7. Best-bet Options on Soil and Water Conservation

P Pathak[1], PK Mishra[2], KV Rao[3], Suhas P Wani[1] and R Sudi[1]

[1]International Crops Research Institute for the Semi Arid Tropics (ICRISAT)
Patancheru 502 324, Andhra Pradesh, India
[2]Central Soil and Water Conservation Research and Training Institute (CSWCRIT)
Research Center, Bellary, Karnataka, India
[3]Central Research Institute for Dryland Agriculture (CRIDA)
Santoshnagar, Hyderabad 500 069, Andhra Pradesh, India

Abstract

The soil and water conservation is one of the most important components of integrated watershed program. Earlier in soil and water conservation programs, efforts were concentrated on construction of various types of bunds across the slope. This helped in controlling erosion and reducing soil loss rather than increasing crop yields through additional moisture conservation. Current emphasis is more on improving moisture through various field- and community-based moisture conservation practices. This paper discusses the key findings from the various watershed programs and research stations on field- and community-based soil and water conservation interventions that were found promising for improving productivity and reducing land degradation in different regions of India.

Keywords: Soil conservation, rainwater, runoff, watershed, *in-situ*.

Introduction

Soil and water are vital natural resources for human survival. Growing world population and increasing standard of living are placing tremendous pressure on these resources. Because the soil and water resources are finite, their optimal management without adverse environmental consequences is necessary, if human survival is to be assured and development is to be sustained. There is growing realization throughout the world that no longer can we afford to misuse these resources. Furthermore, these resources have to be managed using an integrated approach. Fundamental to this approach is the invocation of the watershed-based management.

In India, the problem of soil and water resource degradation has been in existence in the past, however, the pace of degradation has greatly increased in recent times due to burgeoning population and the enhanced means of exploitation of natural resources. An insight into the various regions show a grim picture of water scarcity, fragile ecosystems, drought and land degradation due to soil erosion by wind and water, low rainwater-use efficiency, high population pressure, poverty, low investments in water use efficiency measures and inappropriate policies.

Soil and Water Conservation Problems in Various Rainfall Regions of India

Based on experiences from the various watershed programs and research station works in India, the soil and water conservation practices for the different agroclimatic zones of India were identified and are given in table 1. It clearly shows that for different regions the problems of soil and water conservations are quite different. This information is useful in determining the appropriate soil and water conservation practices for various regions. This classification and related information also assists in utilizing the research and field experience of one place to other places of identical soil, climatic and topographic conditions.

Table 1. Soil and water conservation problems in various soil conservation regions of India.

Sl.No	Soil conservation region	Rainfall (mm)	Important areas	Problems
1	North Himalayan (excluding cold desert areas)	500-2000	Mountains, temperate, arid, semiarid and sub humid areas of J&K, hill areas and Himachal Pradesh	Soil erosion along hill slopes, land slides, torrent, management of ravine lands, siltation of reservoirs, over grazing and deforestation
2	North eastern Himalayan	1500-2500	North eastern hills of Sikkim, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Assam, Nagaland, Tripura and West Bengal	Shifting cultivation, land slides, torrents and gullies problems of riverine lands, siltation of reservoirs and stream beds
3	Indo-Gangetic Alluvium soils	700-1000	Punjab, Haryana, north eastern Rajasthan, UP and Bihar plains Chambal command in Rajasthan, command area in Gujarat	Sheet erosion, ravine lands, floods, stream bank erosion, saline, alkaline lands, water-logging, prolonged dry spells and failure of rains
4	Assam Valley and Gangetic delta	1500-2500	Plains of Assam, Tripura, North Bengal and Gangetic delta, areas of West Bengal	Gully erosion, stream bank erosion, waterlogging, coastal salinity

Contd...

Contd...

Sl.No	Soil conservation region	Rainfall (mm)	Important areas	Problems
5	Desertic area	150-500	Western central Rajasthan, contiguous areas of Haryana and Gujarat, Runn of Kutch	Shifting sand dunes, wind erosion, extreme moisture stress and drought, over grazing, improper land management
6	Mixed red, black and yellow soils	600-700	District of Pali, Bhilwara, Ajmer, Chittorgarh, Udaipur, Rajasamand, Jhalawar in Rajasthan and southern UP (including Bundelkhand area) and northern MP	Ravine, shortage of moisture, recurring drought, problem of drainage, overgrazing, siltation of reservoirs and tanks
7	Black soils	500-700	South eastern Rajasthan, part of Madhya Pradesh, tracts of Maharashtra, Andhra Pradesh, Karnataka and small parts of Tamil Nadu	Sheet erosion, acute water shortage, recurring droughts, ill drained soils, siltation of reservoirs, lack of groundwater recharge
8	Black soils (deep and medium deep)	800-1300	Parts of Madhya Pradesh, Andhra Pradesh and Maharashtra	High soil erosion, gully formation, waterlogging, poor workability of soil, shortage of water during post-rainy season
9	Eastern red soils	1000-1500	Bulk of West Bengal, Bihar, Orissa and Eastern Madhya Pradesh including Chotanagapur and Chattisgarh area, part of Andhra Pradesh	Problems of sheet erosion, gullies, acute water shortage, recurring drought, heavy grazing and improper land management, siltation of reservoir and tanks
10	Southern red soils	Around 750 in Kerala upto 2500	Bulk of Kerala, Tamil Nadu hills and plains, Karnataka, Andhra Pradesh and part of Maharashtra	Sheet erosion, gullies, acute water shortage, recurring drought, siltation of reservoir and tanks, lack of groundwater recharge
11	East-west coasts	East coast about 1000 and rest heavy rainfall	East and West coast from Orissa to Saurashtra	Problems of coastal salinity, soil erosion, coastal sand dunes, wind erosion and flooding of cultivated lands by the sea water or rainwater

(Source: Modified table from Raj Vir Singh, 2000).

Field-based Soil and Water Conservation

Field based soil and water conservation measures are essential for *in-situ* conservation of soil and water. The main aim of these practices is to reduce or prevent either water erosion or wind erosion, while achieving the desired moisture for sustainable production. The suitability of any *in-situ* soil and water management practices depend greatly upon soil, topography, climate, cropping system and farmers' resources. Based on past experiences several field-based soil and water conservation measures have been found promising for the various rainfall zones in India (Table 2).

Table 2. Prioritized field based 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 • Ridging sowing across slopes • Mulching • Scoops • Tied ridges • Off-season tillage • Inter row water harvesting system • Small basins • Contour bunds • Field bunds • Khadin	• Contour cultivation with conservation furrows • Ridging • Sowing across slopes • Scoops • Tide ridges • Mulching • Zingg terrace • Off-season tillage • BBF • Inter row water harvesting system • Small basins • Modified contour bunds • Field bunds • Khadin	• BBF (Vertisols) • Conservation furrows • Sowing across slopes • Tillage • Lock and spill drains • Small basins • Field bunds • Vegetative bunds • Graded bunds • Nadi • Zingg terrace	• BBF (Vertisols) • Field bunds • Vegetative bunds • Graded bunds • Chos • Level terraces

Some of the most promising practices found from the various watershed programs are discussed in detail.

Broad-bed and Furrow System

On black soils the problem of water logging and water scarcity occurring during the same cropping season are quite common. There is a need for an *in-situ* soil and water conservation and proper drainage technology on deep black soils that can protect the soil from erosion through out the season and provide control at the place where the rain falls. A raised land configuration "Broad-bed and furrow" (BBF) system has been found to satisfactorily attain these goals (Fig. 1).

BBF formation with tropicultor.

Groundnut crop on BBF.

Figure 1. Broad-bed and furrow system at ICRISAT center Patancheru, Andhra Pradesh.

Recommended agro-ecology: Soil : medium to deep black soils (*Vertisols*)
Rainfall : 700 – 1300 mm
Slope : maximum upto 5%

Description: The BBF system consists of a relatively raised flat bed or ridge approximately 95 cm wide and shallow furrow about 55 cm wide and 15 cm deep (Fig.2). The BBF system is laid out on a grade of 0.4 – 0.8 % for optimum performance. It is important to attain a uniform shape without sudden and sharp edges because of the need in many crops and cropping systems to plant rows on the shoulder of the broad-bed. This BBF system is most effectively implemented in several operations or passes. After the direction of cultivation has been set out, based on the topographic survey (Fig.2), furrow making is done by an implement attached with two ridgers with a chain tied to ridgers or a multipurpose tool carrier called "Tropicultor" to which two ridgers are attached, and used for this operation (Fig 1). It is important to have the ridgers operate at shallow depth to attain straight lines; sharp curves must be avoided. A bed former is used to further shape up the broad-beds. If opportunity arises (after showers) before the beginning of the rainy season, another cultivation is done to control weeds and improve the shape of the BBF. Thus, at the beginning of the growing season this seedbed is receptive to rainfall and, importantly, moisture from early rains is stored in the surface layers without disappearing in deep cracks in black soils. The BBF formed during the first year can be maintained for the long term (25-30 years). This will save considerable cost as well as improve the soil health (Kampen, 1982).

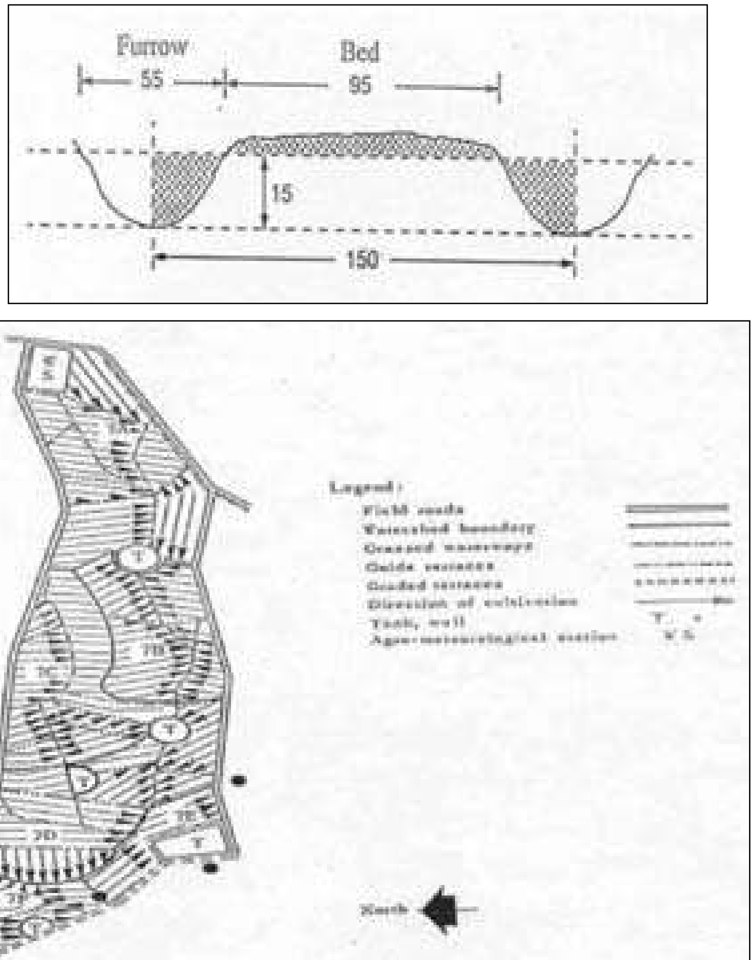

Figure 2. Broad-bed and furrow system dimension (in centimeters) and field layout based on topographic map.

Benefits:

- The raised bed portion acts as an *in-situ* 'bund' to conserve more moisture and ensures soil stability; the shallow furrows provides good surface drainage to promote aeration in the seedbed and root zone; prevents water logging of crops on the bed.
- The BBF design is quite flexible for accommodating crops and cropping systems with widely differing row spacing requirements.
- Precision operations such as seed and fertilizer placement and mechanical weeding are facilitated by the defined traffic zone (furrows), which saves energy, time, cost of operation and inputs.

- Can be maintained on the long term (25-30 years).
- Reduces runoff and soil loss and improves soil properties over the years.
- Facilitates double cropping and increases crop yields.
- Can be adopted for groundnut crop in red soils with a reduced gradient along the bed (0.2–0.4%).

Conservation Furrow System

The conservation furrow is a simple and low cost *in-situ* soil and water conservation practice for rain-fed areas with moderate slope.

***Recommended agro-ecology*:** Soil : Alfisols and associated soils
Rainfall: 400 – 900 mm
Slope : 1 - 4%

Description: This practice is highly suitable for soils with severe problems of crusting, sealing and hard setting. Due to these problems the early runoff is quite common on these soils. In this system series of furrows are opened on contour or across the slope at 3-5 m apart (Fig.3). The spacing between the furrows and its size can be

Groundnut crop with conservation furrow.

Formation of conservation furrows using local implements.

Figure 3. Conservation furrow system at Hedigonda watershed, Haveri, Karnataka.

chosen based on the rainfall, soils, crops and topography. The furrows can be made either during planting time or during interculture operation using country plough. Two to three passes in the same furrow may be needed to obtain the required furrow size. These furrows harvest the local runoff water and improve the soil moisture in the adjoining crop rows, particularly during the period of water stress. The practice has been found to increase the crop yields by 10-25% and it costs around Rs 250-350 ha^{-1}. To improve its further effectiveness it is recommended to use this system along with contour cultivation or cultivation across the slope (Ram Mohan Rao et al. 1981).

Benefits:

- Furrows harvest the local runoff and increase the soil moisture for adjoining crop rows.
- Reduced runoff and soil loss.
- Simple and low cost system.
- Easy to adopt and can be implemented using traditional farm implements.
- Increased crop yields (10-25%).

Modified Contour Bunds

Well-designed and maintained conventional contour bunds on Alfisols and other light soils undoubtedly conserve soil and for this purpose contour bunds are perhaps efficient. However, the associated disadvantages – mainly water stagnation (particularly during the rainy season) (Fig. 4) causing reduction in crop yields – outweigh any advantage from the viewpoint of soil conservation. The modified contour bunds with gated-outlets have shown good promise because of the better control on ponded runoff water (Fig. 5).

Recommended agro-ecology: Soil : Alfisols and associated soils
Rainfall: 500 – 900 mm
Slope : 1 - 8%

Description: Modified contour bunding involves constructing embankments on contours with gated-outlet at the lower end of the field (Fig. 5). This gated-outlet allows the runoff to be stored in the field for a desired period, and then released at a predetermined rate through the spillway, thus reducing the time of water stagnation behind the bund, which will have no adverse effect on crop growth and yield and also facilitates the water infiltration into soil to its optimum capacity (Pathak et al. 1989).

Figure 4. Conventional contour bund system.

Figure 5. Gated-outlet contour bund with water stagnation (gated-outlets are shown in inset).

Benefits:

- The problem of prolonged water stagnation around the contour bund is reduced in the gated outlet contour bund system. This results in the better crop growth and higher crop yield.
- The chances of bund breaching are less in this system, while in conventional contour bunds the occasional breaching of bunds is common mainly because of prolonged water ponding.
- Low peak runoff rate compared to conventional contour bunds.
- More timely tillage and other cultural operations are possible in the gated-outlet contour bund system because of better control on ponded runoff water.
- Gated-outlet contour bund system involves low cost for modification and is simple to adopt.

Contour Cultivation or Cultivation Across Slope

The common method of cultivation on sloping lands is up and down the slope. This is one of the causes of poor rainfall infiltration and accelerated soil erosion. Contour cultivation or cultivation across the slope are simple methods of cultivations, which can effectively reduce the runoff and soil loss on gentle sloping lands.

Recommended agro-ecology: Soil : All most all soil types
Rainfall: Upto 1000 mm
Slope : 1.5 – 4.0%

Description: In contour cultivation all the field operations such as ploughing, planting and intercultivation are performed on the contour (Fig. 6). It helps in reduction of runoff by impounding water in small depressions and reduces the developments of rills. In practice it is often difficult to establish all crop rows on the true contour because of non-uniform slopes in most of the fields. In order to establish row directions adjusted contours are laid out at one or more elevations in the field. In some situations it is desirable to provide a small slope along the row (cultivation a cross the slope), to prevent runoff from a large storm breaking over the small ridges formed during the contour cultivations. The effectiveness of this practice varies with rainfall, soil type and topography. Maximum effectiveness of this practice is on medium slopes and on permeable soil. The relative effectiveness decreases as the land grades becomes very flat or very steep. On long slopes, where bunding is done to decrease the slope length, the bunds can act as guidelines for contour cultivation. On the mild slopes where bunding is not necessary, contour guidelines may be marked in the field (Ram Mohan Rao et al. 1981).

Figure 6. Contour cultivation at Kurnool watershed in Andhra Pradesh.

On undulating fields having number of depressions and ridges, contour cultivation is likely to be difficult. Land smoothing is needed to fill up such depressions. Contour cultivation on steep slopes or under conditions of high rainfall intensity may cause formation of gullies because row breaks may release the stored runoff water to next down stream row. Moreover, break over causes cumulative damage as the volume of runoff water increases with each succeeding down stream row.

Benefits:

- Reduces runoff and soil losses.
- Increase in crop yields.
- Simple, low cost and technically feasible even for small farmers.

Vegetative Barriers

Vegetative barriers or vegetative hedges or live bunds are effective in reducing soil erosion and conserving moisture. In several situations the vegetative barriers are more effective and economical than the mechanical measures viz. bunding.

Recommended agro-ecology:

Soil :	Alfisols, Vertisols, Vertic-Inceptisols and associated soils
Rainfall:	400-2500 mm
Slope :	More than 2.5%

Description: Vegetative barriers can be established either on contour or on moderate slope of 0.4 to 0.8%. In this system, the vegetative hedges act as barriers to runoff flow, which slow down the runoff velocity resulting in the deposition of eroded sediments and increased rainwater infiltration. It is advisable to establish the vegetative hedges on small bund. This increases its effectiveness particularly during the first few years when the vegetative hedges are not so well established. The key aspect of design of vegetative hedge is the horizontal distance between the hedge rows which mainly depends on rainfall, soil type and land slope. Species of vegetative barrier to be grown, number of hedge rows, plant to plant spacing and method of planting are very important and should be decided based on the main purpose of the vegetative barrier. If the main purpose of the vegetative barrier is to act as a filter to trap the eroded sediments and reduce the velocity of runoff then the grass species such as vetiver, sewan (*Lasiurus sindicus*), sania (*Crotolaria burhia*) and kair (*Capparis aphylla*) could be used. But if the purpose of vegetative hedges is to stabilize the bund then plants such as *Glyricidia* or others could be effectively used (Fig. 7). The *Glyricidia* plants grown on bunds not only strengthen the bunds while preventing soil erosion, but also provide N-rich green biomass, fodder and fuel. The cross section of earthen bund can also be reduced. Study conducted at

Figure 7. Glyricidia plants on bunds and over view of a watershed with Glyricidia on graded bunds, ICRISAT center, patancheru, Andhra Pradesh.

ICRISAT research center indicated that by adding the N-rich green biomass from the *Glyricidia* plants planted on bund at a spacing of 0.5 m apart for a length of 700 m could provide about 30-45 kg N ha^{-1} yr^{-1} (Wani and Kumar, 2002).

In areas with long dry periods, vegetative hedges may have difficulties in surviving. In very low rainfall areas, the establishment and in high rainfall area, the maintenance could be the main problem. Proper care is required to control pests, rodents and diseases for optimum growth and survival of both vegetative hedges and main crops.

Benefits:

- Once properly established the system is self sustaining and almost maintenance free.
- Land under the hedge is used for multipurpose viz. N-rich biomass, fodder and fuel.
- Can be successfully used under wide range of rainfall (400-2500 mm) and topography.
- Economical and often more effective than other erosion control measures.

Community-based Water Harvesting and Soil Conservation Structures

Currently in most of the watershed programs in India, the community-based soil and water conservation are playing the key role in improving surface and groundwater availability and controlling soil erosion. Large percentage of total watershed fund is currently used in implementing these measures. Studies conducted by ICRISAT have shown that the cost of water harvesting and groundwater recharging structures varies considerably with type of structures and selection of appropriate location. Large variation is found in the cost of water harvesting in different structures (Fig. 8). Selection of appropriate location for structures also can play very important role in reducing the cost of structures (Fig. 9).

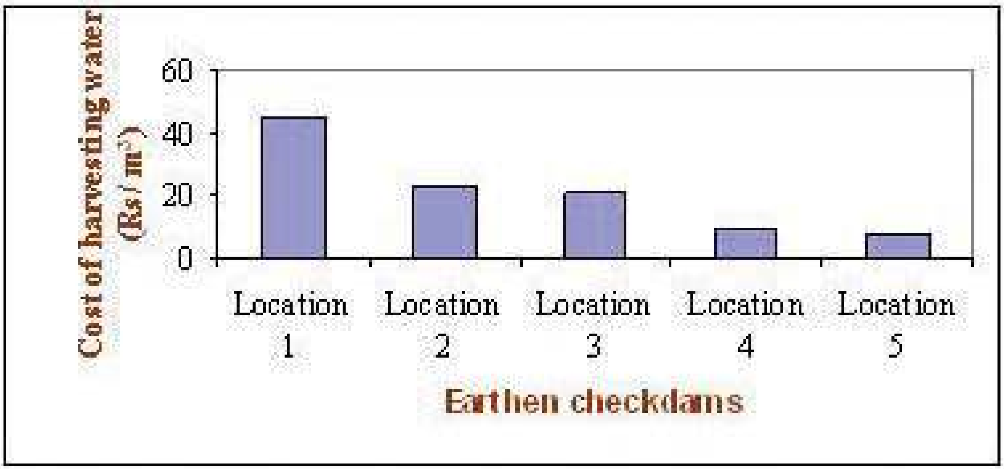

Figure 8. Cost of water harvesting at different locations in Lalatora watershed, Madhya Pradesh.

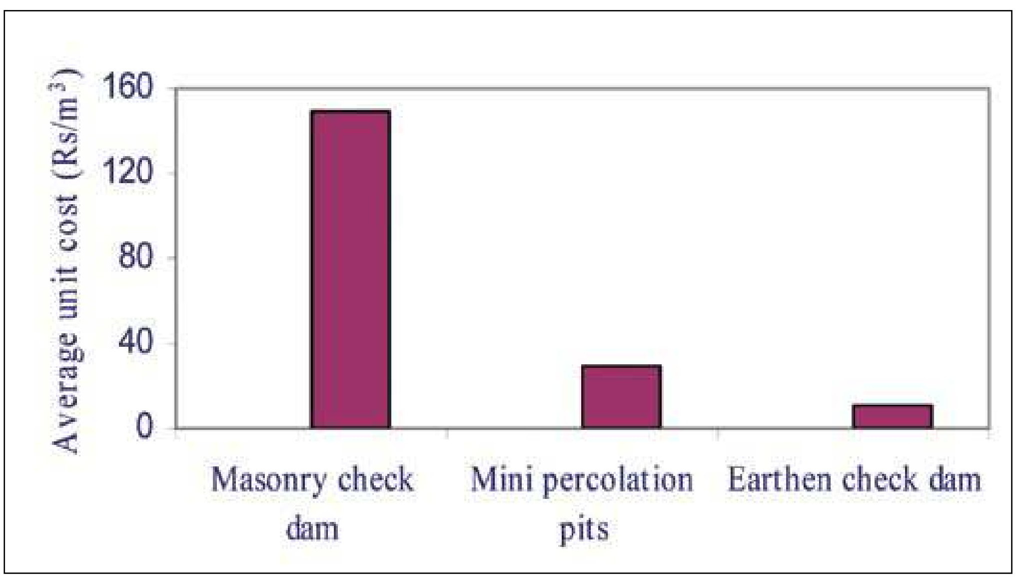

Figure 9. Cost of harvesting water in different structures at Kothapally watershed.

Some of the most promising community based soil and water conservation measures are discussed in detail.

Masonry Check Dam

Masonry check dams are permanent structures effectively used for controlling gully erosion, water harvesting and groundwater recharging (Fig. 10). These structures are popular in watershed programs in India. The cost of construction is generally quite high.

Figure 10. A masonry check dam at Kothapally watershed, Ranga Reddy, Andhra Pradesh.

Description: These structures are preferred at sites where velocity of runoff water flow in gullies/streams is very high and stable structure is needed to withstand the difficult condition. Proper investigations, planning and design are needed before construction of masonry check dams. Masonry check dams are designed on the basis of engineering principles. The basic requirements for designing the masonry check dams are: hydrologic data, information on soils and geology, the nature and properties of the soils in the command area and profile survey and cross-sectional details of the stream or gully. A narrow gorge should be selected for erecting the dam to keep the ratio of earthwork to storage at minimum. Runoff availability for the reservoir should be computed on the basis of rainfall runoff relationship. Depending upon the assumed depth of structure and the corresponding area to be submerged, suitable height of the dam may be selected to provide adequate storage in a given topographic situation (Katyal et al. 1995).

The cross-section of dam and other specifications are finalized considering the following criteria: there should be no possibility of the dam being over-topped by flood-water, the seepage line should be well within the toe at the downstream face;

the upstream and downstream faces should be stable under the worst conditions, the foundation shear stress should be within safe limit; proper spillway should be constructed to handle the excess runoff and the dam and foundation should be safe against piping and undermining.

Benefits:

- Long lasting structures with little regular maintenance.
- Effective in controlling gully and harvesting water under high runoff flow condition.

Low-cost Earthen Check Dam

Earthen check dams are very popular in the watershed programs in India for controlling gully erosion and for harvesting runoff water. These are constructed using locally available materials. The cost of construction is generally quite low.

Recommended agro-ecology: Soil : All soil types
Rainfall: 350-1300 mm

Description: Earthen check dams are those water harvesting structures that have an embankment constructed across the waterway (Fig. 11). The size of the dam depends on the site conditions. In some cases, the stone pitching may be required to protect the bund from scouring. The earthen check dams are used for multiple purposes. They are used as surface water storage structures as well as for recharging groundwater. Economic analysis study of structures in ICRISAT's benchmark watersheds in India revealed that the unit cost of harvesting/recharging of water of these small and medium earthen check dams were Rs 10-45 per m^3, which was less than 1/3rd cost of masonry structures.

Fig. 11. Earthen check dam at Lalatora watershed, Vidisha, Madhya Pradesh.

Benefits:

- These structures serve as water storage and recharging groundwater.
- These structures can be constructed using locally available materials.
- Simple in design and can be easily constructed by local community.
- These structures are low-cost as well as cost-effective (cost of recharging per unit volume of water).

Khadin System

Khadin is a land-use system developed centuries ago in the Jaisalmer district of western Rajasthan. This system is practiced by single larger farmer or by group of small farmers. It is highly suitable for areas with very low and erratic rainfall conditions.

Recommended agro-ecology:

Soil :	Sandy and other light soils
Rainfall :	250-700 mm

Description: In *khadin* system, preferably an earthen or masonry embankment is made across the major slope to harvest the runoff water and prevent soil erosion for improving crop production. *Khadin* is practiced where rocky catchments and valley plains occur in proximity. The runoff from the catchment is stored in the lower valley floor enclosed by an earthen/stone '*bund*' (Fig. 12). Any surplus water passes out through a spillway. The water arrested stands in the *khadin* throughout the monsoon period. It may be fully absorbed by the soil during October to November, leaving the surface moist. If standing water persists longer, it is discharged through

Figure 12. Crop cultivation in Khadin system at Goverdhanpura watershed, Bundi, Rajasthan.

the sluice before sowing. Wheat, chickpea or other crops are then planted. These crops mature without irrigation. The soils in the *khadins* are extremely fertile because of the frequent deposition of fine sediment, while the water that seeps away removes salts. The *khadin* is, therefore, a land-use system, which prevents soil deterioration (Kolarkar et al. 1983). This practice has a distinct advantage under saline groundwater condition, as rainwater is the only source of good quality water in such area.

Benefits:

- It improves surface and groundwater availability in the area.
- The *khadin* bed is used for growing post-rainy season crops.
- This requires minimum maintenance (once in 5 years).
- This system results in assured rainy and post rainy season crops, there by improving soci-economic condition of farmer.
- This system provides source of drinking water for livestock.
- It reduces flood or peak rate of runoff.
- It conserves soil and improves rainwater use efficiently.

Farm Ponds

Farm ponds are very age old practice of harvesting runoff water in India. These are bodies of water, either constructed by excavating a pit or by constructing an embankment across a water-course or the combination of both (Fig.13).

Figure 13. A dugout farm pond at Guntimadugu watershed, Kadapa, Andhra Pradesh.

Description: Farm pond size is decided on the total requirement of water for irrigation, livestock and domestic use. If the expected runoff is low, the capacity of the pond will only include the requirement for livestock and domestic use. Once the capacity of the pond is determined, the next step is to determine the dimensions of the pond. To achieve the overall higher efficiency, the following guidelines should be adopted in the design and construction of farm ponds.

- **High-storage efficiency (ratio of volume of water storage to excavation):** This can be achieved by locating the pond in a gully, depression, or on land having steep slopes. Whenever possible, use the raised inlet system to capture runoff water from the upstream. This design will considerably improve the storage efficiency of the structure.
- **Reduce the seepage losses:** This can be achieved by selecting the pond site having subsoils with low saturated hydraulic conductivity. As a rough guide, the silt and clay content of the least conducting soil layer is inversely linked with seepage losses. Therefore, it is best to select the site having subsoil with higher clay and silt and less coarse sand. Also, reduce the pond wetted surface area in relation to water storage volume. This can be achieved by making the pond of a circular shape or close to circular shape.
- **Minimize the evaporation losses:** As far as possible, the ponds should be made deeper but with acceptable storage efficiency to reduce water surface exposure and to use smaller land area under the pond.

Benefits:

- Multiple use of stored water.
- Simple to construct using locally available material.
- Useful for the upstream parts of watershed particularly where groundwater availability is low.

Gully Checks with Loose Boulder Wall

Loose boulder gully checks are quite popular in the watershed program for controlling gully erosion and for increasing groundwater recharge (Fig.14). These are very low cost structures and quite simple in construction.

Description: These gully checks are built with loose boulder only, and may be reinforced by wire mesh, steel posts, if required for stability. Often it is found on the land and thus eliminates expenditure for long hauls. The quality, shape, size and distribution of the boulders used in the construction of gully checks affect the life span of the structures. Obviously, boulders that disintegrate rapidly when exposed to water and atmosphere will have a short structural life. Further, if only small boulders are used in a dam, they may be moved by the impact of the first large water flow. In contrast, a gully checks constructed of large boulders that leave large voids in the structure will offer resistance to the flow, but may create water jets through the voids. These jets can be highly destructive if directed toward openings in the bank protection work or other unprotected parts of the channel. Large voids in gully checks also prevent the accumulation of sediment above the structures. In general, this accumulation is desirable because it increases the stability of structures and enhances stabilization of the gully.

Benefits:

- Low-cost and simple in construction with the locally available materials
- These are effective in controlling gully and improving groundwater

Figure 14. Series of loose boulder wall gully checks at Bundi watershed, Rajasthan.

References

Kampen J. 1982. An approach to improved productivity on deep Vertisols. ICRISAT Information Bulletin II, Patancheru 502 324, Andhra Pradesh, India.

Kolarkar AS, **Murthy KNK** and **Singh N.** 1983. *Khadin* – a method of harvesting water for agriculture in the Thar Desert. Journal of Arid Environments 6 (1): 59-66.

Katiyal KC, Shriniwas Sharma, Padmanabham MV, Das SK and **Mishra PK.** 1995. Field manual on watershed management. Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, India. 165 pp.

Pathak P, Laryea KB and **Singh S.** 1989. A modified contour bunding system for Alfisols of the semi-arid tropics. Agricultural Water Management 16:187-199.

Ram Mohan Rao MS, Chittaranjan S, Selvarajan S and **Krishnamurthy K.** 1981. Proceedings of the panel discussion on soil and water conservation in red and black soils, 20 March 1981, UAS, Bangalore, Karnataka: Central and Soil and Water Conservation Research and Training Institute, Research Center, Bellary, Karnataka and University of Agricultural Sciences, Bangalore, India. 127 pp.

Raj Vir Singh. 2000. Watershed planning and management. Bikaner, India: Yash Publishing House. 470 pp.

Wani SP and **Kumar MS.** 2002. On-farm generation of N-rich organic material. *In*: A Training Manual on Integrated Management of Watersheds. SP Wani, P Pathak and TJ Rego, ICRISAT, (eds.) Patancheru, Andhra Pradesh, India. 30 pp.