spillways: A drop inlet spillway is a closed conduit that carries water under pressure from above an embankment to a lower elevation. The usual function of a drop inlet spillway is to convey a portion of the runoff through or under an embankment without erosion. It is a very efficient structure for controlling relatively high gully heads usually above 3.0m.

Chute spillways: A chute spillway is an open channel with a steep slope, in which flow is carried at a supercritical velocity. It consists of an inlet, vertical curve section, steep sloped channel and a out let. Reinforced concrete is widely used to construct chute spillways and adopted particularly to high overfall gullies, detention dams to reduce the required capacity.

Brick/stone masonry check dams

In locations, where natural streams are available in lower reaches of the watershed, the brick/stone masonry check dams can be an alternative for runoff harvesting and recycling to cope with climatic aberrations such as mid seasonal and terminal droughts and floods. The construction of brick stone masonry structures involves high cost without any scheme/ programme the adoptability by these structures is low. The rubber and plastic check dams are the cost effective and easyfor construction. These will reduce the construction difficulties. These are easily adopted by watershed management schemes for rainwater harvesting and water management practices for a long period without incurring any substantial maintenance cost.


Brick, Stone masonry checkdams

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Artificial Recharge Technology

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Introduction

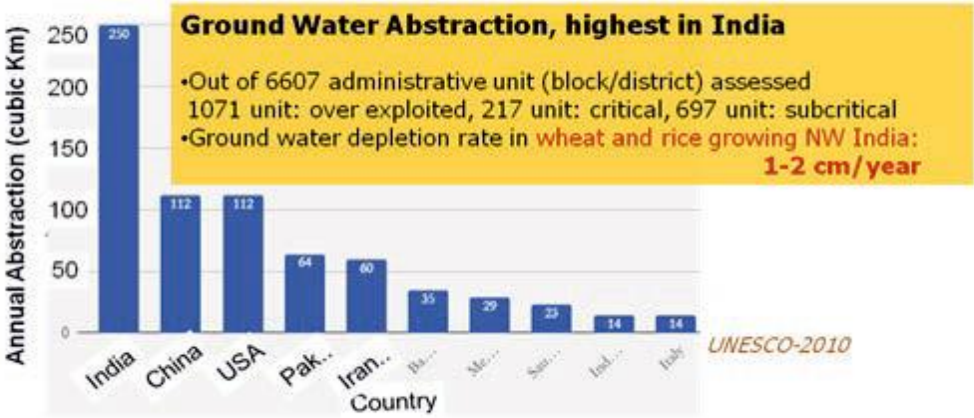
Once perceived inexhaustible, fresh water resources of India are understandably shrinking under intensive multiple sectors demand. Subsurface warehouse of water is one of the major sources of fresh water in India. A total annual replenishable ground water resource in India is estimated as 433 billion cubic meter (BCM) where as the net annual ground water availability is 399 BCM **(CWC-2011; Jha- 2008).** High productivity and efficiency per unit of irrigated area by using ground water resources, development through low cost pump, more dependable supply and advantage of local initiative led to fast expansion of ground water utilization (Sharda et al., 2007). Ground water extraction rate is one of the highest in India across the globe (Fig1). With large variation in stage, the overall ground water development is 61% in the country (Jain, 2012). About 60 % of irrigated agriculture in India is attributed to ground water (Gandhi, and Namboodiri, 2009; Shiferaw et al., 2003). It provides about 80% of water for domestic use in rural areas (CGWB master plan). Intensive use of ground water due to relatively easy access and high degree of perceived surety has done damage too. This precious resource is being depleted by two ways, firstly by over extraction and secondly by decreasing recharge. Out of 5845 assessment units, 803 units in India are over exploited (Jain, 2012). Large numbers of dried and defunct wells across the country are witness of unsustainable management. Digging deep in search of more water resulted in poor quality water. Depletion of ground water also involves the risk of collapse in water bearing porous structure leading permanent loss of ground water potentials. Fortunately it has been timely realized by scientists and policymakers of the country and several programmes have been initiated to augment and preserve

this precious natural resource.

Groundwater recharge defined as ‘the downward flow of water reaching the water table, forming an addition to the groundwater reservoir’ (Lerner et al., 1990) has been in focus of various stakeholders. The quantity of recharge to an aquifer is considered equivalent to the "safe yield" i.e. quantity of water that could be removed from an aquifer on a sustainable basis. The rate of natural recharge is low and runoff is more subjected to loss by evaporation and surface flow. The natural recharge surface is decreasing due to urbanization and industrialization. High atmospheric demands (potential evaporation) in arid and semi arid condition not only ruin the possibility of surface water storage in small structures but also reduce natural recharge especially in surface spreading method. With wide range of variation across the places (150- 11690mm), India receive about 1160 mm rainfall annually but highly skewed distribution of rainfall and intense monsoon rainfall make the natural ground recharge a difficult proposition and majority of rainfall goes off the land as surface runoff. About 55% of India is already under high to extremely high water stress. Artificial recharge is seen and advocated as a solution to this ominous problem in India.

Artificial recharge to ground water is a process by which the ground water reservoir is augmented at a rate higher than natural recharge rate. Any human efforts that add water to an aquifer may be considered to be an artificial recharge. Various techniques of artificial recharge are available which are mainly surface spreading techniques and sub-surface techniques. Direct well recharge in one option, if cautiously done reduces evaporation losses considerably. The large number of dried, defunct and drying wells in various parts of the country offers an opportunity for augmented recharge.

Fig 1. Annual ground water abstraction in different countries
Advantage of ground water recharge



o Surface inundation is avoided and the storage space is available at no cost

o Evaporation loss is minimized

o Infiltration also improves water quality

o The adverse social effect of surface water stogie including displacement of local population, loss of land and vegetation etc is avoided.

o The ground water is relatively safe from natural catastrophe including earth quack or dam breach under extreme events.

o It also gives opportunity of thermal buffering due to geo-cooling/geo-heating

Artificial recharge techniques

Three broad approaches/General Recharge methods used in India are based on Water Spreading (ii) Water Injection (Recharge Wells) (iii) Induced Recharge Water spreading: One of the most tradition methods of ground water recharge is water spreading as thin sheet. This gives opportunity of infiltration. The technique is fit for alluvial plain region with moderate to high infiltration rate. In area of low infiltration rate and harsh climate, evaporation loss may be substantial. It also occupies substantial area to work. Mostly common property resources and natural depressions are used for the purpose. Clogging due to suspended particle in runoff by swelling and soil dispersion, by algal growth etc. reduce the efficiency of the measures.

Percolation tanks

Percolation tank is a tank (shallow pond) created for the purpose of recharge. It is one of the most prevalent methods in India mainly because it requires less space than the water spreading techniques. It is more suitable on highly fractured and weathered rock for speedy recharge. Bouldary formations are ideal for locating Percolation Tanks on alluvial soil.

Ditch and furrow system

Closely spaced, flat bottomed shallow ditches are used for ground water recharge in the areas with irregular topography having water from source stream or canal. Generally three patterns of ditch and furrow system are adopted i.e. Lateral Ditch Pattern, Dendritic Pattern, and Contour Pattern. Though aimed for recharge, the water contact area seldom exceeds 10 percent of the total recharge area. Sufficient slope to maintain flow velocity and to reduce sediment deposition is necessary.

Over irrigations Over irrigation results into percolation of water reaching to ground water ut this is not a common practice in water scarce region. However ground water recharge through over irrigation is observed often in canal command area.

Stream augmentation/checkdam/nala bund: A barrier (height < 2m) is constructed across small streams hiving gentle slope. The method is suitable both in hard rock and alluvial region. This is in fact a checkdam made in the stream. A series of such check dams are desired for increasing the ground water recharge. There are subsurfacemethods to augment ground water recharge

Injection wells or recharges wells

Injection wells are similar to a tube well but that is used for groundwater recharge preferably of a confined aquifer or aquifer having confining layer of low permeability. Treated surface water is introduced into aquifer under pressure. In this method land requirement is substantially reduced and therefore mostly adopted in urban areas. It has been used successfully in putting diverted river water for ground water recharge using the filter. The effectiveness of injection well recharge is determined by (a) Pumping Rate (b) Permeability of aquifer (c) Distance from stream (d) Natural ground water gradient (e) Type of well. In alluvial system number of injection wells can be constructed to recharge a single aquifer but in the area where aquifers are separated it gas to be well designed to recharge different aquifers. This is a relatively costly option and also need specialized skill for construction and operations. It needs a fairly treated water to be injected and better suitable in over pumped area and in coastal region.

Recharge pits and shafts

These are the most efficient and cost effective structures to recharge the aquifer directly. In the areas where source of water is available either for some time or perennially e.g. base flow, springs etc. the recharge shaft can be constructed in areawhere impervious layers is present at shallow depth

Dug well recharge

In alluvial as well as hard rock areas, large number of dug wells have declined considerably or dried. These dug wells also provide an opportunity be used as recharge stricture. Storm water, tank water, canal water and water from reservoir is diverted into these structures to directly recharge the dried aquifer. A pipe is used to carry water to the bottom of well, below the water level to avoid scoring of bottom and entrapment ofair bubbles in the aquifer.

Bore hole flooding

Smaller diameter boreholes are used to directly recharge or dilute shallow aquifers in area having aquifer with low permeability upper boundary. In this case high quality is used for this purpose. Deep and high-yielding boreholes are generally used in area dug wells gets dry or where groundwater is saline. When water can be injected into borehole and recovered from another at a distance from the first, to increase the benefit of the water treatment capacity of the aquifer. This is also referred to Aquifer Storage Transfer and Recovery (ASTR). This method is best suitable for area of low natural recharge and of high amount and quality runoff. Filter system can also be combined with this method to improve the quality of water to be used for recharge

Induced recharge from surface water source

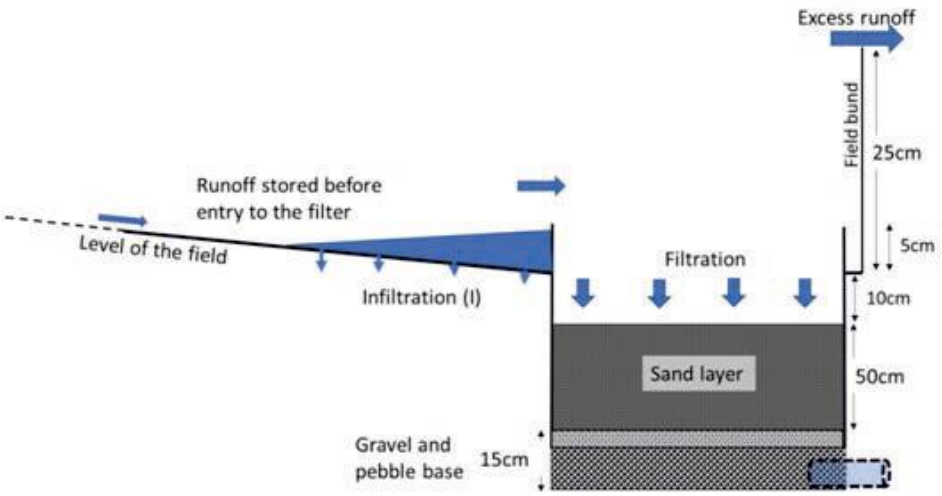
In this method water is pumped out from aquifer hydraulically connected with surface water, to induce recharge to the ground water reservoir. The idea is to intercepts river recharge boundary by creating cone of depression. In this method there is no artificial build up of ground water storage but only passage of surface water to the pump through an aquifer is facilitated. Abandoned channels often provide good sites for induced recharge. The improvement in the quality of surface water due to its path through the aquifer material before it is discharged from the pumping well is the greatest advantage of this method. Aquifer modification, Natural openings, cavity fillings, Basin or percolation tanks with pit shaft or wells and any combination of the three categories of methods can be used for ground water recharge. In additional to the above targeted approach, water conservation structures, viz, trenches, bunds, chechdams (gabion checkdam, masonary checkdam), subsurface dike are extensively used in watershed programme or otherwise land treatment plan for ground water recharge. Sub surface dyke are used to prevent the flow of ground water out of the sub basin and increase the storagecapacity of the aquifer.

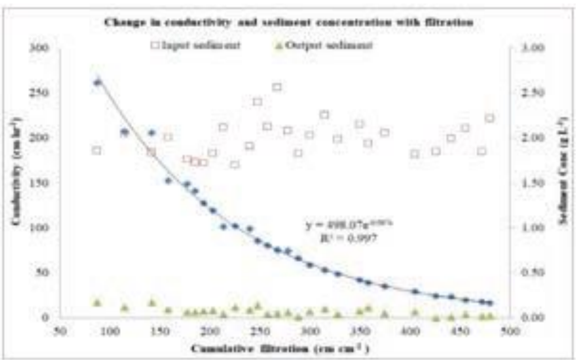
Major Limitations in adoption of methods of artificial ground water recharge at Individual level:

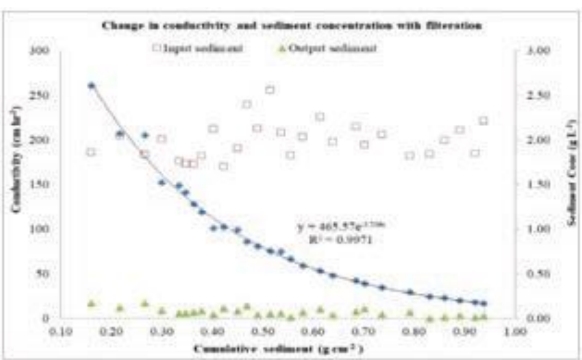
1. Benefits of artificial recharge are well defined, but it is not in proportion to the investment made by individual as it becomes available for others i.e. beneficiaries are ill defined.
2. Improving quality of runoff before using for ground water recharge becomes difficult at individual level and often ignored.
3. Maintenance of recharge structure is another major challenge at individual level. Adopting various recharge structures in a community participation mode preferably under watershed programme or other land development programmes is desired.

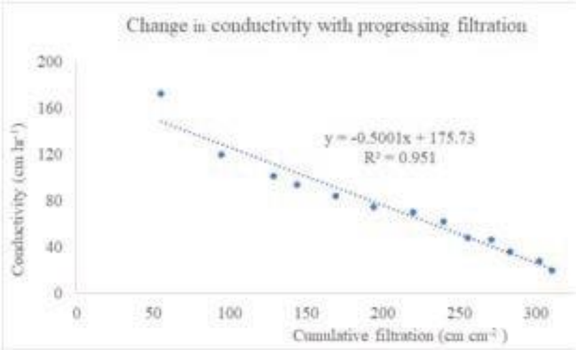
Case study:

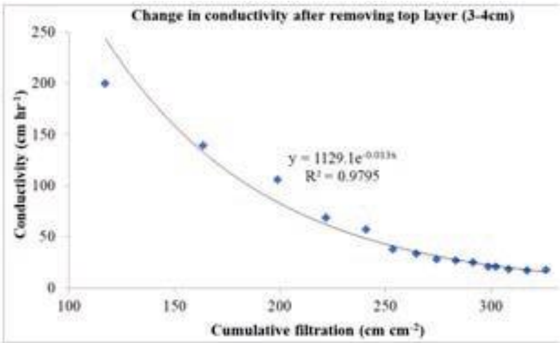
In initial recharge programme the inclination was more towards increasing the quantity of recharge, quality was considered secondary. However with increasing environmental concern, the runoff water being added to the ground water is treated for quality improvement. Attempt was made to develop design of sand and gravel filter (filter) for different land conditions for direct well recharge using dried and defunct wells.



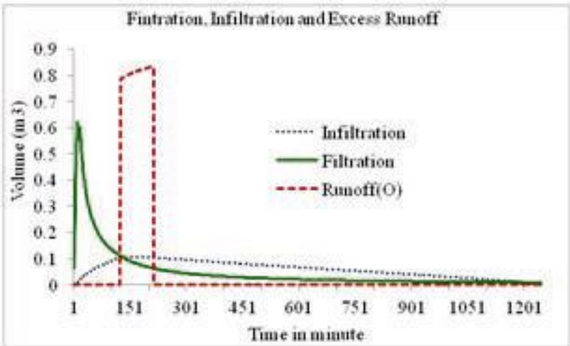


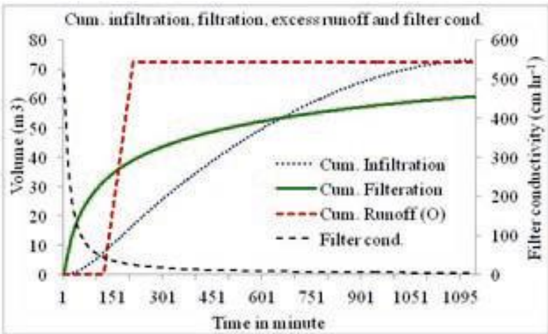


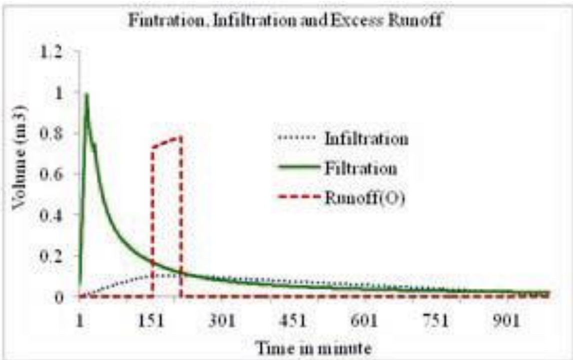


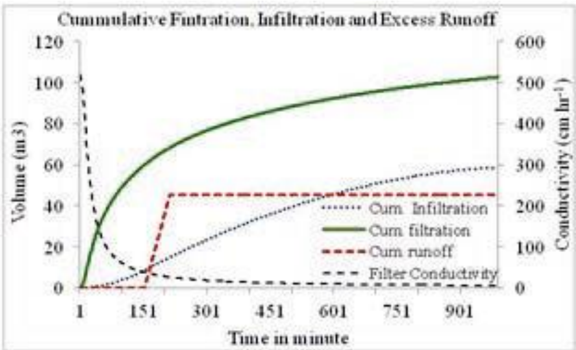


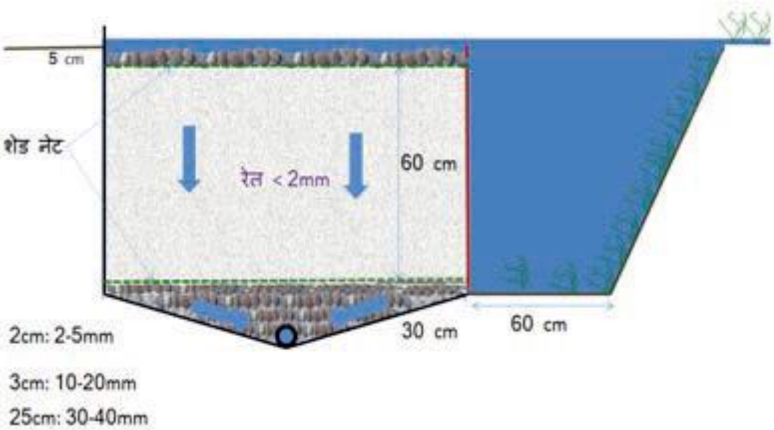
I. Con.: Initial conductivity using sediment free tap water, Cum. F.: Cumulative filtration by which conductivity reduced below 20cm hr-1. Con. Equations: The relation between conductivity (y) and cumulative filtration (x), Cons. Head: constant head of leachate maintained during filtration test. # conductivity came down to about 90 cm /hour notless than 20cm/hour. DL: Double layer of agronet,











Filtration, infiltration and excess runoff per minute (a&c) cumulative infiltration, filtration and excess runoff (b &d) from leveled filter of size 9m2 (upper) and 16m2 (lower) from a field of 100m X50m with bund height 0.25m, infiltration rate 1cm hr-1 and slope 2%, for rainfall of 100 mm in a day with uniform intensity of 30mm hr-1 (runoff-205.69, q peak-0.0167m3 s-1).

A practical design to be adopted for large scale filtration of agricultural runoff for direct well recharge

Conclusions

Artificial groundwater recharge technology is need of the time to avert the crisis of ground water depletion. The artificial recharge plays an important role in reducing runoff, increasing water availability and equity; improve drainage, revival of spring and improvement of ground water quality. Direct well recharge using dried and defunct wells is one of the practical and feasible options provided filtration setup is in place.

Different designs of recharge filter for direct well recharge were tested in laboratory using customized lab setup. Gravity based filter were extensively tested and modification for improvement in effective life was suggested. Two alternate designs up flow filter and two component filters were also tested in lab nd were constructed in the field.

Sharp reduction in conductivity with progress of filtration was observed in case of direct entry of sediment led water into gravity based filter. Provision of sedimentation before runoff entry to the main filter was found effective in reducing sediment load that helped maintain better conductivity. The conductivity of fresh sand materials was found exponentially reducing with cumulative filtration or cumulative sediment entry to the filter system. Scrapping of top surface (3-4 cm) along with deposited sediment helped improved the filter conductivity and can be a better option for field adoption. The up flow filter was found less prone to clogging thus longer effective life. The hydraulic efficiency was considerably higher but filtration efficiency poorer than the gravity based filer. In case of higher water head there is high risk of churning of the filter material therefore it is suitable only for plain field of slope < 3 % and bund height of less than 30cm. Two components filter having up-flow through gravel filter as first component and modified gravity based filter as second component was found intermediate in performance both in terms of hydraulic and filtration efficiency. The new designs were also installed in field for demonstration and have been adopted in developmental plan.

Agro-ecology specific rainwater management interventions for higher productivity and income in rainfed areas

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1. Introduction

Rainfed agriculture constitutes 80% of global agriculture, and plays a critical role in achieving global food security. However, growing world population, water scarcity, and climate change threaten rainfed farming through increased vulnerability to droughts and other extreme weather events. Out of the total population of 7.3 billion, about 1 billion are food-insecure, and 60% of these live in South Asia (SA) and Sub-Saharan Africa (SSA). The importance of rainfed agriculture varies regionally, but it produces most food for poor communities in developing countries. The proportion of rainfed agriculture is about 95% in SSA, 90% in Latin America, 60% in SA, 65% in East Asia, and 75% in Near East and North Africa (Srinivasarao *et al*., 2015).

With diverse climate, India has a high spatial and temporal variability in rainfall and temperature (Rao *et al*., 2010). For example, southern Tamil Nadu experiences typical tropical temperatures with north-east monsoon being the main source of rainfall, whereas Punjab and Haryana in north-western India experience continental climates with extremes of temperatures varying from 45e50 _C in summer and near freezing temperatures in winter. The rainfed farming in north-western India is practiced under south-west monsoon rains. Thus, the climate of rainfed dry land farming ranges from arid, semiarid to subhumid, with mean annual rainfall varying between 412 and 1378 mm. In terms of the distribution of rainfall, 15 million hectare (Mha) of the land receives an annual rainfall of <500 mm, 15 Mha of 500-750 mm, 42 Mha of 750-1150 mm, and 25 Mha of >1150 mm.

2. Water resources in India

There has been a paradigm shift in water resources use in India since 1950s from communities (tanks and small water structures) to government (major and medium irrigation projects), and the private domain (groundwater). Groundwater provides about 70% of the irrigation and 80% of the drinking water. The principal source of water is precipitation (rainfall and snowfall), but only a part of the rainfall is stored as groundwater and the remaining is lost as runoff and evaporation.

Out of the total annual precipitation (including snowfall) of around 4000 km3 in the country, the availability from surface water and replenishable groundwater is w1869 km3, comprising of 690 km3 (37%) of surface water, and 432 km3 of groundwater (GOI, 2002). Total annual national water use may exceed the utilizable water resource by 2050 or 2060, unless significant changes occur through increased water storage and efficient water management. Thus, available water resources must be judiciously used. Nonconventional methods for utilization of water (e.g., through inter basin transfers, artificial recharge of groundwater, and desalination of brackish or sea water) as well as traditional water conservation practices (e.g., rainwater harvesting, including rooftop rainwater harvesting) must be practiced further to increase the utilizable water resources.

3. Rainwater management

In rainfed regions, due to the temporal and spatial variability and due to skewed distribution of rainfall, crops invariably suffer from moisture stress at one or the other stages of crop growth. Besides, the demand for water is growing continuously at an accelerated pace for meeting the requirements of various other sectors such as drinking, domestic, energy and industry, resulting in strain on water resource availability for agriculture sector. As the rainfall is the single largest source of water and water being the critical input for rainfed agriculture, effective rainwater management is critical for successful rainfed agriculture. The strategy for rainwater management in arid and semiarid regions mainly consists of selection of short duration and low water requiring crops and conserving as much rainwater as possible so that crops can escape moisture stress during the growing period. In addition to *in-situ* conservation, efforts need to be made to divert the surplus water into storage structures, which can be used either as standalone resource or in conjunction with groundwater for meeting the critical irrigation requirements. In relatively high rainfall regions, the strategy is to conserve as much rainwater as possible and to harvest the surplus water for lifesaving irrigation and also for enhancing the cropping intensity, and to maximize returns from the harvested water. Apart from enhancing the availability of water by various methods, the approach is to increase the water-use efficiency by arresting losses associated with utilization of water and to maximize returns from every drop of harvested water. Watershed management is the flagship program of the country to enhance the water resource availability, which aims at reducing the severity of erosion, drought, and floods; optimize the use of land, water, and vegetation; and improve agricultural production and enhance the availability of fuel and fodder on a sustained basis.

3.1 *In-situ* moisture conservation

As large part of rainfed agriculture consists of marginal and small holdings, *in-situ* moisture conservation measures are more practical. Location specific *in-situ* moisture conservation practices were developed by AICRPDA based on rainfall, soil types and overall agro-ecology

(Table 1). Treating land before commencing rains through summer ploughing, broad bed furrow (BBF) raised and sunken bunds etc facilitates the maximum intake of rainwater into soil profile thus successful crop production is possible in rainfed regions of India. Ridge furrow, sowing across the slope and paired row sowing are important water conservation measures which have proved to be highly effective not only for water conservation but also draining out of excess rainwater during heavy rains. The yield improvements with these technologies varied from 20 to 40% depending upon rainfall and its distribution. BBF and ridge-furrow technology implementation have saved soybean and maize crops during 2013 from heavy rains in Malwa regions of MP and Vidarbha region in Maharashtra and crops without these interventions completely failed. Based on the success of these technologies, Government of Maharashtra is implementing these *in-situ* moisture conservation measures in large scale under Dryland Farming Mission of Maharashtra state.

***In-situ* moisture conservation through conservation furrow**

Table 1. Recommended soil and water conservation measures for various rainfall zones in India

Seasonal rainfall (mm)			
< 500	500-700	750-1000	> 1000
Contour cultivation with conservation furrows	Contour cultivation with conservation furrows	BBF (Vertisols) conservation furrows	BBF (Vertisols)
Ridging	Ridging	Sowing across slopes	Field bunds
Sowing across slopes	Sowing across slopes	Tillage	Vegetative bunds
Mulching	Scoops	Lock and spill drains	Graded bunds
Scoops	Tied ridges	Small basins	Level terrace
Tied ridges	Mulching	Field bunds	
Off-season tillage	Zing terrace	Vegetative bunds	
Inter-row water harvesting systems	Off-season tillage	Graded bunds	
Small basins	BBF	*Nadi*	
Contour bunds	Inter-row water harvesting system	Zing terrace	
Field bunds	Small basins		
Khadin	Modified contour bunds		
	Field bunds		

3.1.1 Leveling and bunding: Leveling of the soil and bunding is the simplest and most important operation required to effectively utilize the rainwater and uniform distribution of fertilizers and seeds under rainfed situations. Different types of bunds are suggested depending on soil type and rainfall pattern. For Alfisols having slopes more than 1.5%, contour bunding is found to be the most promising. Well designed and maintained contour bunds on Alfisols conserve soil and water more effectively than graded and field bunds (Pathak *et al.,* 1985). Graded bunds are suggested in areas having higher rainfall with less permeable, deep heavy soils. In Northern Karnataka adoption of graded bunds in Vertisols for pigeonpea, horsegram, blackgram, greengram and chickpea recorded higher seed yields by 17, 54, 12, 25 and 23%, respectively compared to control in rainfed environments (Guled *et al.*, 2003).

3.1.2 Tillage: Summer/off-season tillage is one of the most important traditional practices in rainfed areas. Off-season tillage has been found to be useful in increasing rainwater infiltration and minimizing water evaporation by a 'mulching' effect. Deep ploughing plays an important role in stabilizing the productivity of rainfed pulses through *in situ* soil moisture conservation (AICRPDA, 2003). Summer tillage with two-bottom mouldboard plough utilizing residual moisture or pre-monsoon showers is recommended to make the land ready for planting in eastern Uttar Pradesh. This practice helps in greater retention of rainwater (36% higher than conventional method) and enhances the yield of pigeonpea by 86% compared to farmers' practice (Venkateswarlu *et al.,* 2009). In another experiment in medium deep black soils at AICRPDA centre Arjia (Bhilwara district, Rajasthan), *in situ* moisture conservation with summer deep ploughing with raised bed of 40 cm width gave highest blackgram yield (1243 kg/ha), rainwater use efficiency and lowest runoff and soil loss compared to farmers' practice of flat bed (AICRPDA, 2011). It is evident from several experiments that the effects of deep tillage could last for 2 to 5 years depending upon the soil texture and rainfall. On Alfisols, the problem of crusting and sealing is encountered during early stages of crop growth resulting in uneven germination and plant stand. Under stress conditions, shallow tillage as an additional inter cultivation has been found to be effective in breaking up the crust, improve infiltration, and reduce moisture losses through evaporation by creating dust mulch (AICRPDA 2011).

3.1.3 Compartmental bunding: It is another *in situ* moisture conservation practice in medium to deep Vertisols in post-monsoon predominant cropping areas like northern dry zone of Karnataka. Dividing the field into parcels of 4.5 x 4.5 m and 3 x 3 m on lands having slopes of 2% and 3%, respectively is called compartmental bunding (Guled *et al.,* 2003). In a study conducted at Bijapur, there was reduction in runoff in compartment bunded plots (6.8%) compared to conventional practice (15.6%). It is an affordable technology, which can be adopted by employing a simple bund former.

3.1.4 Land configuration: Raised land configurations such as broadbed and furrow (BBF), raised and sunken beds etc. not only help in efficient conservation of rainwater but also drain out excess water during high rainfall events, particularly in black soils, thereby enhance the productivity of crops. BBF system refers to modifying the land surface into alternative wide (1.5 m) beds and narrow (50 cm) furrows. This system has been found useful in vertisols of low to medium rainfall (<1000 mm) regions. In Southern Tamilnadu, *in-situ* moisture conservation thorough BBF in greengram recorded higher seed yield (750 kg/ha) over flat bed sowing (630 kg/ha) (AICRPDA-NICRA, 2016). Similarly, raised and sunken bed system is advocated for vertisols of high rainfall (>1000 mm) regions. In northwest plain zone, land configuration improved the productivity of pigeonpea by 40% with raised bed at 2.7 m width compared to flat bed system. In Bastar plateau region of Chhattisgarh, ½ feet raised/sunken bed improved seed yield of cowpea by 35% compared to flat bed method (3454 kg/ha) (AICRPDA, 2015).

In eastern Uttar Pradesh, ridge-furrow planting of pigeonpea (on ridge) and rice (in furrows) both in uplands and medium lands helped in runoff modulation, crop diversification, risk reduction and disruption of pest cycle. This system produced a rice equivalent yield of 8866 kg/ha and 47% higher income as against 3500 kg/ha of rice with farmers' practice of sole rice under flat bed planting. In Kandi region of Punjab, ridge planting of greengram and blackgram gave 33 and 12% higher seed yields compared to flat planting, respectively (AICRPDA-NICRA, 2016).

3.1.5 Conservation furrows: Conservation furrows are the opening of furrows parallel to rainfed crop rows across the land slope, with a country plough, 3 to 4 weeks after the germination of the main crop (Venkateswarlu *et al*., 2008). During runoff causing rainfall events, the rainwater gets concentrated within these furrows, infiltrates into the soil (root zone) and is available to the crop for meeting the evapo-transpiration demand for a longer duration compared to no furrow. Large scale demonstrations in Karnataka proved that finger millet + pigeonpea intercropping system (8:2) with staggered moisture conservation furrow gave higher net returns (Rs. 14198/ha) as compared to farmers' practice (Ramachandrappa *et al*., 2010). In scarce rainfall zone of Andhra Pradesh, *in-situ* moisture conservation through opening of conservation furrows recorded 9% higher seed yield of pigeonpea (738 kg/ha) compared to control (AICRPDA-NICRA, 2016).

Set furrow cultivation is another effective micro-site improvement process which conserves rainwater effectively and offers excellent drought proofing. In this technique, crop rows are set permanently by opening deep furrows of 25 to 30 cm at wider distance (135 cm) and all the inputs (crop residues, manures and fertilizers) are applied in the set furrows before sowing. At Bijapur (Vertisols), set furrow with residue incorporation + glyricidia (5 t/ha) in pigeonpea +

groundnut intercropping (2:4) resulted in efficient *in-situ* moisture conservation and gave higher pigeonpea equivalent yield (1864 kg/ha) and net returns (Rs. 71931/ha) than farmers' practice (1479 kg/ha) (AICRPDA, 2015).

3.1.6 Contour farming: While tillage helps in improving water intake, contour cultivation boosts it further by building up temporary water storage capacity in furrows across the slope. Contour cultivation is, however, difficult to achieve on small and narrow fields. Under such situations, cultivation across the slope is a viable alternative for efficient *in situ* moisture conservation. It consists of performing all agricultural operations (tillage, sowing, inter-cultivation etc) along the contour. Taley (2012) reported that the soil moisture content increased by 22-75% due to contour cultivation and enhanced the productivity of greengram (62.5%), pigeonpea (75%) and soybean + pigeonpea (46-50%). Further, due to cultivation of chickpea across the slope, there was increase in soil moisture content (16-36%), chickpea yield and rainwater use efficiency (RWUE) in deep black soils. Similarly, contour cultivation with opening of contour furrows at 20 m HI and formation of square basins (20 x 20 m) enhanced yield of chickpea by 50 and 66.6%, respectively.

3.1.7 Mulching: Mulching is useful for achieving higher rainfall infiltration, reduced soil erosion, structural stability and minimize soil moisture losses through evaporation. Different materials such as crop residues, green manure, sand, polyethylene and pebbles can be used as mulch. Soil water content under sand mulch at any point of time in a year could be 85-98% compared to no mulch. The practice of sand mulching in sodic Vertisols of northern marnataka enables double cropping of groundnut or green gram in *kharif* followed by sorghum or chickpea in *rabi*. The cost of sand application can be recovered within 2 years of cropping. A uniform layer of pebbles on soil surface will prevent transfer of heat from the surrounding air to the soil, reducing evaporation losses. It also helps control runoff water effectively. Large scale demonstrations conducted on an area of 500 ha in Bagalkot taluk of Karnataka clearly indicated the yield advantage of 200% in greengram (Guled *et al*., 2003). In scarce rainfall zone of Andhra Pradesh, *in-situ* moisture conservation through conservation furrow and mulching with groundnut shells recorded higher seed yield of pigeonpea (610 kg/ha) compared to control (270 kg/ha). Similarly, in Central Maharashtra, *in-situ* moisture conservation through mulching with crop residues gave 8-10% higher yields of greengram, blackgram and pigeonpea compared to no mulching (AICRPDA-NICRA, 2016). The effect of mulches on crop productivity and profitability in different locations are given in Table 2.

Table 2. Effect of various mulch materials on crop productivity and profitability at different locations in India

Location	Crop	Type of mulch	Yield increase over without mulch (%)	Net return (Rs/ha)	
				With mulch	Without mulch
Ballowal Saunkri (Punjab)	Sarson	Paddy straw	41.9	9820	4453
	Lentil	Subabul	35.2	9042	4462
	Maize	Sugarcane trash	56.8	8359	6600
	Wheat	Paddy straw	59.7	15067	12358
SK Nagar (Gujarat)	Castor	Crop residue	28.5	16594	12595
Indore (Madhya Pradesh)	Pigeonpea	Crop residue	8.7	23812	21766
	Soybean	Polythene	42.7	34839	23666
Varanasi (Uttar Pradesh)	Upland rice	Straw	19.4	3799	1802

Source: Compiled by authors from Annual Reports of AICRPDA

3.2 *Ex-situ* rainwater harvesting and efficient utilization

The importance of rainwater harvesting has increased in recent years due to the increased rainfall variability, heavy rains and depletion of groundwater levels. Rainwater harvesting and recycling through farm ponds, restoration of old rainwater harvesting structures in dryland/ rainfed areas, percolation ponds for recharging of open wells, bore wells and injection wells for recharging ground water are taken up for enhancing farm level water storage in drylands. Watershed management is the flagship program of the country to enhance the water resource availability, which aims at reducing the severity of erosion, drought, and floods, optimize the use of land, water and vegetation, and improve agricultural production and enhance the availability of fuel and fodder on a sustained basis.

Rainwater harvesting in farm ponds

It has been estimated that, 27.5 M ha of rainfed area of the country, excluding the very arid and wet areas, can contribute an amount of 114 billion m^3 of water for water harvesting which is adequate to provide one supplementary irrigation of 100 mm depth to 20 M ha during drought years and 25 M ha during normal years (Sharma et al., 2010). Harvesting the runoff water and storing it in farm ponds is a possibility in rainfed regions and the size of the pond depends on the rainfall, topography, and soils of the region. The so harvested water during the *kharif* (rainy) season can be used either for supplemental irrigation during dry spells coinciding with critical crop stages in *kharif* or for establishment of *rabi* (winter) crops. The advantages of supplemental irrigation are significant and considerable improvement in crop yields has been noticed at locations of various AICRPDA centers as given in Table 3.

Table 3. Effect of one supplemental irrigation (5 cm) from harvested rainwater in farm ponds on yield of rainfed crops

Crop	Yield (kg/ha)	Yield increase due to irrigation (%)	Location
Sorghum	1270	19	Anantapur
Sorghum	1350	32	Bijapur
Maize	4333	71	Arjia
Cotton	1730	14	Kovilpatti
Soybean	2050	14	Indore
Castor	1320	31	Hyderabad
Wheat	2143	25	Ballowal Saunkhri
Pea	2207	44	Varanasi
Barley	3001	32	Agra
Safflower	1014	48	Parbhani

Source: Compiled by authors from Annual Reports of AICRPDA

The rainwater harvesting and efficient utilization as supplemental irrigation to rainfed crops during prolonged periods of dry spells enhanced productivity and profitability (Ravindra Chary et al., 2016) (Table 4).

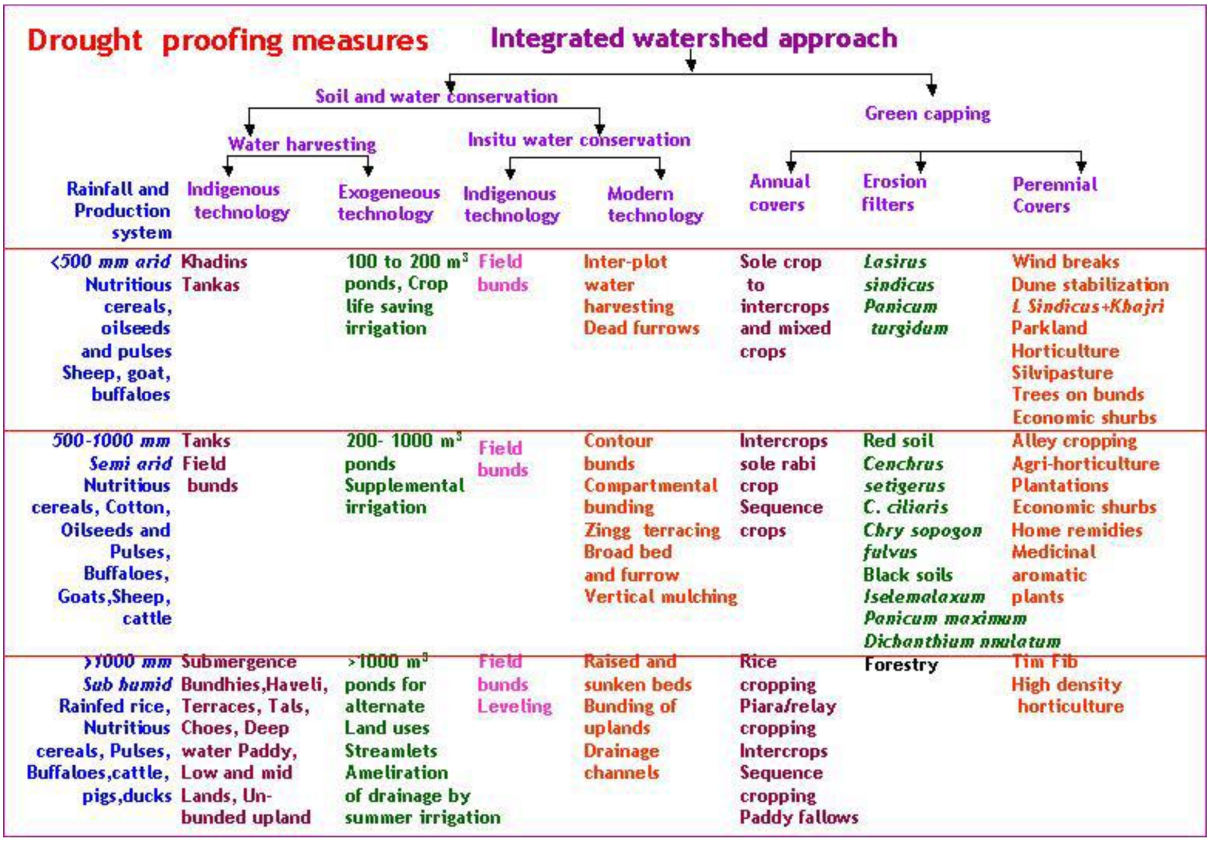
Table 4. Response of pulses to supplemental irrigation

Location/ State	Climate (MARF* mm)	Dominant soil type	Crop	Yield (kg/ha)		Increase in yield (%)	Source
				Irrigated	Control		
Akola (Maharashtra)	Semiarid hot moist (824)	Vertisols	Pigeonpea Chickpea	1000 1000	600 375	67 167	Taley (2012)
Rewa (Madhya Pradesh)	Sub humid hot dry (1088)	Vertisols	Chickpea	1905	1270	50	AICRPDA (2010)
Agra (Uttar Pradesh)	Semiarid hot dry (665)	Inceptisols	Lentil	1353	1119	21	AICRPDA (2011)
Parbhani (Maharashtra)	Semiarid hot moist (901)	Vertisols	Pigeonpea	748	435	72	AICRPDA-NICRA (2016)

*Mean annual rainfall

3.3 Watershed approach for rainwater management

Watershed management is a holistic approach towards optimizing the use of land, water and vegetation to alleviate drought, moderate floods, prevent soil erosion, and improve water availability and increase fuel, fodder, fibre and agricultural production on a sustained basis. Integrated watershed management (IWM) is the key to conservation and efficient utilization of vital natural resources viz., ‘soil’ and ‘water’, particularly in rainfed agriculture where water is the foremost limiting factor for agricultural production. The prioritized steps involved in resource conservation are the use of practices based on the existing traditional systems. (Fig . 1).



Rainfall and Production system	Water harvesting: Indigenous technology	Water harvesting: Exogeneous technology	Insitu water conservation: Indigenous technology	Insitu water conservation: Modern technology	Green capping: Annual covers	Green capping: Erosion filters	Green capping: Perennial Covers
<500 mm arid Nutritious cereals, oilseeds and pulses Sheep, goat, buffaloes	Khadins Tankas	100 to 200 m^3 ponds, Crop life saving irrigation	Field bunds	Inter-plot water harvesting Dead furrows	Sole crop to intercrops and mixed crops	*Lasirus sindicus Panicum turgidum*	Wind breaks Dune stabilization *L Sindicus+Khajri* Parkland Horticulture Silvipasture Trees on bunds Economic shurbs
500-1000 mm Semi arid Nutritious cereals, Cotton, Oilseeds and Pulses, Buffaloes, Goats,Sheep, cattle	Tanks Field bunds	200- 1000 m^3 ponds Supplemental irrigation	Field bunds	Contour bunds Compartmental bunding Zingg terracing Broad bed and furrow Vertical mulching	Intercrops sole rabi crop Sequence crops	Red soil *Cenchrus setigerus C. ciliaris Chry sopogon fulvus* Black soils *Iselemalaxum Panicum maximum Dichanthium nnulatum*	Alley cropping Agri-horticulture Plantations Economic shurbs Home remidies Medicinal aromatic plants
>1000 mm Sub humid Rainfed rice, Nutritious cereals, Pulses, Buffaloes,cattle, pigs,ducks	Submergence Bundhies,Haveli, Terraces, Tals, Choes, Deep water Paddy, Low and mid Lands, Un-bunded upland	>1000 m^3 ponds for alternate Land uses Streamlets Amelioration of drainage by summer irrigation	Field bunds Leveling	Raised and sunken beds Bunding of uplands Drainage channels	Rice cropping Piara/relay cropping Intercrops Sequence cropping Paddy fallows	Forestry	Tim Fib High density horticulture

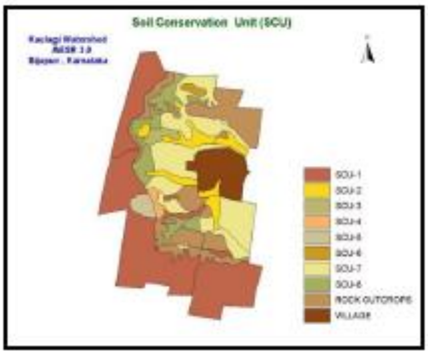
Fig 2. Drought proofing measures in arid, semi-arid and sub-humid regions (Vittal *et al.*, 2003)

Meta analysis of 311 watershed case studies from different agro-eco regions in India revealed that watershed programs benefitted farmers through enhanced irrigation areas by 33.5%, increase in cropping intensity by 63%, reduction in soil loss by 0.8 t/ha and runoff by 13% and improvement in groundwater availability. Economic assessment showed that the watershed programs were beneficial and viable with a benefit-cost ratio of 1:2.14 and an internal rate of return of 22% (Joshi et al., 2005).

4. Scientific Rainfed Land Use Planning

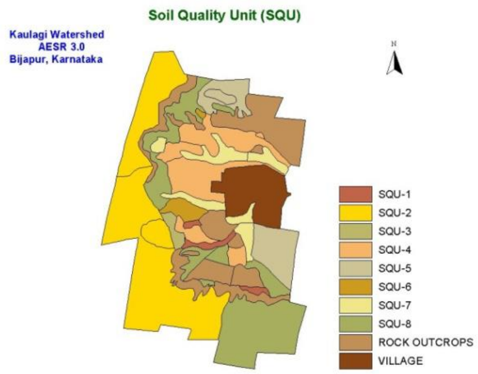
Scientific land use planning in drought prone regions is one of the rational approaches for drought mitigation. The ICAR- National Agricultural Technology Project (NATP)- Mission Mode Project on Land Use Planning for Managing Agricultural Resources – Rainfed Agroeco system was implemented by 13 AICRPDA centers in an area of 5258 ha in 16 Micro watersheds across arid, semiarid and subhumid agroeco subregions. Based on the evaluation of the existing land use and land evaluation for suitability of crops, 932 on-farm trials were conducted in 603 ha at 1294 sites on 132 soil sub-groups on varying topo- equences and the outcome distinctly indicated that in a micro watershed at cadastral level (1:10000/25000) the scientific land use on a soil-landscape continuum could enhance the land productivity from 20 to 50% compared to traditional land use. The cadastral level soil-site specific cropping systems centred land use modules were developed/identified, for example, *Mucuna utilis* on alfisols of Bangalore, pigeonpea+greengram, coriander and chickpea +senna inter/relay crops together in post monsoon Vertisols of Kovilpatti, sesame+castor in Vertisols of Akola, rainfed rice+pigeonpea in inceptisols of Varanasi, groundnut –vamu sequence in Vertisols of Bellary, safflower with compartmental bunding in deep Vertisols of Solapur (Ravindra Chary *et al*., 2008; Final Report - NATP-MMALUP-III- 28-Rainfed groecosystem, 2005).

Further, based on the cadastral level soil resource information in the micro watersheds, Ravindra Chary *et al.* (2005) developed Land Management Units (LMUs) for land resource management since these units are homogeneous and has a wider application. As a first step, the Soil Conservation Units (SQUs) and Soil Quality Units (SQUs) were delineated and secondly, the SCUs and SQUs are merged in GIS environment to delineate land parcels in to homogenous Land Management Units with farm boundaries. A resilient, less risk prone farming system based on the land requirements and farmers' capacities can be developed to mitigate the drought and to address the unabated land degradation and imminent climate change. The SCUs are basically for soil and water conservation prioritized activities to mitigate drought and could be linked to programmes like MG National Rural Employment Guarantee Scheme (MGNREGS) in a watershed/ village to create physical assets like farm ponds etc. SQUs are to address soil resilience and improve soil organic carbon, problem soils amelioration and wastelands treatment and linked to various schemes and programmes in operational like National Horticultural Mission (NHM), Rashtriya Krishi Vikas Yojana (RKVY), etc. LMUs would be operational zed at farm level for taking decisions on arable, non-arable and common lands for cropping, agroforestry, agrohorti culture, etc., and further, for leving the most fragile land parcels for ecorestoration. Rainfed land use planning modules should be based on these units for risk minimization, enhanced land productivity and income, finally for drought proofing. An example of delineation of these units for the Kaulagi watershed, Bijapur district, Karnataka is shown in Fig. 3, 4, and 5.



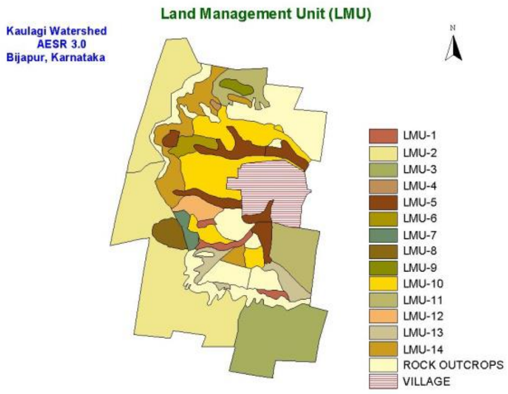
SCU	Details	Area (%)
2	Deep + low erosion	50.23
3	Shallow + very low erosion	7.68
4	Shallow + moderate erosion	1.61
5	Deep + moderate erosion	1.17
6	Deep + high and very high erosion	1.99
7	Very shallow + low erosion	0.83
8	Very shallow + moderate erosion	27.31
9	Very shallow + high and very high erosion	9.18

Fig 3. Soil Conservation Units (SCUs) in the Kaulagi watershed, Bijapur district, Karnataka



SQU	Details	Area (%)
1	Non gravel + neutral (pH) + low (OC) + normal (EC) + calcareous ($CaCO_3$)	1.67
2	Non gravel + neutral (pH) + low (OC)+ high (EC) + calcareous	36.76
3	Non gravel + alkaline (pH) + low (OC)+ normal (Eke) +calcareous	1.17
4	Gravel + alkaline (pH) + high (OC) + normal (EC) + calcareous	15.71
5	Gravel + alkaline (pH) + medium (OC)+ normal (EC) + calcareous	10.07
6	Gravel + alkaline (pH) + low (OC) + normal (EC) + calcareous	2.12
7	Gravel + alkaline (pH) + low (OC) + critical (EC)+ calcareous	7.51
8	Extremely gravel + alkaline (pH) + low (OC) + normal (EC) + calcareous (CaCO3)	25.00

Fig 4. Soil Quality Units (SQUs) in the Kaulagi watershed, Bijapur district, Karnataka



LMU	SCU	SQU	Soil Series
LMU-1	SCU - 1	SQU - 1	15 F
LMU – 2	SCU - 1	SQU - 2	1 A/2A
LMU – 3	SCU - 1	SQU - 8	5 B
LMU – 4	SCU - 2	SQU - 6	9 D
LMU – 5	SCU -2	SQU - 7	8 D/9D/10D/11D
LMU – 6	SCU - 3	SQU - 4	12 E
LMU – 7	SCU - 4	SQU – 3	4 C
LMU – 8	SCU - 5	SQU – 2	3 A
LMU – 9	SCU - 6	SQU -5	17 G
LMU – 10	SCU - 7	SQU – 4	12E/132E/14E
LMU – 11	SCU - 7	SQU – 5	16G
LMU -12	SCU - 7	SQU – 6	13E
LMU – 13	SCU - 7	SQU – 8	18H
LMU -14	SCU - 8	SQU – 8	18H

Fig 5. Land Management Units (LMUs) in the Kaulagi watershed of Bijapur district, Karnataka

Participatory land use planning is a buzzword for achieving the different goals of the various stakeholders. In stressed ecosystems like rainfed where in the major crop based production systems are established as best land use planning over a period of time, no single land use or single criteria has sustained the land productivities, incomes, ecosystem and finally the livelihoods reasons being highly complex situations of risk, diverse socioeconomic settings and subsistence agriculture. Thus, land use planning in drought prone areas majorly occurring in rainfed regions should aim at increased land productivity in totality through various means from annuals to perennials by coping with aberrant weather causing drought and inherent unabated land degradation. The final aim is to build a bio-diverse mixed farming system model for individual farmer to sustain the farming system and achieving the goals of food, nutritional economic and ecological securities with complimentary benefits of drought irrigation or drought proofing and land management and a buffer to impact of land use change.

Water Resources - Irrigation Structures

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Next to air, the other important requirement for human life to exist is water. It is the Nature's free gift to human race. The use of water by man, plants and animals is universal.

Water plays important role in agriculture, manufacture of essential commodities, generation of electricity, transportation, recreation, industrial activities, etc. But to ensure their services for all the time to come, it becomes necessary to maintain, conserve and use these resources very carefully in every sphere of life.

Limited Fresh Water

Although water is the most widely occurring substance on Earth, only 2.53% of it is fresh water. The remaining 97.47% is saltwater. Of the small amount of freshwater, only one third is easily available for human consumption, the large majority being locked up in glaciers' and snow cover.

Water Crisis

Water crisis is the one that lies at the heart of our survival, and that of our planet earth. As all different modes of water use have continued to increase, many countries, especially those located in arid and semi arid regions have started to face crises, although the magnitude, intensity and extent of the crisis could vary from country to another or even within the same country, and also over time. There are many, often interrelated, factors that could make the water crisis more pervasive in different parts of the world in the coming years.

Increasing population and higher levels of human activities, including effluent disposals to surface and ground water sources, have made sustainable management of water resources a very complex task throughout the world. In addition, per capita demand for water in most countries is steadily increasing as more and more people achieve higher standards of living and as lifestyles are changing rapidly.

Water Usage

Water is essential to life in every way, we need clean water for drinking, adequate water for sanitation and hygiene, sufficient water for food and industrial production, and much of our energy generation relies on or affects water supplies. Demographic and urban growth over the next century will mean a far greater demand for water for industrial production. Water usage pattern which is growing at alarming rate, is shown in the

Comparison of water usage in different sector

Sector	Usage in (%)			
	World	Europe	Africa	India
Agriculture	69	33	88	82
Industry & others	23	54	5	12
Domestic use	8	13	7	6

Water for Agriculture

Almost 70% of all available freshwater is used for agriculture. Over pumping of ground water by the world's farmers exceeds natural replenishment by at least 160 billion cubic meters a year. It takes an enormous amount of water to produce crops: three cubic meters to yield just one kilo of rice. Land in agricultural use has increased by 12% since the 1960s to about 1.5 billion hectares. Current global water withdrawals for irrigation are estimated at about 2,000 to 2,555 km3 per year.

Agriculture is responsible for most of the depletion of ground water, along with up to 70% of the pollution. Both are accelerating. Many of the world's most important grain lands are consuming ground water at unsustainable rates.

For the last half-century, agriculture's principal challenge has been raising land productivity – getting more crops out of each hectare of land. As we have stepped into the twenty first century, the new frontier is boosting water productivity getting morefrom every litre of water devoted to crop production.

The key is to custom design strategies to fit the farming culture, climate, hydrology, crop choice, water use pattern, environmental conditions, and other characteristics of each particular area.

Drip irrigation ranks near the top of measures with substantial untapped potential. In contrast to a flooded field, which allow a large share of water to evaporate without benefitting a crop, drip irrigation results in negligible evaporation losses. When combined with soil moisture monitoring or other ways of assessing crop's water needs accurately, drip irrigation can achieve efficiencies as high as 95 percent, compared with 50-70 % for more conventional flood or furrow irrigation.

Irrigation structures

Irrigation projects are classified based on the extent of irrigated ayacut (commandable area).

Major irrigation project Ayacut above 25000 Acres (10,000 ha.)are termed as Major Projects.

Medium irrigation project Ayacut above 5000 Acres (2000 ha) & up to 25000 Acres (10000 ha.)are termed as Medium projects

Minor irrigation project Ayacut upto 5000 Acres (2000 ha) are known as Minor projects.

Components of irrigation system

– Head works

– Conveyance system

– Submergence area/catchment area

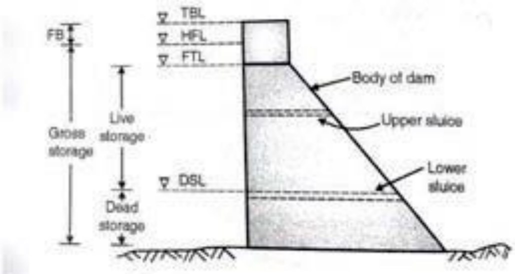
– Command area

Reservoir A reservoir is an artificial lake where water is stored. Most reservoirs are formed by constructing dams across rivers. A reservoir can also be formed from a natural lake whose outlet has been dammed to control the water level. The dam controls the amount of water that flows out of the reservoir.

Dam: when a barrier is constructed across a river in the form of dam, water gets stored on upstream side of the barrier, forming a pool of water called dam reservoir or impounding reservoirs or a storage reservoirs or a river reservoirs.

Weir A weir or low head dam is a barrier across the width of a river that alters the flow characteristics of water and usually results in a change in the height of the river level. They are also used to control the flow of water for outlets of lakes, ponds, and reservoirs.

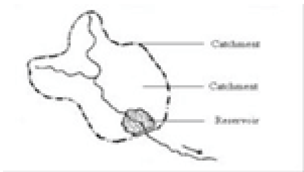
Balancing Reservoir A reservoir downstream of the main reservoir for holding water let down from the main reservoir in excess of that required for irrigation, power generation or other purposes.



Catchment area of a hydro site is the total area located behind the dam, Draining water into the reservoir. The place is usually steep at this point. And the Dam head acts as outlet point to let out the water after utilizing it for power production.

Command Area Command area means an area irrigated or capable of being irrigated either by gravitational flow or by lift irrigation or by any other method from a Government source and includes every such area whether it is called 'Command Area' or by any other name under any law for the time being in force

Canal system Head works: It is the collective term used for all works (weirs or diversion dams) to regulate the flow at the head end to a canal system



Main canal Takes its supply directly from the reservoir or river diversion work. Capacity of main canals in India usually varies from 280 to 425 cumec. Branch canals or laterals: Take off from the main canal and convey the water to different major parts of irrigated areas. Branch canals generally carry discharge ranging from 4 to 8.5 cumec

Major distributory Take off from the branch canals and sometimes from main canals and supply water to minor distributories or outlets. Major distributory generally carry discharge ranging from 0.7 to 5.5 cumec

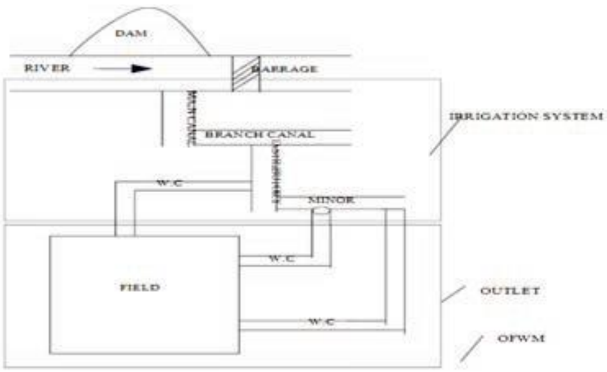
Minor distributory minors are smaller channels taking their supply from major distributory and supply water to outlets. The carrying capacity is usually less than 750lps.

Canal outlet The water course originates from the canal outlet. The size of an outlet depends upon the irrigated area it commands.

Regulation Works

Canal Falls While canals are designed with a slope which is close to the regime slope, the ground slope may differ from it considerably. Many a times, the ground slope is more than the canal slope and this may result in a canal in heavy filling. To overcome this situation, the canal has to be provided with falls. which require a masonary or concrete work.

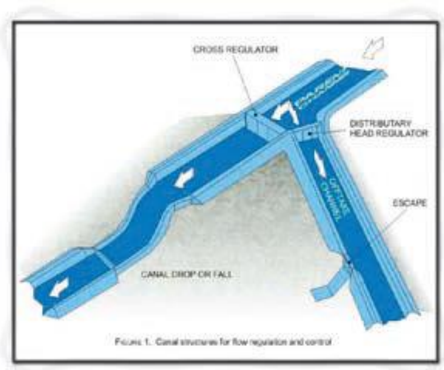
Distributory Head Regulator This is the work provided at the head of a branch canal or a distributary and serves the purpose of controlling and regulating the flow into the offtake as well as metering of the flow



Cross Regulator Cross regulators are structures constructed across a canal and spanning its entire width. The width is divided into suitable number of spans and provided with gates so as to regulate the flow in the canal downstream of the regulator.

Cross Drainage Works These are works provided at the crossing of a canal and a stream. depending on whether the canal crosses the stream at top, bottom or at the same level, these are divided into three categories.

Aqueducts: Aqueducts are works where the canal crosses over the stream and the high flood level of the stream is lower than the canal bed level so that the flow in the stream remains an open channel flow.



Super passages and Siphons These are works where the stream crosses over the canal. In a super passage the canal full supply level is lower than the river bed level and the flow in canal is an open channel flow. In a siphon the canal full supply level is higher than the stream bed level and therefore the canal water flows under pressure through barrels under the stream trough.

Level Crossing In this work the canal and stream cross at nearly the same level. There is intermixing of the canal and river water and the flow is controlled by regulator gates on the canal as well as the stream. A sill with its top at the canal full supply level is provided on the upstream side of the stream to prevent stagnant water pool in the stream during dry season

Soil and Water Conservation Measures for Arable and Non Arable Lands in Rainfed Areas

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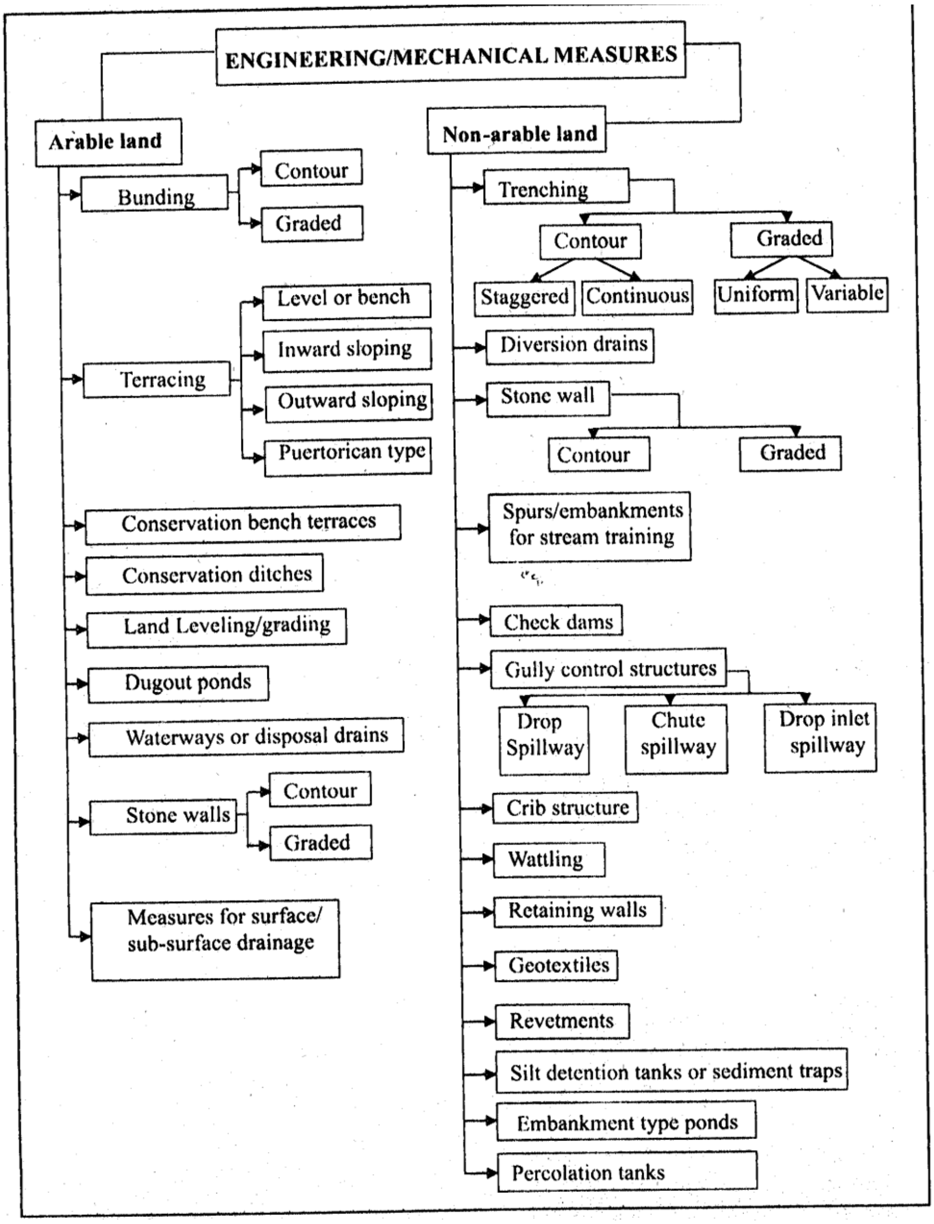
The suitability of a given type of conservation measure in an area depends upon slope, rainfall (amount and distribution), soil type and depth, water holding capacity, location of impervious layer, agricultural practices, power/equipments used and economics. Lands having less than 2% slopes do not require any of the structural measures in general. Lands up to 10% slope may require narrow or broad based terraces. The broad based terraces are useful when land holdings are large and machinery is used for farming operations. It is doubtful if narrow based terracing i.e. blinding be of any practical use in lands having slopes more than 6%. In high rainfall areas, such land slopes will require uneconomically closer spacings resulting in more loss of area. It is difficult to achieve uniformity in blinding practice on lands steeper than 4% and in any case steeper than 6%. For lands with slopes above 10% and up to 33%, bench terracing is an effective measure as it breaks the length and also reduces the degree of slope. It, however, restricts farming operations, is expensive and significant area is lost out of cultivation.

From the point of view of efficient water management, graded terraces are to be adopted in areas where rainfall is more or for areas where inspite of moderate rainfall, runoff disposal is a problem. Level terraces are for drier tracts with scanty or erratic rainfall where moisture conservation is of prime importance. Area lost out of cultivation is highest in bench terracing while under blinding, 5- 10% area is lost which can be put to alternate land uses.

Importance of conservation structures

- Increasing the time of concentration and thereby allowing more runoff water to be absorbed and stored in the soil profile due to enhance infiltration opportunity time.
- Intercepting a long slope into several short ones, so as to maintain less than the critical velocity for the runoff water.
- Protection against damage owing to excessive runoff.
- Reducing the steepness (degree) of slope.
- Terracing/bunding is the most effective and widely used practice for controlling or preventing erosion on agricultural lands in different agro-ecological regions.



Area treatment measures for arable lands
Bunding

- Contour blinds are constructed along approximate contours (with permissible deviations) for moisture conservation.
- Side bunds are constructed at extreme ends of the contour bunds running along the slope.
- Lateral bunds are constructed along the slope in between two side bunds in order to prevent concentration of water along one side and to break the length of contour bund into convenient bits.
- Supplemental bunds are constructed between two contour bunds so as to limit a horizontal spacing to the maximum required.
- Marginal bunds are constructed along boundaries of the micro-watersheds, road margins, river or stream margins, gully margins etc.

- Graded bunds are constructed along a predetermined grade (uniform/variable) for safe disposal of excess runoff.
- Broad based bunds are adopted for soil and moisture conservation in large land holdings where farming is done by machines.

Shoulder bunds are constructed on the outer end of bench terraces to contain runoff and soil loss usually in outwardly slopping terraces.

Contour bunding

Function

For slopes ranging between 2-6 % with scanty or erratic rainfall (less than 800 mm annually),contour bunding is practiced to intercept the runoff flowing down the slope by an embankment with either open or closed ends to conserve moisture as well as reduce erosion.

Soils

Contour bunds can be adapted on most types of relatively permeable soils that are alluvilial, red, laterite, brown, shallow, medium black except the clayey deep black soils.

Specifications

The planners need the following information

- *How far the bunds should be spaced?*
- *What should be the deviation freedom to go higher and lower than the contour bunds for getting better alignment in undulating areas?*
- *What should be the cross section?*

Graded bunding

Functions

The function of graded bunds consist of constructing wide and relatively shallow channels across the slope, very near the contour ridges are and at suitable vertical intervals. These terraces act primarily at drainage channel for inducing and regulating the excess runoff water and draining it with a mild and non-erosive velocity.

Suitability

These bunds are adopted in areas receiving rainfall exceeding 750mm particularly in soils having infiltration rate less than 8mm per hour.

Factors to be considered

- Location of the most desirable terrace outlets
- As a safety factor, a terrace system comprising of short terraces and several outlets located in natural water courses.
- Strengthened natural waterways have the advantage of terrace outlets.

- If vegetation alone is not capable of providing protection to conduct concentrated water down the slope, structures need to be constructed to encounter sudden drops, excessive velocities, and poor grass cover.

Specifications

It includes vertical interval (V.I.), channel grade and cross section.

Peripheral bunds

The bund which is constructed at periphery of the field, where the chances of formation of the gully, elongation of gully head, rills and ravines are known as Peripheral bund. These prevents erosion, purtrher elongation of gully head etc.

Field bunds

These bunds are constructed between field across the slope to prevent soil erosion and formation of rills. This bund prevent soil and nutrient losses.

Bench terraces: are flat beds constructed across the hill slopes along the contours with half cutting and half filling. They serve as barriers to break the slope length and also reduce the degree of slope thereby eliminating the all erosion hazards. Experiences show that, onstruction of dry bench terraces even up to 40 to 50 % slope in NE region are feasible (Prasad, *et al* 1987 & Satapathy, 2000). The vertical interval of such terraces should not be more than 1.0 m. Such measures can be adopted where soil depth is more than 1 m. Bench terraces can also be developed with vertical stone walling and are in use by the farmers of the region. Side bunds on the outer edge of the terrace should be provided to prevent slipping down of soil and overtopping of excess runoff from the terraces. To maintain top soils in terraces, the construction should start from the foot hills. There are three types of terraces mostly using. These are

Level bench terraces: Benches are almost leveled to ensure uniform depth of impounding water. This type of bench terrace is used for paddy cultivation.

Inwardly slopping bench terraces: Benches are made inward slopping to drain runoff as quickly as possible. These types of bench terraces are preferred for cultivation of tuber crops such as potato, ginger, turmeric, and sweet potato which are susceptible to water logging.

Half-moon terraces: The half-moon terraces are constructed for planting and maintaining saplings of fruit and fodder trees in horticulture and agroforestry land use system. The construction of this type of terrace is made by earth cutting in half-moon shape to create circular level bed having 1 to 1.5 m diameter.

Erosion control measures	Suitability			
	Land slope (%)	Soil depth	Rainfall (mm)	Crops or land use
1	2	3	4	5
1. Bunding				
a) Contour bunding	< 6	Shallow to deep, permeable	< 800	Small millets, pulses, oil seeds coarse grain, root crops
b) Graded bunding	< 6	-do-	800-1500	-do- and wheat vegetables
	< 6	Impermeable soils	<800	-do-
c) Contour terrace* wall (stone pitched contour bunds)	16 to 33	Good and very high infiltration rate	> 1000	Root crops, vegetables etc.
2. Bench terracing				
a) Level	< 33	Medium to deep	< 2500-3000 (High rainfall)	i) Paddy, ii) Small millets, pulses, oil seed, coarse grain, vegetables in low rainfall
b) Inward sloping	< 33	-do-	-do-	Potato, other vegetables maize, oats etc.
c) Outward sloping	< 33	Shallow	< 1200	Small millets, oats, barley etc.
3. Puertorican Terraces		Medium to deep	< 1500	Root crops, vegetables, oats, small millets etc.
a) With vegetative barrier	< 12			
b) With mechanical barriers				
4. Trenching				
a) Contour trenches				
i) Continuous	< 8	Medium to deep	< 1500	Tapioca, ginger, turmeric and similar annual crops
ii) Staggered	< 8	Shallow to medium	< 800	Papaya, banana
	< 33	Medium to deep but well drained	< 2000	Tea, coffee, arecanut, coconut, black pepper, nutmeg, cinnamon, papaya, banana etc.
b) Graded trenches	< 33	Medium to deep soil but well drained	2000-3000	-do-
5. Conservation bench terracing	< 10	-do-	< 1200-2000	Paddy on lower portion and maize crop on sloping portion
6. Zingg terracing	<10	Shallow to medium	< 1200-2000	Paddy on lower portion and cover crop on sloping portion
7. Stone wall				
a) Contour	< 33	Shallow to medium	< 1500	Annual crops like tea, coffee spices etc.
b) Graded	< 33	-do-	1500-2500	-do-

Outwardly slopping bench terraces Benches are made outward slopping and these are used in low rainfall areas.

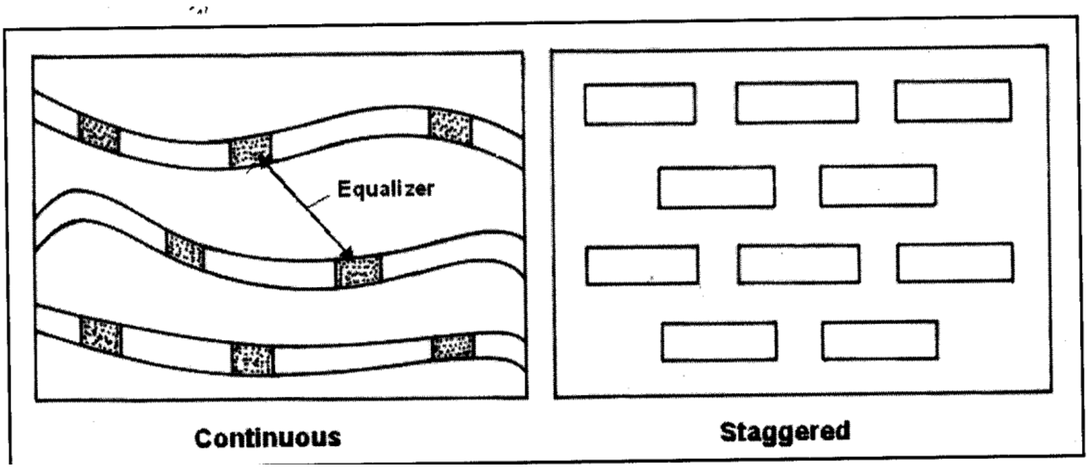
Puertorican or California type of terraces: These terraces are formed by gradual conversion of land between two barriers into terrace by natural levelling process. Mechanical barriers (bunds) or vegetative barriers (grasses or shrubs) or combination of both, are laid along the contours. Due to ploughing and interculture operations soil is eroded and gets deposited at the barriers. Thus, in due course terraces are formed.

Area treatment techniques for Non Arable Lands

Four land capability classes viz. V, VI, VII, VIII have one or more limitations of the slope, erosion, stoniness, rockiness, shallow soils, wetness, flooding etc. which make them usually unsuited for crop production. There use is mainly limited to pasture, forest, wild life & recreation. These lands are generally confined to upper reaches of watershed and have an undulating topography and are foci for the soil erosion. In lands with steep slopes and subjected to the soil erosion, vegetative cover do not established. Due to lack of vegetative cover soil erosion is accelerated transporting large amount of sediment in to streams below. Uncontrolled runoff from the sloping lands also causes extensive damage in lower reaches of the watersheds. In order to prevent the degradation of these lands, vegetative and mechanical measures are employed together and are complimentary to each other. Mechanical measures act like the foundation of building whereas the vegetative measures act like super structure which helps in improving the productivity of non arable lands. These lands have a great potential for producing fodder, fuel, minor forest produce, fruits and low quality timber. These lands having some water conservation measures.

The practices such as contour trenching, gradonies, installation of temporary and permanent gully control structure, construction of sediment retention structures and retaining walls, reclamation of ravine lands, improvement and management of grass lands and rehabilitation of mined lands can be adopted for soil and water conservation measure in non arable areas of watershed.

Contour trenches: are any form of depression or micro pit or trench constructed over the land surface. In order to prevent soil erosion and to absorb rainwater in non arable lands, trenches constructed along the contours (called contour trenches) on hill slopes above 15% with vegetative supports for forestry and horticulture land uses. Generally trenches may be dug with a cross section of 0.30 m x 0.30 m at 1 to 2 m vertical interval (Thansanga, 1997). For proper drainage of excessive runoff, they may be connected with longitudinal drains and drop pits. They are called continuous when there is no break in length and maximum length can be 100 to 200 m long across the slope depending on the width of the field. However, when these are laid scattered with maximum length of 2 to 4 m, they are called staggered contour trench. The trenches may be trapezoidal orrectangular in cross section but flatter upstream side slopes are preferred in order to minimize the risk of scouring by incoming runoff.



Vejalpur/Rampura watershed in 1 hectare of land continuous contour trenches are constructed. The length of trench is 100 m(field width is 100 m). The depth is 0.3 m, width is 0.3 m. the spacing of the trenches is 10 m. Determine the volume of watershed in 1hectere of land.

Length of watershed =10,000 m^2/100 m

=100 m

No of Trenches =100 m/ 10 m= 10

Volume of one trench = 0.3 X 0.3 X 100 = 9 m^3.

Volume of total trenches= 9 X 10 = 90 m^3

Climate Smart Soil and Water Management Techniques

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Alternatives to continuous flooding of rice have been the research focus over the past few years because of climate change. Flooded rice fields emit methane and are important contributors to the increasing atmospheric methane concentration. Anaerobic decomposition of organic material in flooded rice fields produces methane (CH4), which escapes to the atmosphere primarily by diffusive transport through the rice plants during the growing season. Upland rice fields, which are not flooded, do not produce significant quantities of CH4, account for approximately 10 per cent of the global rice production and about 15 per cent of the global rice area under cultivation.

Modified crop establishment practices like System of Rice Intensifications (SRI), direct seeding in puddled and unpuddled soil (aerobic rice), minimum/zero tillage conservation agriculture have been looked as possible alternatives to discount enormously on water input in rice cultivation.

Direct Seeded Rice

Direct seeding of rice (DSR) is considered as one of the potential alternatives to transplanted rice. It may solve the problem of emerging shortages and high costs of water and labour. There is potential of 20-30% saving of irrigation water with direct seeding compared to transplanted rice.

Agronomic practices

A seed rate of 20-30 kg/ha is found to be optimum for DSR. Sowing of direct seeded rice should be completed in first fortnight of June. A row spacing of 20 cm and seeding depth of 2-3 cm should be maintained for proper germination and better crop establishment. Placement of seeds below 3 cm adversely affects the dynamics of seed emergence due to rapid drying of the soil surface in hot summers.

Irrigation management There is a considerable difference in soil physical, chemical and biological properties between direct seeded and puddled rice. A heavy pre-sowing irrigation 2-3 days before is advisable. Due to high temperature in the month of June, there is rapid loss of moisture from the surface soil, therefore, immediate light irrigation (30 mm) after seeding is necessary to facilitate germination. Subsequent irrigation depends on the soil moisture status and the amount of each irrigation should be

Direct seeding under drip

adequate enough to bring the upper 20 cm soil layer to field capacity. Field should be kept moistened (not flooded) throughout the season to avoid moisture stress.

Iron deficiency Micronutrient deficiency is commonly seen in DSR due to absence of reduced conditions in the soil. Symptoms of Fe deficiency include intervenal chlorosis of new leaves, decreased dry matter production; entire plant becomes chlorotic and dies if deficiency is severe. To overcome this, Fe-efficient varieties should be grown. Addition of organic matter (crop residues, FYM etc) and a foliar spray of 1 % solution of ferrous sulphate in water or ferrous ammonium sulphate are recommended for the management of iron deficiency. Water should be kept standing in the field if acute deficiency persists.

Zinc deficiency Zn deficiencies appear 4-6 weeks after sowing. Zn deficiency can beefficiently corrected by soil application of ZnSO4 (Zinc sulphate). ZnSO4 being highlywater soluble is preferred over ZnO. In case, deficiency symptoms appear in the field, a dose of 10-25 kg/ha of ZnSO4, 7H2O, 7H2O mixed with sand (1:3) should be applied over the soil surface.

Iron deficiency in direct seeded rice

Direct wet seeded rice under puddle

Condition (Wet seeded rice) Direct seeding under puddle in rice is becoming a popular alternative to transplanting system as it reduces the labour and the cost of labour and the grain yield is often higher than transplanted rice under irrigated condition.

Sowing with Drum seeder

Field after drum seeding

Direct sowing pre-germinated seeds in puddled soils in the irrigated and rainfed lowland ecosystems can easily avoid raising nurseries and transplanting operations. The direct sown crop also matures earlier than the transplanted crop by 8- 10 days. The main problem in direct sown crop by broadcast seeding pre-germinated seeds is the unevenness in the plant stand and population density. These problems can be overcome by paddy drum seeder.

Benefits of the direct drum seeded rice are as follows

Water saving is possible to certain extent because it is not needed to nursery, prepare and puddle the main field early.

- Crop duration is reduced by 7-12 days making it possible to have short duration pulse crop after two direct sown rice crops.
- Low investment and less labour requirements.
- Eight row drum seeder can be used as substitute for transplanting when droughts/floods occur where raising nursery is not possible.

Aerobic Rice- A Potential Water Saving Technology

Aerobic Rice is a new development in water saving technologies. Well ploughed, and no or very little clods/clumps in field is required like any dry land crops. Seed rate: 25-30 kg/ha(varies for Hybrids and High Yielding Varieties). Seeding can be done manually or by seed drill in shallow furrows of 2-3 cm depth, at a spacing of 20X10 cm for HYVs and 20X15 cm for Hybrids. Soil must to be kept aerated to get the advantage of aerobic cultivation. Need based irrigation (5-7 days interval) is needed to maintain moist situation upon noticing visible symptoms of hairline cracks on soil surface. Maintenance of saturated condition at critical stags of active tillering, panicle initiation, flowering to grain filling stage is essential. (Fig.).

Weed Management Weeds are one of the major constrains to aerobic rice production system, as dry-tillage, alternate wetting & drying conditions are conducive to germination, growth of weeds causing grain yield losses of 50-91%. Sequential application of Pendimethalin 30 EC @ 1.5 kg a.i./ha. application as pre-emergence 1-2 days after sowing, followed by Bispyribacsodium 10% SC @ 20 g a.i/ha at 3-4 leaf stage of weeds is recommended.

Alternate Wetting & Drying (AWD)

Alternate wetting and drying (AWD) is a rice management practice that reduces water use by up to 30% and can save farmers money on irrigation and pumping costs. At present, AWD is widely accepted as the most promising practice for reducing GHG emissions from irrigated rice for its large methane reductions and multiple benefits.

Benefits of AWD

1. Reduced water use. By reducing the number of irrigation events required, AWD can reduce water use by up to 30%. It can help farmers cope with water scarcity and increase reliability of downstream irrigation water supply.

2. Greenhouse gas mitigation potential. In the 2006 IPCC methodology, AWD is assumed to reduce methane (CH_4) emissions by an average of 48% compared to continuous flooding.

Combining AWD with nitrogen-use efficiency and management of organic inputs can further reduce greenhouse gas emissions. This set of practices can be referred to as AWD+.

3. Increased net return for farmers "Safe" AWD does not reduce yields when compared to continuous flooding, AWD in fact increase yields by promoting more effective tillering and stronger root growth of rice plants. Farmers who use pump irrigation can save money on irrigation costs and see a higher net return by using AWD. AWD may reduce labor costs by improving field conditions (soil stability) at harvest, allowing for mechanical harvesting.

Where can AWD be practiced?

In general, lowland rice - growing areas where soils can be drained in 5-day intervals are suitable for AWD. High rainfall may impede AWD. If rainfall exceeds water lost to evapotranspiration and seepage, the field will be unable to dry during the rice growing period. Farmers must have control over irrigation of their fields and know that they will have access to water once fields have drained. AWD in rainfed rice is not recommended due to uncertain water availability when fields have to be reflooded.

Mitigation potential of AWD

Flooded rice systems (comprising irrigated, rainfed, and deepwater rice) emit significant amounts of CH4. Although estimates vary and have high uncertainty, recent work suggests that flooded rice contributes about 10 - 12% of anthropogenic emissions from the agriculture sector. Water regime and organic inputs are the primary determinants of CH4 emissions in rice systems but soil type, weather/climate, tillage management, residue, fertilizers, and rice cultivars also play a role. Research has consistently found that noncontinuous water regimes such as AWD produce significantly lower CH4 emissions than continuous flooding. According to empirical models, 15–20% of the benefit gained by decreasing CH4 emission is offset by the increase in N2O emissions. However, net GWP is still significantly lower under AWD than in continuously flooded fields. The mitigation potential of AWD depends strongly on its proper execution. Incomplete drainage (not allowing the water table to drop to 15 cm below soil surface) can result in negligible reductions in GHG emissions.

Using IPCC 2006 guidelines, it has been estimated that if all continuously flooded rice fields were drained at least once during the growing season, global CH4 emissions would be reduced by 4.1 Mt per year.

Emissions models estimate that application of rice straw in the fallow period instead of soil incorporation directly during puddling would further significantly reduce CH4 emissions.

How does AWD reduce GHG emissions?

Ch_4 in wet or "paddy" rice soil is produced by the anaerobic decomposition of organic material after the flooding of rice fields. Allowing the field to drain removes the anaerobic condition for a time and halts the production of CH_4, thus reducing the total quantity of CH_4 released during the growing season. The production of N_2O is also regulated by the presence of oxygen. In contrast to CH_4 however, the recurring shift between aerobic and anaerobic conditions favors bacterial conversion of other nitrogen compounds to N_2O and its release from the soil. The production of N_2O is also strongly influenced by the availability of nitrogen in the soil. Thus, N_2O emissions increase with the amount of nitrogen fertilizer applied to rice paddies.

The feasibility of this practice depends on the cropping calendar, as in some areas fields are also irrigated during the dry season, leaving little time for aerobic decomposition of organic inputs. Straw and manure, which can also be composted, emit less CH_4 than fresh organic material once applied to rice soils. Ideally, management of organic residue includes biogas technology. Biogas (CH_4) produced from rice straw reduces fossil fuel consumption. The remaining biogas slurry represents a good form of fertilizer with low CH_4 emission potential, compared with soil application of fresh organic material.

Soil, Water and Crop Management Strategies for Climate Resilient Agriculture in Coastal areas

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India lies in the Indian plate, the northern portion of the Indo- Australian plate, whose continental crust forms the Indian subcontinent. The country is situated north of the equator between 8°44’ to 37°6’ north latitude and 68°7’ to 97°25’ east longitude. It is the seventh largest country in the world, with a total area of 3,287,263 square kilometres. It has a land frontier of 15,200 km and a coastline of 7,516.6 km. Of this, mainland coastline length is 5422.6 kilometres whereas Island territories coastline length is 2094 kilometres.

Coastal length of Indian different states and union territories:

- Andhra Pradesh (973.7 km)
- Tamilnadu (906.9 km)
- Maharashtra (652.6 km)
- Kerala (569.7 km)
- Odisha (476.4 km)
- Karnataka (280 km)
- Goa with Daman & Diu (160.5 km)
- West Bengal (157.5 km)
- Puducherry (30.6 km)
- Andaman Nicobar Islands (1962 km)
- Lakshadweep Islands (132 km)

The areas along the vast coastline of India have diversified conditions related to soil, rainfall, water resource, agricultural, horticultural and forest crops, fisheries etc. The area is rich in diversified natural resources. The total coastal area in India is about 10.78 millon ha.

India is quite susceptible to cyclones and floods due to its geographical location surrounded by water on three sides. Coastal regions are more vulnerable to damage from cyclones. Cyclone is an atmospheric system characterised by the rapid inward circulation of air masses about a low-pressure centre, usually accompanied by stormy, often destructive weather. Cyclones circulate counter clockwise in the northern hemisphere and clockwise in the southern hemisphere. Cyclones in coastal areas affect field crops, horticultural crops, agro- forestry plants, live stock and fisheries through direct damage by high wind, torrential rain and extensive flooding. In addition rise in sea-level and increase in sea surface temperature are the most probable major climate change induced changes in coastal ecosystem.

Coastal soils in a number of situations are constrained by excess accumulation of soluble salts and alkalinity in soil, toxicity and deficiency of nutrients in soils, intrusion of seawater into coastal aquifers, high depth to underground water table rich in salts, periodic inundation of soil surface by the tidal water vis-a-vis climate disaster and their influences on soil properties, poor in filterability of soils in many areas, eutriphication, hypoxia and nutrient imbalance and erosion & sedimentation of soil.

With this back ground it is understood that the major concerns of agricultural productivity are cyclones and accumulation of salts due to ingress of sea water in coastal areas. There is possibility of realising good crop yields in coastal areas where fresh water is available for irrigation. The major crop preferred in these areas is rice. The major concern is agricultural productivity under rainfed conditions. Therefore, the consequences of cyclone and making use of cyclonic rains for rainfed agriculture and management of salty soils in the changed climatic scenario are discussed in this chapter.

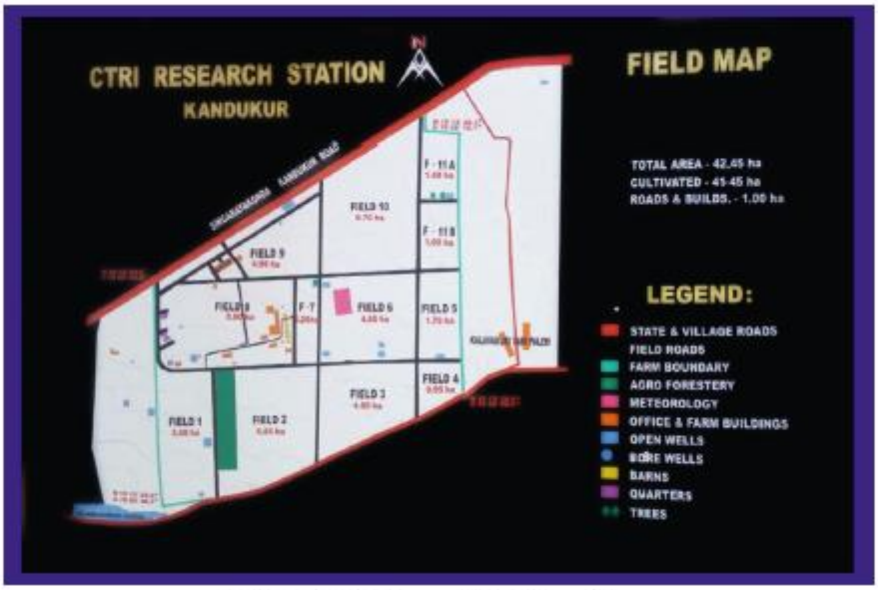
The cyclones and its associated flood incidence cause severe damage to agriculture. When the storm surges, it results in inundation of low lying areas, drowning of human beings & live stock, destroy vegetation and reduce the soil fertility. Very strong winds cause destruction of installation, dwelling and communication systems, uprooting of trees & crops. Heavy and prolonged rain results in submergence of low-lying areas and pollutes drinking water sources and ruin crops. The effects vary across crops depending on their growing season & the month the cyclone strikes.

There are cyclone shocks all year round, but the two main cyclone seasons in India are May-June, September – November, There are two main cropping seasons in India, Kharif crops are sown in spring & harvested in autumn Rabi crops are sown in late autumn & harvested the following spring. Cyclones cannot be stopped but it can be managed by adapting suitable contingency measures. Immediate measures include protection of livestock supply of agricultural inputs based on the commencement of the crop season and capacity building for efficient utilisation of available resources. Medium term measures are financial support for crop raising, harvest and post harvest operations through low interest agricultural credit, arranging feed, fodder and veterinary support to live stock farmers. Long term measures include rehabilitation of damaged and degraded lands, construction of flood protection dams and on farm water control structures, introduction of flood tolerant crops and suitable varieties and mechanised operations. Crop management strategies are provision of wind brake plantation, nursery management technology and Bio-drainage plants (Ashwinikumar, 2014).

The cyclonic heavy rains can be harvested and utilised for giving irrigation and realising good yields in the crops grown under rainfed condition. A micro water shed developed at CTRI Research Station , Kandukur and details of lined farm pond are given as the examples for efficient utilization of cyclonic rain water in rainfed ecosystem of south coastal Andhra Pradesh.

Micro water shed – Rain water harvesting and recycling through networking of ponds at ICAR-CTRI Research Station, Kandukur (Sreenivasulu *et al*., 2005).

ICAR-CTRI Research station is located at Kandukur in prakasam district of Andhra Pradesh located at 15.2165_0 N and 79.9042_0 E is prone to both droughts and floods. The area receives rainfall from both South-West monsoon and North east monsoon. The main crop is tobacco and the cropping period is October-February, which coincides with North-East monsoon. Although ground water is available in some pockets, it is not fit for irrigation as it contains high salts particularly chlorides, which affects the quality of tobacco crop. The solution lies in the harvesting of rain water and its recycling, as there is good potential due to frequent depressions in Bay of Bengal resulting in heavy down pour.



ICAR-CTRI Research Station plan

The area was surveyed for delineating micro-watershed using "Total Station Survey Equipment" and different thematic maps were prepared. CTRI Micro watershed is covered in toposheet number 57M/16, Nellore and Prakasam districts, with North latitude $79_0$55'45" and East longitude of E 15_0 13'33" with a permanent bench mark at 16.53 m mean sea level (MSL). This micro-watershed falls under Mutteru basin, Index No 086/128. Catchment -4, Sub-Catchmnet -A and watershed code no 74 that drains in to Manneru river which in turn joins into Bay of Bengal. Waterways were designed based on catchment area of different fields, rainfall intensity and peak flow rate for safe disposal and harvest of rain water. A total length of 3926 m of waterways was dugout for networking of different structures. A total amount of 8020 m_3 of rainwater is conserved every year in different storage structures.

Capacity and catchment area of different storage structures

S.No	Farm pond/ Percolation pond	Location	Catch ment area (ha)	Dimensions Top-Bottom-Depth (m)	Excavated Volume (m^3)	Storage capacit y (m^3)
1	Farm pond-1	Field No. 5	2.0	16 x 16 m 8.4 x 8.4 ; 3.8 m	580	500
2	Farm pond-2	Field No .6	2.5	16.5 x 16.5 m 8.5 x 8.5 ; 4.0 m	645	550
3	Farm pond-3	Field No .6	3.7	28.5 x 20.0 m 20.1x11.4 ; 4.20m	1575	1275
4	Farm pond - 4	Field No. 9	4.7	32.5 x 19.0 m + * 23.5 x 8.0 ; 4.5 m	2300	1900
5	Farm pond - 5	Field No. 8	2.0	16.5 x 16.5 m 8.5 x 8.5 ; 4.0 m	645	580
6	Farm pond-6	Field No. 1	2.7	16.5 x 16.5 m 8.5 x 8.5 ; 4.0 m	645	560
7	Percolation pond-1	Field No.11B Old dugout renovated	3.0	18.5 x 18.5 m 8 x 8 ; 4.5 m	900	790
8	Percolation pond – 2	Field No. 6 Defunct well renovated	2. 5	18.5 x 18.5 m 8 x 8 ; 7.0 m	1400	1065
9	Percolation pond – 3	Field No. 8 Defunct well renovated	3.9	19.5 x 18.5 m 8.5 x 8.5 ; 6.5 m	1000	800
10	Roof rain water harvesting structure	Near office	400 m^2	8.0 x 5.0 m 2.9 m	116	100

Note: There was surplus flow even after filling of all structures.

A total capacity of 8020 m^3 was harvested from catchment of 26 ha of farm land, which comes to an average of 308 m^3 ha^{-1}. The volume of water harvested was sufficient enough for irrigating 10 ha area by flood method (40 mm depth) after considering the losses due to evaporation and seepage.

A case study of lined Farm Pond (FP-5): Farm pond of 580 m^3 storage capacity lined with brick and cement mortar was found sufficient enough to irrigate 1.2 ha area of tobacco by flood method of irrigation (40 mm). Furrow and perfo methods of irrigation were found effective in saving of water and increased the area under life saving irrigation from 1.2 ha to 1,6 ha. Number of farm ponds, their capacity and area irrigated by different methods during 2003-2004 and 2004-2005 are given below.

Area irrigated with different methods of irrigation using stored water from different storage structures

S.No	Farm pond (FP)/Percolation pond (PP)	Location	Storage capacity (m^3)	Water available at the time of irrigation	Area covered (ha)	Method of irrigation	Average depth of irrigation
2003-2004							
1	FP-2	Field No-6	550	500	1.20	Flood	40
2	FP-1	Field No-5	435	250	0.80	Furrow	30
3	PP-1	Field No-11B	790	300	1.00	Perfo	30
4	PP-2	Field No-6	750	400	1.00	Flood	40
2004-2005							
1	FP-1	Field No-5	435	300	0.85	Perfo	35.3
2	FP-2	Field No-6	550	385	0.90	Flood	40.8
3	FP-3	Field No-6	600	600	1.80	Furrow	33.3
4	FP-4	Field No-9	1900	1360	3.10	Flood	43.9
5	FP-5	Field No-8	580	430	1.05	Flood	40
6	PP-1	Field No-11B	790	580	1.60	perfo	36.3
7	PP-2	Field No-6	750	550	1.70	Furrow	32.4

Water of farm pond -5 filled during south west monsoon was utilised for raising tobacco nursery. The farm pond is filled by the end of October from the catchment area of 3.7 ha. The water available for irrigation after evaporation losses by December month was 457 m3 and is sufficient to irrigate an area of 1.14 ha of land at 40 mm depth. This water is sufficient to irrigate 1,83 ha at 25 mm depth for furrow method of irrigation (m3).

Farm pond at CTRI Research Station, Kandukur

Water budgeting of lined farm pond (brick lining in cement mortar 1:6) having a dimension of 16 m X 16 m top, 8.4 m X 8.4 m bottom and 4 m depth

S. No	Particulars	Magnitude
1	Full capacity of farm pond by October end (m^3)	580
2	Catchment area (ha)	3.7
3	Water loss by evaporation from October to December (m^3)	123
4	Water available for irrigation (m^3)	457
5	Water requirement for one irrigation for one hectare at 25 mm depth for furrow method of irrigation (m^3)	250
6	Area irrigated with available water (ha)	1.83

This region receives rain during *rabi* season due to cyclones. The intensity of the rain is high during cyclonic period and the ponds get filled. Normally there is possibility of two fillings in one season. One filling can be used for raising nursery and another for supplemental irrigation to field crop of tobacco.

One life saving irrigation using harvested water resulted in increase of cured leaf yield by 23%. The economics of one life saving irrigation during 2007-2008 is Rs 10,204/- There is possibility of recovering the cost of the pond in 10-12 years. Now government is encouraging the farm ponds and the work is being done through MGNREAS.

Salinisation in Coastal Soils

Salinization in coastal soils is mainly due to sea water intrusion i.e., salinity ingress of ground water aquifers, for which the main factors responsible are excessive and heavy withdrawals of ground water from coastal plain aquifers, seawater ingress, tidal water ingress, relatively less recharge, and poor land and water management. The approaches for control of sea water ingress into aquifers are modification of ground water pumping and extraction pattern, artificial recharge, subsurface barriers tidal regulators/ Check Dams/reservoirs etc.

Soil Salinity: Three main types of salt soils exist in the coastal plain. They are saline soils, sodic soils and acid sulphate soils.

Saline soils: These soils are characterised by high in salt concentration. pH of the soils is <8.5. These soils affect plants by osmotic effect & toxicity of Na. Soils have good water infiltration capacity.

Management of Saline soils: In saline soils, the problem of high concentration of soluble salts in the rooting zone can be overcome by leaching out the excess salts using good quality water. If irrigation water is saline in nature, micro irrigation may be followed and cropping may be avoided during summer season to reduce the salt buildup in the soil. Agronomic approaches like cultivation of crops in broad bed and furrow system, ridges and furrows helps to avoid direct contact of roots with salt.

Sodic soils: pH of soils is >8.5. Salt imbalance caused by Na as dominant cation rather than Ca. These soils have water infiltration problems

Management of sodic soils: Despite many limitations, the sodic soils, once ameliorated partially, by using gypsum technology, can be used successfully for growing sodium- tolerant or semi tolerant crops, such as rice, sugarbeet, wheat, barley, amla etc. Provision should be made for proper drainage, judicious supply of irrigation water, farmyard manure, or green manure and fertilizers to boost the agricultural production.

Acid sulphate soils: These soils are characterized by low pH. Strongly acidic soils have few basic cations (Ca, K, Mg, etc.) available for absorption. These soils contain high amounts of Al, Mn, etc., and slow down the microbial process & N fixation.

Management of acid sulphate soils: Application of lime is recommended for reclaiming acid soils. Lime improves the base saturation, inactivates iron, manganese and aluminum in soil solution leading to reduce phosphorus fixation. It should be applied once in five years depending upon soil pH. As flooding alleviates acidity, rice is the choice on acid sulphate soils in warm regions. Millets, groundnut, tea, potato can be grown in these soils. Leaching losses of nitrogen fertilizer can be reduced by applying fertilizers in splits.

In field conditions, saline soils can be recognized by the spotty growth of crops and often by the presence of white salt crusts on the surface. Leaves of plants growing in salt infested areas may be smaller and darker blue-green in colour than the normal leaves. Increased succulence often results from salinity, particularly if the concentration of chloride ions in the soil solution is high. Plants in salt-affected soils often have the same appearance as plants growing under moisture stress (drought) conditions although the wilting of plants is far less prevalent because the osmotic potential of the soil solution usually changes gradually and plants adjust their internal salt content sufficiently to maintain turgor and avoid wilting. These soils can be reclaimed with proper drainage and desalinisation techniques and use of soil amendments.

Water management strategies: Water is a critical input for agricultural productivity. In coastal regions the fresh water runoff must be stored properly and used for increasing agricultural productivity. A cass study regarding a micro water shed developed at ICARCTRI Research station is already discussed. Different sources of irrigation other than surface fresh water are marginally saline water, ground water skimming, sea water desalinisation and weather modification. In areas where fresh water availability is limited judicial combination of saline and fresh water available can be used to save the crop under drought situations. Large diameter skimming wells with sump based Doruvu technology can be a source of irrigation especially in coastal sandy soils of Andhra Pradesh. Seawater desalinisation uses large amounts of energy and specialised expensive infrastructure making it costly compared o fresh water from rivers. The way of manipulating weather for rain formation through cloud seeding is used in some countries. However its effectiveness is not clear.

Efficient utilisation of water is very important strategy in coastal rainfed areas. Different methods of irrigation include flooding, furrow irrigation, alternate furrow irrigation and surge flow furrow irrigation. In general, farmers practice flooding method which causes lot of water loss. The improved methods of irrigation results in enhanced water use efficiency and increased productivity. Micro irrigation methods viz., sprinkler, micro sprinkler, drip and fertigation methods are very effective in not only water saving but also enhances crop yields. Government is also encouraging farmers to use improved methods of irrigation by providing subsidy. Agronomic practices like raised bed planting, ridge-furrow method of sowing, subsurface irrigation, and precision farming helps to economise water use.

There is scope for increasing income through crop diversification and integration of fish, poultry and other enterprises in the farming system. The multiple water use approach can generate more income benefits, and decrease vulnerability by allowing more diversified livelihood strategies and increasing the sustainability of ecosystems. Emphasis should be given on water resource conservation through watershed development in suitable areas and development of micro-water structures for rainwater harvesting. The promotion of water conservation efforts has direct implications for water resources availability, groundwater recharge, and socio-economic conditions of the population.

Crop management strategies: The coastal areas in general are endowed with abundant sunshine, solar as well wind energy precipitation, diverse soils, physiography, climate etc. They have tremendous opportunities for supporting a host of perennial and annual crops like trees, fruit plants, cereals, root crops, pulses, oil seeds commercial crops, vegetables etc. Suitable crop cafeteria should be developed for specific agro-ecologies as well as their interactions. Crop Improvement strategies for salt/drought/flood tolerant varieties create great impact in changing agricultural scenario in the coastal regions (Yadav *etal*., 2014).

Relative tolerance of crops to different levels provide useful selection guide lines for saline Soils

Crop	Tolerance level	Crop	Tolerance level
Field crops		Vegetables and fruits	
Barley	High	Broccoli	Moderate
Cotton	High	Spinach	Moderate
Sugar beet	High	Tomato	
Sorghum	Moderate	Bean	Low
Wheat	Moderate	Starwberry	Low
Cowpea	Moderate	Pineapple	Low
Peas	Low	Grasses and Forages	
Corn	Low	Whet grass tall	High
Rice	Low	Bermuda	High
		Alfalfa	Moderate

Crop management practices viz., organic mulch, *in situ* green manuring with sun hemp/pillipesara etc., crop rotation, use of soil amendments, change in planting dates and planting method, making conservation furrows across the slope, mechanisation, irrigation through drip/sprinkler/, fertigation, helps to resilience the climate induced changes in coastal ecosystem.

Conclusion

Agriculture development in coastal ecosystem can be improved by planning upland farm layouts with respect to drainage patterns, encouraging sustainable intensification of agriculture, promoting compatible crops, implementing soil and water conservation practices to control crop land erosion and surface water runoff, promoting use of organic fertilisers, biological pest control and non-persistent biocides. Regulation of ground water withdrawal to prevent salt water intrusion, utilisation of non-structural solutions for flood damage control, efficient utilisation available quality water helps to improve productivity. Making use of advanced crop management interventions and moisture conservation techniques helps to enhance productivity and encouraging fresh water pond based integrated farming system approach helps for sustainability in changing climatic scenario.

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Watershed Based Water Management

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Introduction

A watershed is a geo-hydrological unit, which drains at a common point. Rain falling on the mountain starts flowing down into small rivulets. Many of them, as they come down, join to form small streams. The small streams form bigger streams; and finally the bigger streams join to form a nullah to drain out excess water from a village. The entire area that supplies water to a stream or river, that is, the drainage basin or catchment area, is called the watershed of that particular stream or river.

A watershed is made up of its physical and hydrological natural resources as well as human resources. Management of a watershed thus entails the rational utilization of land and water resources for optimum production while causing minimum trauma to natural and human resources. Therefore, watershed management is the process of guiding and organizing land use and use of other resources in the watershed to provide desired goods and services without adversely affecting soil and water resources. Embedded in this concept is the recognition of the inter-relationships among land use, soil and water, and the linkages between uplands and downstream areas.

Watershed based Interventions for Natural Resource Management

In watershed based interventions for sustainable natural resource management were broadly classified into hydrological and biological interventions. These interventions are to manage land, water and biomass. The hydrological interventions are to manage land and water.

Land characteristics like terrain, slope, formation, depth, texture, moisture, infiltration rate and soil capability are the major determinants of land management activities in a watershed. The broad category of land management interventions can be as follows;

Structural measures, vegetative measures, production measures, protection measures. Mechanical conservation measures may become necessary in watershed management in the initial stages. Structural measure include interventions like contour bunds, stone bunds, earthen bunds, graded bunds, compartmentnal bunds, contour terrace walls, contour trenches, benchterracing, broad based terraces, centripetalterraces, field bunds, channel walls, streambank stabilization, check dams etc. The broad interventions for water management are rain water harvesting, ground water recharge, maintenance of water balance preventing water pollution economic use of water. Rainwater harvesting forms the major component of water management. The rainwater collected can be recharged into the ground. Roof top water harvesting, diversion of perennial springs and streams in to storage structures, farm ponds etc are the methods widely used for rainwater harvesting. Some simple and cost effective rainwater harvesting structures are Percolation pits/tanks, recharge trenches/rain pits, recharge wells ferro cement tanks, farm ponds, V ditch, bench terracing, economic use of water and avoidance of affluence in use of water at individual and community levels.

Engineering Measures

Engineering measures are also called mechanical measures. These measures are aimed at arresting the movement of eroded soil by reducing the slope length and / or slope steepness or gradient. Some of these measures suitable for agricultural lands arediscussed below.

Contour bunds are mechanical (earth made) barriers created across the slope following the line of contour. Contour bund may follow exactly the line of contour in the low rainfall areas where the objective is to conserve entire amount of rainfall in–situ. But in high rainfall areas,in addition to the in situ conservation of rainfall, safe disposal of runoff is also one of the objectives. Owing to the generation of large volume of runoff due to high rainfall amount & intensity, and land gradient, 0.5% longitudinal gradient to the contour bund should be provided. Such bunds are called graded bunds. The graded bunds divert the excess runoff during rains to the grassed waterways and retain eroded soil. Theoretically, bunding is suitable for lands with slopes ranging from 2 to 10 % but experiences indicate that it can be adopted for land with slope upto 30%. Crop cultivation practice is continued in the area within the two bunds, with the slow process of silt deposition within the bunds, the area between the two bunds gets leveled up and takes shape of terrace in due course of about 4-8 years time. It has been found that developing bench terraces through slow process with the help of contour bunds is very effective, as this method avoids sudden disturbance of the soil profile exposing the subsoil as happens in case of bench terracing by cut-fill method. The results of an experiment in the ICAR RC for NEH showed that after cultivating 3 crops, slope of land surface reduced to an average slope of 7.8% from original slope of 28.8%.

Bench terraces are flat beds constructed across the hill slopes along the contours with half cutting and half filling. They serve as barriers to break the slope length and also reduce the degree of slope thereby eliminating the all erosion hazards. Experiences show that, construction of dry bench terraces even up to 40 to 50 % slope in NE region are feasible. The vertical interval of such terraces should not be more than 1.0 m. Such measures can be adopted where soil depth is more than 1 m. Bench terraces can also be developed with vertical stone walling and are in use by the farmers of the region. Side bunds on the outer edge of the terrace should be provided to prevent slipping down of soil and overtopping of excess runoff from the terraces. To maintain top soils in terraces, the construction should start from the foot hills. There are three types of terraces mostly using. These are

Level bench terraces Benches are almost leveled to ensure uniform depth of impounding water. This type of bench terrace is used for paddy cultivation.

Inwardly slopping bench terraces Benches are made inward slopping to drain runoff as quickly as possible. These types of bench terraces are preferred for cultivation of tuber crops such as potato, ginger, turmeric, and sweet potato which are susceptible to water logging.

Outwardly slopping bench terraces Benches are made outward slopping and these are used in low rainfall areas.

Puertorican or California type of terraces These terraces are formed by gradual 96 conversion of land between two barriers into terrace by natural leveling process. Mechanical barriers (bunds) or vegetative barriers (grasses or shrubs) or combination of both, are laid along the contours. Due to ploughing and interculture operations soil is eroded and gets deposited at the barriers. Thus, in due course terraces are formed.

Half-moon terraces The half-moon terraces are constructed for planting and maintaining saplings of fruit and fodder trees in horticulture and agroforestry land use system. The construction of this type of terrace is made by earth cutting in half-moon shape to create circular level bed having 1 to 1.5 m diameter. The bed may also have inward slope.

Contour trenches are any form of depression or micro pit or trench constructed over the land surface. In order to prevent soil erosion and to absorb rainwater in non arable lands, trenches constructed along the contours (called contour trenches) on hill slopes above 15% with vegetative supports for forestry and horticulture land uses. Generally trenches may be dug with a cross section of 0.30 m x 0.30 m at 1 to 2 m vertical interval. For proper drainage of excessive runoff, they may be connected with longitudinal drains and drop pits. They are called continuous when there is no break in length and maximum length can be 100 to 200 m long across the slope depending on the width of the field. However, when these are laid scattered with maximum length of 2 to 4 m, they are called staggered contour trench. The trenches may be trapezoidal or rectangular in cross section but flatter upstream side slopes are preferred in order to minimize the risk of scouring by incoming runoff.

Peripheral Bunds In ravine areas the enlargement of gully head can be prevented by digging peripheral bunds (top width 0.3 m, bottom width 1.5 m, height 0.6m, side slopes 2:1) from 1.5 m from the gully heads.

Grassed waterways The main function of grassed waterways is to drain out excess runoff from the field at non-erosive velocity. It helps protect land against rill and gully erosion. Turfs or sod of perennial grasses which are drought resistant, erosion resistant and submergence resistant should be established to protect the channel section against any kind of erosion because of the concentrated flow. The trapezoidal section of grassed waterways is more appropriate because it is more stable and has larger capacity as compared to other cross sections. Moreover, trapezoidal shape will assume parabolic shape in due course.

Diversion drains Diversion drains are sometimes called simply diversions. They are the channels constructed across the slope for the purpose of intercepting runoff and conveying the same to a safe outlet. Diversion drains are located above the agricultural lands at lower reaches of hill slope. Diversion drains are also constructed at the gully heads or at the upstream of bunded or terraced areas to intercept the surface runoff to avoid any damage from concentrated flow.

Bio-engineering measures

In landslide, mine spoiled, torrent and gully cum ravine areas the combination of biological and engineering measures have been observed as most suitable measure. The most common control measures adapted in rehabilitation of such mass eroded areas are: diversion channels, spurs, retards, wattling, mulching using “geojute”, crib structures, jacks etc.

Wattling is a method of breaking the length of slope into shorter portions by providing contour wattles at 3 to 5 m interval over steep slope. Trenches 0.3 m wide and 1 m deep are dug up on contour and filled with brushwood bundles (5-6 cm diameter) lying horizontally. On the downhill side of the trenches, posts of species which sprout (eg. Erythrina) on planting are placed at 100-125 cm spacing. If such species are not available then posts of other hard wood species can be used. The trench is then filled up with dug up earth till about 10 cm from the ground level. The posts are woven around with locally available shrubs up to 20 cm above the ground level. These are now live contour wattles and they obstruct movement of debris and allow runoff to pass through. These are preferred on fragile slopes where working or trenching is difficult.

Geojute also called as soil saver is a natural geotextile used as mulch. This is essentially a jute matting with and open mesh of 2-5 mm thick jute yarn having 10 mm apertures and is biodegradable. The technique of geojute application include (a) spreading of geojute by overlapping and joining adjacent widths, (b) driving wooden sticks to a depth of 1 m to secure matting in place, (c) planting rooted slips of local grasses and cuttings of bushes in openings between the geojute strands at close spacing. Geojute material prevents surface erosion providing support temporarily for the new vegetation to stabilize the eroded area, up to a period of six months (one rainy season) provided the material is laid out and the species is planted timely and free grazing of animal is prevented.

Crib structures Log wood crib structures filled with stone/brush wood can be used in stabilizing steep slopes (>40%). Poles of 2 to 3 m length and 8 to 12 cm diameter are driven to depth of 50 to 75 cm and erected in two lines, 1 m apart line to line and pole to pole and these are nailed together by providing horizontal braces of poles. The height of the structure may be kept 1.5 to 2.0 m above the ground. The interspaces may be vegetated with suitable quick growing vegetation.

Retards serve the purpose of dampening stream velocity sufficiently near the bank to prevent erosion of the banks or scour its toe by inducing deposition. There are three types of retards. **Live hedges** – are commonly employed in small streams and torrents successfully. Shoots of Ipomoea carna, Arundo donax, Jatropha curcas, etc. may be planted in trenches (60 cm wide) to serve as live hedges. Arundo donax has very strong root and shoot systems to resist the flood flows. **Jacks** – These are wooden posts of 8 cm dia. and 2 to 3 m in length, which are placed in series along the eroding bank and are tied together. **Jetted posts** – These are green posts of 2 to 2.5 m in length and 6 to 12 cm dia. which is erected along the actively eroding banks in two rows, 1.0 cm apart. Fuel, fooder, fibre and even horticultural plantations can be raised in the reclaimed lands along the banks of the torrents.

Drainage line treatment structures

In order to check the erosion at the up stream of drainage line and to prevent flow, sediment and debris to the down stream or valley land or within gullies of a watershed; the vegetative and mechanical measures are provided.

Retaining walls and revetment A retaining wall acts as revetment on steep slopes near the toe. As a rule of thumb, for gabion structures the bottom width is kept 2/3 rd the height for walls up to 6 m in height with 1 m top width and for stone wall it may be kept aminimum one-third of the height.

Temporary gully control structures For stabilization of gullies through vegetation is a difficult task. Temporary mechanical measures are adopted to prevent washing away of the plantation by large volume of run-off that provides to establish the vegetation. Vegetations once established will be able to take care of the gully. Followings are some such mechanical measures / structures; a) Check Dams; - (i) Temporary check dams, (ii) Brush dam, (iii) Semi permanent check dams. b) Loose Rock Dam c) Log Wood Dam.

Permanent gully control structures Permanent Gully Control Structures are necessary where vegetative or temporary structures are not adequate. Permanent Structures such as masonry check dams, flumes or earth dams supplemented by vegetations are provided to convey the run-off over critical portion of the gully. Principal types of permanent structures are drop spillways, drop inlet spillways and chute spillways.

Drop spillway: The drop spill way is a weir structure. Flow passes through the weir opening, drops to an approximately level apron or stilling basin and the passes to the down stream channel Drop spillway may be constructed of reinforced concrete, plain concrete, rock masonry and concrete blocks with or without reinforcing or gabions. The spillway is an efficient structure for controlling relatively low heads, normally up to 3.0meters.

Drop inlet Spillways: A drop inlet spillway is a closed conduit that carries water under pressure from above an embankment to a lower elevation. The usual function of a drop inlet spillway is to convey a portion of the runoff through or under an embankment without erosion. It is a very efficient structure for controlling relatively high gully heads usually above 3.0m.

Chute Spillways: A chute spillway is an open channel with a steep slope, in which flow is carried at a supercritical velocity. It consists of an inlet, vertical curve section, steep sloped channel and a out let. Reinforced concrete is widely used to construct chute spillways and adopted particularly to high overfall gullies, detention dams to reduce the required capacity.

Retaining wall: Dams, weirs, wing walls and other erosion control structure walls act as retaining wall against water and earth pressure. The walls of reinforced concrete are more economical. The stability of a gravity retaining wall is due to the self-weight of the wall, perhaps aided by passive resistance developed in front of the walls. Dams and weirs are subjected to water pressure and wing walls etc. are subjected to earth pressure. The center of gravity of the structure and the angle of repose of the earth against earth pressure are to be taken care at the time of designing and construction of such structures.

Earthen Dams: Earth dam can create ponds with partial digging at suitable locations in hills and cost for such structures can be involved 80% as manual labour inputs and useof local earth, stone and grasses.

Water harvesting ponds:

Experiences on water harvesting in dugout-cum-embankment type of pond in hilly region of North East India clearly indicate the feasibility of harvesting runoff from watersheds to an extent of 38% of monsoon rainfall. Contribution of subsurface flow from upper slopes accounts for 82-90% of the annual into the water harvesting pond located in the lower reaches and only 10-18% comes from direct interception of rainfall and collection of surface runoff. Stored water is used for crop, livestock and fish production.

The various soil and water conservation measures such as agronomic, engineering, bio-engineering measures, drainage line treatment techniques, water harvesting technology and integrated farming systems technology, when adopted within the boundary of watershed can enhance sustainability of the production system in the rained regions. These technologies conserve the natural resources of a watershed there by enhance the agricultural production.

Agronomic/Vegetative interventions

Biological interventions include production measures and vegetative measures. The production measures include interventions aimed at increasing the productivity of land like mixed cropping, strip cropping, cover cropping, crop rotations, cultivation of shrubs and herbs, contour cultivation conservation tillage, land levelling, use of improved verity of seeds, horticulture, increased productivity of animals income & employment generation activities coordination of health & sanitation etc.

The vegetative measures include vegetative cover, plant cover, mulching, vegetative hedges, grass land management, vettiver fencing, biomass regeneration, forest management & conservation, plant protection agro-forestry, & social forestry.

Major intervention areas for biomass management are biomass regeneration, forest management & conservation, plant protection & social forestry, increased productivity of animals income & employment generation activities coordination of health & sanitation.

Maintaining a dense canopy cover is the most effective biological means for minimizing soil and water losses on hill slopes. Growing of two or more crops in mixed, inter or strip cropping systems provide better canopy cover and obstruct overland flow. Dense foliage of erosion resistant leguminous crops like cowpea and soybean reduces soil loss by preventing the rains from beating the soil surface desirably. If arable cropping is unavoidable on steep lands due to socio-cultural factors, the grass cover should be integrated with arable cropping systems in strips at suitable intervals to minimize runoff and soil erosion.

Impact Assessment Watershed treatment technologies in Watershed Projects

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Introduction

A watershed is a geo-hydrological unit, which drains at a common point. Rain falling on the mountain starts flowing down into small rivulets. Many of them, as they come down, join to form small streams. The small streams form bigger streams; and finally the bigger streams join to form a stream to drain out excess water from a village. The entire area that supplies water to a stream or river, that is, the drainage basin or catchment area, is called the watershed of that particular stream or river.

A watershed is made up of its physical and hydrological natural resources as well as human resources. Management of a watershed thus entails the rational utilization of land and water resources for optimum production while causing minimum trauma to natural and human resources. Therefore, watershed management is the process of guiding and organizing land use and use of other resources in the watershed to provide desired goods and services without adversely affecting soil and water resources. Embedded in this concept is the recognition of the inter-relationships among land use, soil and water, and the linkages between uplands and downstream areas.

Biophysical indices

The biophysical indices are hydrological indices, water availability indices, soil erosion and sedimentation indices and land improvement indices

Hydrological Indices

- Ratio of runoff volume before and after
- Ratio of peak runoff rate before and after
- Changes in duration of flow in the stream (i.e. enhanced perenniality of flow)

Water Availability Indices

- Changes in surface water storage e.g. pond, tanks capacities etc.
- Changes in groundwater table (as observed from open wells).
- Increase in water yield/recoupment.
- Change in perenniality (duration of water availability over the year)

Soil Erosion and Sedimentation Indices

- Changes in soil loss.
- Changes in sediment yield of ponds/tanks
- Silt deposition in channel bed behind structures in
- ponds/tanks

Land Improvement Index (LLI)

$$\text{Land Improvement Index (LII)} = \frac{Recommended\ Slope(\%)}{Existing\ or\ Treated\ Slope(\%)}$$

Landuse and Productivity Indices (Biological indices)

a. Crop Yield Index (CYI)

$$\text{CYI} = \frac{\text{Average yield in the watershed (q/ha)}}{\text{Average yield in the area (q/ha)}}$$

b. Crop Productivity Index (CPI)

$$CPI = \sum_{i=1}^{n} (yi/Yi)$$

n = total number of crops in watershed

yi = average yield of ith crop in watershed

ϒi = average yield of ith crop with standard package of

Practices

c. Crop Diversification Index (CDI)

$$\text{CDI} = \sum_{i=1}^{n} \text{Pi}\ Log(\frac{1}{Pi})$$

Where,

Pi = Proportion of area sown under ith crop in comparison to

total cropped area

n = Total number of crops in the watershed.

Higher value of CDI is a measure of better diversification

d. Cropping Intensity Index (CII)

$$\text{CII} = \frac{\text{Gross cropped area of watershed}}{\text{Total watershed area}} \times 100$$

e. Crop Fertilization Index

Indicates extent of fertilizers (NPK) applied to the crop in comparison to recommended level of nutrients in that crop.

f. Cultivated Land Utilization Index (CLUI)

Cultivated land utilization index is defined as the number of days during which the crops occupied the land in a year divided by 365. It indicate that how land has been put to use for inter cropping and multiple cropping system.

$$CLUI = \sum_{i=1}^{n} (\text{aidi/AX365})$$

Where,

i = 1, 2,3…………..n

n = Total number of crops

ai = Area occupied by the ith crop

di = Days that that ith crop occupied
A = Total cultivated land area available during the 365 days period

g. Biometric Measure of Trees

Important growth parameters of trees - Plant height, Girth, Biomass, Survival Percentage.

h. Induced Watershed Eco Index (IWEI)

Induced Watershed Eco-Index is an index showing the additional area under vegetation that included crops, pasture and grassland, horticultural and forestry plantation in the watershed

$$\text{IWEI} = \frac{\text{Additional area brought under perennials during project period}}{\text{Total watershed area}}$$

The watershed management programmes were evaluated with the above mentioned indices.

Assessment of Watershed indices

	Indices	Data required	Procedure
1	Ground Water recharge	Recharge of well (Water table data in the wells)	Impact of on Ground Water Recharge will be assessed from the collected data about rainfall , land use, cropping pattern, ground water recharge structures, water harvesting structures in the watershed from the implementing agencies / villages /secondary sources.
2	Erosion Status	Change in top soil layer and quality)	Survey of water harvesting structures / soil conservation measures will be done to know about deposited soil over years with respect to catchment/watershed area. Volume of soil deposited behind the structure will be divided by catchment area and year to know soil loss per ha per year.
3	Vegetative coverage	i.Crown/canopy coverage, ii. Grass yield iii. Fuel, fodder and other **non-timber produ**cts iv. Status of its availability to the community	• To be assessed from pre and post project Satellite imageries and ground truthing. It will be extended to whole cluster depending on availability of data • Working out grass yield, fuel and fodder availability from available data.
4	Design and Estimate	Adequacy of cost of treatment Durability and Sustainability	Information about design details of structures (SWC and WHS) constructed in watershed will be evaluated by o Hydrological evaluation of peak flow adequacy o Cost of structure/ cu-m of water o Structural design for its durability.

	Indices	Data required	Procedure
			○ Assess maintenance schedule for sustainability.
5	Area under crop	Change in net sown area, Wasteland brought into cultivation, Cropping intensity data	○ Primary as well as secondary survey will be used to estimate the net area sown with different crops during pre-project and different years of project implementation and post project. ○ Change in area under crop cultivation during different years of the project implementation will also be worked out. ○ Result will be extended for the whole cluster using satellite and ground data depending on feasibility
6	Crop production	Estimate in crop yield (Pre and post Watershed data and also year wise data analysis within the watershed project period and beyond)	○ Yield data of different crops will be collected and analyzed for determination of pre-project and post project implementation scenario in respect of area production and productivity of different crops. ○ Depending upon the response trend in yield of the individual crops projection will be made beyond the project period.