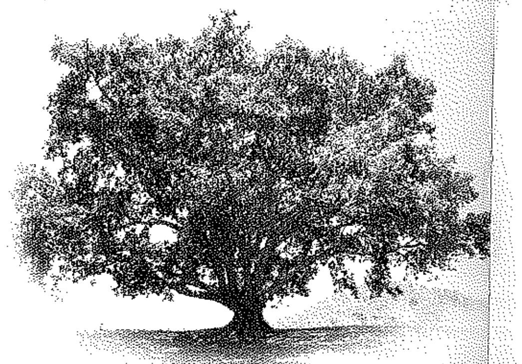


REHABILITATION OF THE DEGRADED SHIVALIK ECO-SYSTEM THROUGH INTEGRATED WATERSHED MANAGEMENT

T.C. JAIN • World Bank • New Delhi
S.S. GREWAL • Watershed Development • Ballowal Saunkhri • Takarla • Punjab
A.S. DOGRA • Integrated Watershed Development Programme (Hills) • Government of Punjab • Chandigarh

INTRODUCTION

Due to the ever increasing pressure of population, poverty and lack of resources, the once rich forests have been converted into barren degraded lands and perennial springs and gentle streams have become ever widening torrent beds

The foothills of the Himalayas locally called Shivaliks covers an area of 8 million ha in five northern states of India (Haryana, Jammu & Kashmir, Himachal Pradesh, Punjab and Uttar Pradesh) and is considered as one of the eight most degraded eco-systems of the country. The low hills are composed of loose, friable and unstable geological strata of soft sandstone. Due to poor vegetative cover and annual rainfall of 1000 to 1500 mm (80% during the monsoon season) with a high coefficient of variation, the area experiences severe soil erosion which manifests itself in frequent landslides and widening gullies. The principal land use is rainfed agriculture in valleys and pasture and forestry on hill slopes. Due to the ever increasing pressure of population, poverty and lack of resources, the once rich forests have been converted into barren degraded lands and perennial springs and gentle streams have become ever widening torrent beds (choes). The centuries old feud between poor people and the naked hills continues with increasing intensity.

Describing the problems in historical perspective and the consequences of resource degradation, the paper highlights the salient environmental, economic and social benefits of some of the operational projects which have changed the watershed development approaches in the region. The objectives, special features, implementation strategies and lessons learnt from the World Bank funded Integrated Watershed Development (IWDP) Hills and other similar projects on Watershed Development have been analyzed. The IWDP (Hills) is being implemented in four states (except UP) from 1990 to March 1999 and so far has treated 180,000 ha at a total cost of Rs. 2,240 million.

It is suggested that to ensure quality and successful implementation of watershed development programs, the project should (a) create a unified implementing agency with a strong cadre of trained manpower; (b) adopt a single window system of providing goods and services without duplicating efforts through different channels; (c) ensure uninterrupted flow of funds irrespective of agency/sources of funding; (d) provide strong adaptive research, training and extension support; and (e) a regular system of monitoring and evaluation. In future projects, institutional development should precede project identification and implementation and emphasis should be placed on community-based organizations for sustainability of project interventions.

Seasonally dry tropics are spread over 20 million sq. km. area in five continents and support more than 600 million people mostly living at subsistence level and practising high risk rainfed farming on small farms where problems of poverty, resource starvation and degradation of natural resources have been defying appropriate solution. India is no exception as most of it lies in the semi arid tropics. Out of 329 ha of geographical area of the country, 111 million ha suffers from water erosion, 39 million ha from aridity and wind erosion and 25 million ha from other soil and water related problems (Das 1985 and Tejwani 1979). Nearly 40 million ha have emerged as wastelands that are difficult to revive. Once the medium of plant growth is degraded, the path to recovery is rather slow and difficult. The deterioration in soil fertility, productivity and quality has become a matter of serious concern. The

efficient management of natural resources would largely determine the prospects of increasing and sustaining productivity in the seasonally dry tropics (Swaminathan 1980). The management approaches shall, however, vary according to rainfall, soil type, crops grown and socio economic conditions of each agro-ecological region.

HISTORY OF RESOURCE DEGRADATION IN THE SHIVALIK ECOSYSTEM

The causes of denudation, in fact, are deeply embedded in the social syndrome of the poverty ridden hilly villages which were neglected for too long in the process of economic development

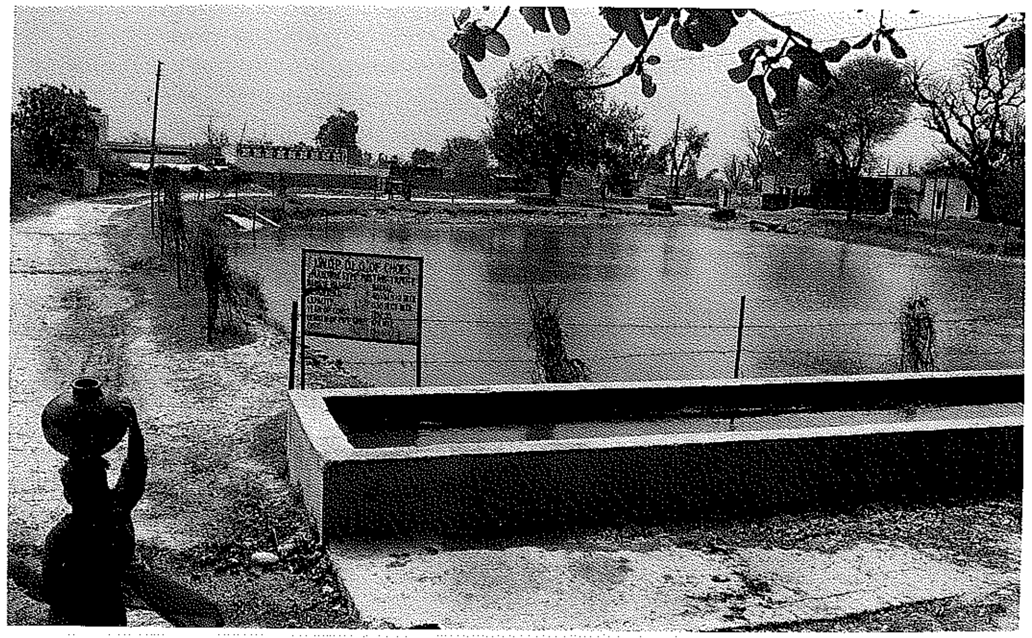
The Shivaliks are sandwiched between the Indo-Gangetic alluvial plains and the rocky Himalayas. These low hills are reported to have thick luxurious natural forests full of wildlife and perennial streams before becoming the target of human greed. Agriculture flourished first along the rivers and streams and then extended into the interiors. The process of land degradation started about 150 years ago and has continued unabated and defied solution (Mishra and Sarin 1987). The forests were recklessly destroyed to expand agriculture, provide fuel to lime kilns, meet firewood demands of troops stationed in the area and labor force engaged in constructing cantonments, canals and railway lines. An area once dotted with perennial springs and gentle streams was converted into one of ever-widening and deepening torrent beds (called choes) which bring flash floods from the barren hills. As the problem assumed serious proportions in the foothills of north India, the Punjab Land Preservation (choes) Act was passed in 1900 to prevent further deterioration. The resistance by the local people to the act led to the grant of limited grazing and tree cutting rights in forests close to villages. The implementation of the law remained weak and the situation continued to deteriorate. The problem of deforestation and resultant degradation of natural resources remained a matter of serious concern much before independence (Holland 1928, Glover 1944 and Gorrie 1946). The control measures of the pre-independence period included legislation, transfer of administrative control of forests from Deputy Commissioners to Forest Officers, spread of bhabar grass (Eulaliopsis binata) culture, eviction of cattle and goats, reclamation of torrent beds by vegetative measures using local species (Lanea grandis, Vitex negundo, Arundo donax, Ipomea cornea, Saccharam munja, sissoo, khair, agave, ficus, tamarax, bamboo); contour bunding, check damming, surplus water disposal in cultivated lands, formation of cooperative societies and large scale demonstration.

SOCIAL DIMENSIONS OF DEGRADATION

The causes of denudation, in fact, are deeply embedded in the social syndrome of the poverty ridden hilly villages which were neglected for too long in the process of economic development. The isolated efforts made by the Government to reverse the process of degradation failed to produce tangible results. The priorities of the people and the Government were poles apart. The foresters wanted to protect the unlocked forest wealth with rules and rod but the desperate people had no other alternative than to rob or steal for mere survival. Neither the hills gained the greenery, nor the people earned their bread. In the process, the poor became poorer, the rill became a gully, the tree became a bush and a gentle stream became a ferocious torrent. The problem defied solution, perhaps because the community, the most powerful denominator in the conservation-production equation, was not assigned any value. Those with no other means than wood to cook their meals cannot leave nearby trees unmolested, even if labeled 'reserved' by the Government. The centuries-old feud between the poor

people and the naked hills was not fully grasped. The need of forage and fuel was never satisfied and hence the rape of the hills continued. The abstract idealism of conservation and the drive to keep distant pastures green was beyond the ken of foraging "Guzzars" (nomadic graziers) who attacked the tiring hills with renewed vigor as they yielded less and less (Bajwa 1983).

Gradually, it became clear that the process could not be reversed by Government efforts alone, and only collective efforts and wisdom could halt the march of degradation. The whole-hearted participation of the people has been lacking and examples of willing participation in the rehabilitation programs were few. It was realized that the gains of the green and white revolutions cannot be sustained for long with barren hills from which severe soil erosion was rapidly silting precious reservoirs providing electricity and water for irrigated plains. The Shivaliks are highly prone to soil erosion because of certain special features which are described here.



Picture 1
Harvesting perennial flow of water to meet pressing needs for human beings and livestock and for supplemental irrigation

SPECIAL FEATURES OF THE SHIVALIKS

- Most of the area receives 1000-1500 mm of mean annual rainfall in a typical bi modal semi-arid monsoon climate. About 80% of the rainfall occurs during the monsoon with a high coefficient of variability both in time and space. Floods and droughts are frequent. The chances of tubewell and canal irrigation are remote because of topographic and groundwater limitations.
- The low hills are composed of loose, heterogeneous, friable and unstable geological strata of soft sandstone, silt stone (shale) with varying amounts of boulders, pebbles and their weathering products formed from sub-aeolian wastes of mountains swept down by rivers and streams. The Shivaliks have one of the most erodible soils of the world and are considered to be one out of the eight most fragile ecosystems of the country.
- Rills and gullies tear the catchments with high drainage density (7-9 km/sq. km). Poor vegetative cover, erodible soils, ever deepening and widening gullies, landslides, land slips, pot holes cause severe soil erosion from forest watersheds (Grewal 1995).

- Because of steep gradient of the hills, the torrents scour beds and banks, but shed debris in beds upon entering relatively flat plains. As the bed rises with debris, water spreads towards the sides and erodes the soft soil of the banks. Torrents meander frequently due to variable (hard and soft) geological formations which make them cut one bank and deposit senile debris on to the other, thus making drainage line control measures difficult.
- Compelled by poverty, many male members migrate to cities for employment, some move with cattle to find greener pastures along rivers and remain away for a major part of the year. Most of the old men and ladies stay back. The decision taking elite of the society is, therefore, not readily available. "Guzzars" dominate the area, who neither believe in small family norms nor in much education, particularly to women.
- The principal land use in the Shivaliks is rainfed agriculture in valleys and pasture and forestry on the hill slopes. The erratic distribution of rainfall, lack of irrigation, soil fertility depletion, heavy soil erosion, small and fragmented land holding, scarcity of food, fodder and fuel and extension of gullies to farm lands are the major problems (Grewal et al 1990). More than 50% of precious rainwater is wasted as runoff causing problems of floods and siltation of reservoirs. Both on-site and off-site damages are colossal. A cycle of poverty and degradation continues with downward spiral.
- Due to the risk of crop failures, poor farmers feel reluctant to invest on costly seeds and chemical fertilizers. Their initiatives have virtually dried and they feel reluctant to accept new innovations unless clearly demonstrated. Large herds of cattle are added to farming systems to supplement low income. The acute scarcity of fodder compels them to let loose their cattle for grazing in the adjoining hills.

The resources spent on rehabilitation simply go waste because the area reverts again to the same situation within a couple of years due to lack of effective closure and lack of people's participation. The local people, in view of the immediate pressing requirements of fuel and fodder, do not appreciate even some of the long-range benefits of the programs of afforestation and check damming. There is a general lack of communication network, education facilities, marketing, credit and banking services. These peculiar social and economic conditions further complicate the implementation of watershed development programs. Unless economically viable and compatible measures are found for these people, it is very difficult to protect the hills and forests.

PROJECTS WHICH CHANGED DEVELOPMENT STRATEGIES

A ray of hope emerged from some innovative projects based upon watershed approach, where willing participation of the people could be enlisted in rehabilitation efforts. A brief description of a few such projects would be appropriate because the seeds of new approaches to watershed development and community participation sprouted here and then got scattered all over the Shivaliks.

Rajgarh Project: In a 50 ha heavily eroded agricultural watershed owned by 28 farmers of village Rajgarh near Chandigarh, field bunding against the slope supported by masonry weirs and check dams for water disposal and a series of drop structures in the drainage lines constructed with due consultation with the farmers improved the land husbandry of the area

(Grewal 1996). The approach was so much liked by the farmers that all repairs and maintenance was attended to by them and no earthen bund or mechanical structure was allowed to fail. The fields were subsequently leveled into half-acre wide series of terraces by their own efforts. The gully beds were converted into level sugarcane fields. All the Government loans were paid with full interest without a single default. The land quality improved and productivity registered a quantum jump. This was the first successful example of land development measures adopted by soil conservation staff of Punjab on watershed basis with community participation.

There are now 120 such projects in the state of Haryana, 56 in Punjab and 23 in Himachal Pradesh. Such Operational Research Projects implemented in real field conditions with consent, cooperation and consultation with the farmers, showed positive results

Sukhomajri Project: A recreational lake was established in the early fifties at Chandigarh by harnessing the monsoon rain water from a 40 sq.km. catchment area of the Shivalik hills and rolling farm lands. In spite of routine conservation measures, the lake lost 70% of its storage capacity in 17 years and silted at the rate of 4% per annum. The bare hill slopes of its catchment were releasing up to 900 tonnes of sediment/ha/year because of reckless felling and overgrazing by the people of Sukhomajri and adjoining villages (Grewal et al 1995).

In the Operational Research Project of ICAR at Sukhomajri near Kalka in Haryana state, four earthen dams were constructed between 1978-1983 to store rainwater from hilly forest catchments and used for supplemental irrigation in 24 ha valley land through underground pipelines. In addition, the Agriculture and Forest Departments of Haryana constructed six more dams in nearby villages. This facility revolutionized the rainfed agriculture. Crops and grass yields in catchment areas have increased. Tree density has improved and runoff and soil loss has decreased. The availability of water from forest for thirsty farmlands tied up the economic interest of the farmers with catchment protection. A village cooperative emerged which took the responsibility of protecting the forests (social fencing). Grazing was replaced by stall-feeding. Forest contractors were replaced by village cooperatives taking the contract for extracting forage and commercial grasses. The hills regained the lost greenery and people regained faith in conservation and joint management of resources. There are now 120 such projects in the state of Haryana, 56 in Punjab and 23 in Himachal Pradesh. Such Operational Research Projects implemented in real field conditions with consent, cooperation and consultation with the farmers, showed positive results (Grewal et al 1990).

Nada, Bunga and Relmajra Projects: The successful example of Sukhomajri was replicated in the second phase of Operational Research Project at Nada village with similar results. This was followed by yet another milestone in the history of watershed management in village Bunga (Haryana) where under National Watershed Development Program, rainwater from 150 ha forest land was provided to 240 ha of farm land by constructing a 16m high earthen dam in 1984. This being the largest area covered under this approach, it has firmly established the confidence that farm and forest land could be developed together with community participation. Since these projects were located in Haryana, a similar project was selected in village Relmajra during 1991, near Ropar in the Punjab Shivaliks, with the financial assistance of the Ministry of Environment and Forests, Government of India. In this project, covering 672 ha of land, rainwater harvesting, development of marginal lands under horticulture and forage component and drainage line treatment technology was successfully demonstrated (Samra et al 1995). The village society is generating social funds for maintenance and creating welfare facilities for the community.

Punjab Agricultural University Initiatives: Simultaneously, the Punjab Agricultural University, Ludhiana, with support from the World Bank under the National Agricultural Research Project (NARP) took a bold initiative to establish a full-fledged Regional Research Station for foothill areas of the state in 1983 to

develop and disseminate technologies for rainfed agriculture, horticulture, agro forestry, forage production, soil and water conservation and watershed management. The micro-watershed hydrology studies were initiated at Saleran (Hoshiarpur) and Patiala-ki-Rao (Ropar) watersheds to generate research information on rainfall-runoff relationships and sediment loss. Studies on runoff harvesting and efficient use of limited water were initiated in Karoran, Ballowal Saunkhri and Takarla watersheds. Experiments were also conducted to evaluate the effect of different vegetative barriers on runoff, soil loss and crop yields. This station has generated very useful research information and package of practices which are now being disseminated through various means including the Krishi Vigyan Kendras and Farm Advisory Services operating in the Shivalik region.

National Watershed Development Project for Rainfed Areas (NWDPRA): This is a scheme of the Ministry of Agriculture and Cooperation, Government of India, intended to generate successful watershed development models in all the community development blocks of the country where less than 30% arable area is under assured means of irrigation (WARASA 1991). The project was planned to act as a pace setter for comprehensive development of dry land areas adopting farming systems approach on watershed management principles in order to conserve precious rainwater and top soil. The soil and water conservation programs using vegetative technologies are supported by animal husbandry, agro-forestry, horticulture, fisheries, sericulture and primary agro-processing, etc. Seth (1990) has listed the treatment components for arable, non-arable and drainage lines. In the Punjab Shivaliks, 13 watersheds were selected under NWDPRA (1990-91) covering 19,559 ha of total area out of which11,167 ha was arable and the remaining non-arable. A sum of Rs. 63.8 million was provided for treatment. The Department of Soil Conservation and Wasteland Development was made the nodal agency for coordination of activities with the line departments. The funds for associated activities in the selected watersheds are placed at the disposal of the line departments.

INTEGRATED WATERSHED DEVELOPMENT PROJECT (IWDP) HILLS

This US$ 125.6 million project funded by the World Bank was designed to address the most serious problem of degradation in fragile ecosystems of the Shivaliks with cost effective vegetative technology for soil and water conservation on both arable and non-arable land. Introduction of rainfed horticulture on marginal land, livestock improvement, forage production, drainage line treatment are other components of this 7-year (1990-1997) project, which has now been extended for two more years up to March 31, 1999. The program is being implemented in four northern states of India (Haryana, Himachal Pradesh, Jammu and Kashmir and Punjab) through participatory approach involving beneficiaries (small farmers, landless people and livestock owners) to ensure sustained management of common property resources.

The menu of treatment of five project components is summarized below:

1. Vegetative shrub barriers in trenches
2. Afforestation
3. Silvipasture
4. Vegetative barriers
5. Rainfed agriculture demonstration

6. Rainfed horticulture demonstration
7. On-farm fodder demonstration
8. Vegetative field boundaries/Terrace repair
9. Gully stabilization
   - Masonry cement structures
   - Crate wire structure
   - Dry stone masonry structures
   - Vegetative check dams
10. Stream bank protection
    - Crate wire structure
    - Vegetative spurs
11. Construction of new ponds
12. Rehabilitation of village ponds
13. Makkowal type tanks
14. Silt retention structures
15. Livestock improvement

Special features of IWDP (Hills)

- Integration of staff and activities on watershed basis
- Use of vegetative technology and production systems
- Support for agro forestry, livestock improvement and health and fodder
- Emphasis on sustainability and replicability
- Emphasis on PRA, detailed planning, effective implementation and documentation
- Sensitization to local needs with participatory approach
- On-farm adaptive research support
- Professional training to improve technical competence
- Regular monitoring and evaluation mechanism
- Regular interaction at all levels
- Mid-term review for reorientation of priorities
- Support for waters harvesting structures

Water resources development to meet the pressing demands of drinking water, livestock use and supplemental irrigation was given a very high priority after the Mid Term Review in 1995. Perennial flow from small streams was harvested by specially designed, simple and cost effective structures (Makowal). The main advantages of this system are: gravity flow with no energy costs, reduction in drudgery of women and possibility of rearing fish (Fig . 1). The fee charged for supplemental irrigation goes to a common fund and is used for maintenance of the system. Rainwater was also harvested by constructing small earthen dams and stored water used for limited supplemental irrigation which produced green fodder (clover) for stall fed buffaloes and resulted in increased milk and manure production (Fig. 2).

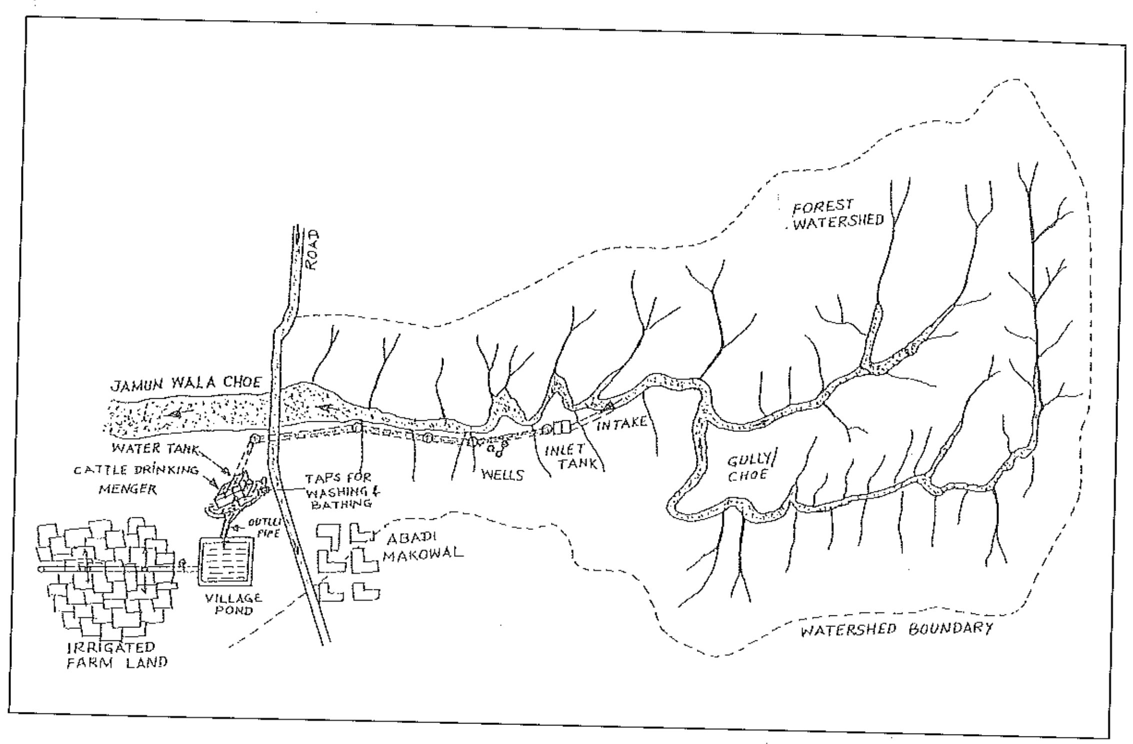


Figure 1: Map of Makowal perennial flow harvesting system - Hoshiarpur (Punjab)

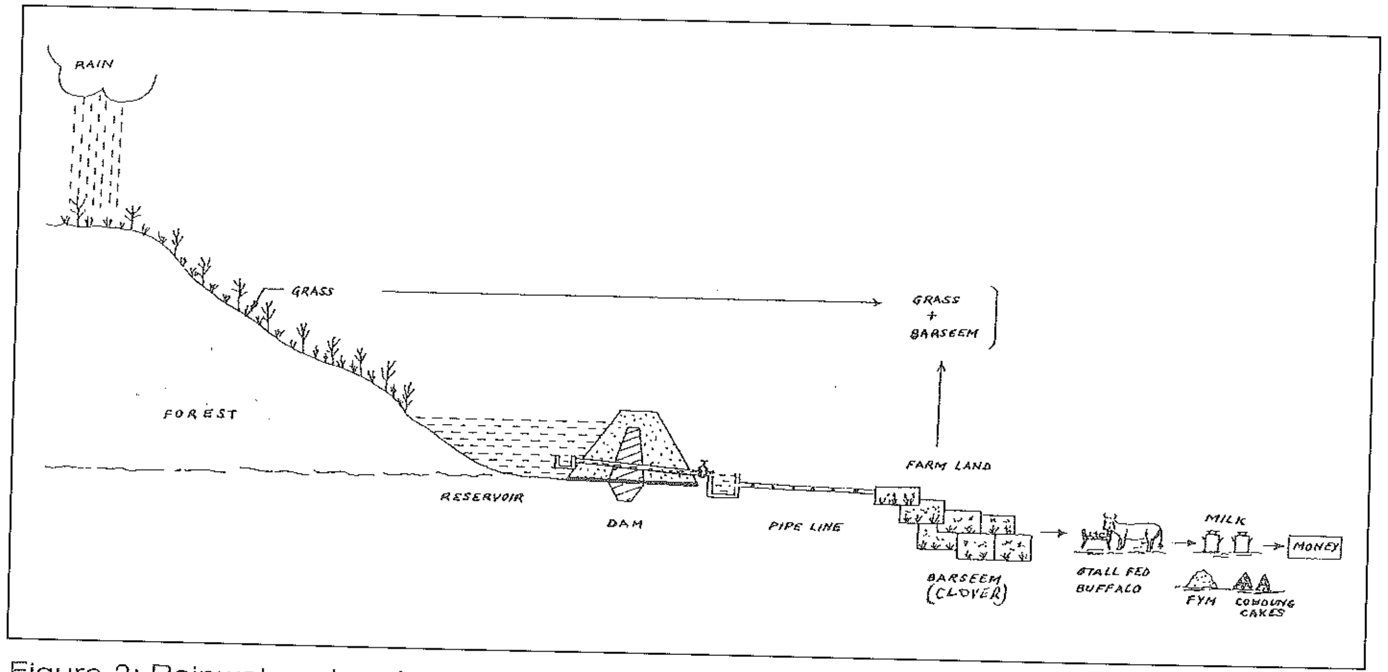


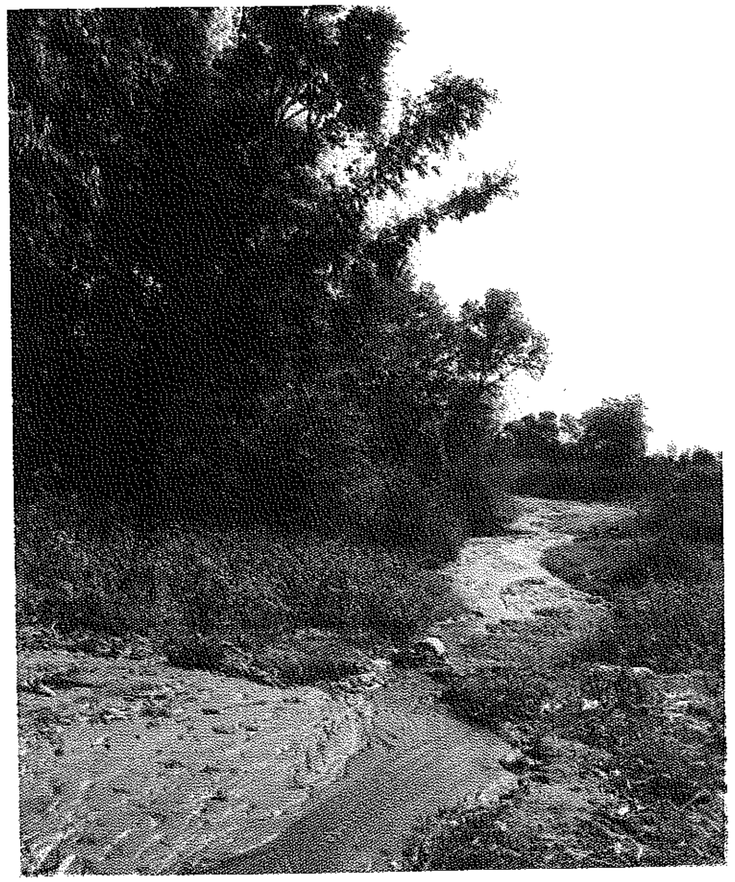
Figure 2: Rainwater when harvested produces money and manure

The project had covered only 53,514 ha during the first three years of the pilot phase, but in subsequent years because of improvement in staff skills as a result of project's program of capacity building, a total area of 180,100 ha was treated up to March 1998 benefiting more than 82,500 families (Table 1).

The effect of conservation measures on rehabilitation of drainage lines and emergence of perennially in dry torrent beds is shown in Picture 2.

Table 1: Physical and financial progress of IWDP (Hills)
(As presented to mission in June 1997)

State	Treated Area in 000 ha	Expenditure Rs. in million	Families covered	Population covered
Haryana	22.7	550.5	22,254	126,715
Himachal Pradesh	55.3	480.3	22,000	184,803
Jammu & Kashmir	46.4	574.8	17,965	92,284
Punjab	55.7	848.8	20,309	194,891
Total	180.1	2454.4	82,528	598,693



Picture 2
Conservation measure in catchment areas have converted seasonal flow of water into perennial streams

RICH DIVIDENDS

As a result of seven years of operation in more than 60 sub-watersheds spread in the entire foothill region, satisfactory results have been obtained. These are briefly described here. Some of these are based on the report of Bakshish Singh (1984)[1]

Impact on environmental features

- Increase in leaf litter on forest floor by 41 to 53 times.
- Increase in organic carbon in forest soil.
- Improvement in soil moisture regime because of conservation measures.
- As a result of improvement in vegetative cover and treatment measures, flood peaks were moderated, perenniality of flow increased, water level in wells located along torrents rose by 2 to 5 m and substantial land area, several villages and roads were protected from the threat of torrents.
- The rate of run-off from treated sub-watersheds has decreased from the range of 36-56% to 5-11% and soil loss from 45-151 to 10-62 t/ha/yr -1 in a period of 5-6 years.

Reducing drudgery of women

- Yield of air-dried commercial bhabar grass (Eulaliopsis binata), green fodder grass and air-dried fuel wood registered an increase of 1.0, 3.2, 1.9 t / ha / yr respectively.
- Time is saved in collecting fodder grass and fuel wood.
- Time is saved in procuring drinking water.

Improving economy and standard of living

- The overall yield of maize increased from 0.80 to 1.34 t/ha/yr and that of wheat from 0.90 to 1.83 t / ha / yr. The use of fertilizer (N) increased from 18.1 to 32.8 and (P) from 4.2 to 14.8 kg / ha / yr during the project period.

- The overall milk yield improved from 3.0 to 7.9 liters/day and the sale of milk in selected sub-watersheds recorded an increase of 1.6 to 5.0 times. The landless farmers received maximum advantage from the animal husbandry component.
- Per capita income increased more in treated sub-watersheds as compared to untreated sub-watersheds.
- There is a general rise in the standard of living of people in area as 10% more people now have tractors while 30% more are have televisions.

Sustainability and community participation

- There was a substantial increase in employment generation. A large number of village ponds and water harvesting structures improved the availability of water. Substantial improvements in productivity and employment generation motivated the stakeholders to take the responsibility of protection of the adjoining hilly forest catchments by forming village cooperatives. Nature has after a long time been allowed to spread its green protective cover on the eroded hills.

LESSONS FROM IWDP (HILLS)

Following are some of the lessons learned from the project as conceived by the implementing project units in the four states:

- Rigid modules of treatment (like vetiver as contour barrier) should not be imposed. Native grasses are far superior to vetiver. Flexibility must be introduced to accommodate experience-dictated changes.
- Five years is too short a period for effective implementation of such projects in which new infrastructure has to be created.
- Amelioration of highly degraded forests is difficult to achieve at low cost without effective closure/social fencing and without optimum mix of biological and mechanical measures.
- Single window system of administration is more efficient in which all disciplines work under one watershed team leader. Subject matter specialists of each discipline should support them.
- Research and training must lead rather than follow project implementation. Local experience and expertise be effectively used in planning, implementation, assessment and evaluation.
- The choice and preferences of farmers must be accommodated.
- A practice which promises returns after 3-5 years with no visible impact and does not take into account the immediate needs is not accepted by the beneficiaries.
- The involvement of landless and absentee landlords in joint management efforts posed problems because the issues like cost and benefit sharing remained unsettled. They need to be involved at all stages of the project from planning to implementation and subsequent maintenance for ensuring sustainability.
- The non-transparency of accounts, favoritism, leadership and caste conflicts, political interference and social and economic disparities in communities, strongly influence project achievement. The social dimensions of watershed development approach are becoming increasingly important but staff is not yet attuned to democratized set of operations and needs a lot of training and orientation. NGOs are yet not activated to share responsibilities.

CONCLUSIONS

The project has demonstrated the possibilities of reversing ecological degradation with active involvement of local communities and this has brought back lost smiles and hope to the desperate sections of society. The interests of future watershed based development programs can be best served by creating awareness about problems and their possible solutions. Success stories and problem solving techniques should be shared so that others are benefited. The course of action both in research and development must attempt on thorough and objective quantification of resource base and problems, undertake research to refine science and technology relevant to restoration and find ways and means to motivate people to understand the problems, their far reaching consequences and make them stand on their own feet rather than look for support and subsidies. In such an endeavor, creating an enabling environment with a one time investment would, however, be necessary.

Looking to the success of this project, the World Bank is already processing a proposal for a follow-on project which would also take into account the lessons learned and weaknesses of the on-going project. Based on the experiences of this project (Jain, 1998) and the deliberations of two recent workshops[2], the following guidelines have been emphasized for the future watershed management projects:

- Sustainability of project activities through emphasis on community-based organizations to own the responsibility of implementing the project activities, cost sharing and full commitment for post project operation and maintenance.
- Cost sharing by beneficiaries should be much less in the community-based activities on common lands than the private owned lands and within the private lands it should be much higher for culturable lands than non-cultural lands (degraded wastelands).
- While treating Government/forest lands, communities' interest in terms of benefit must be ensured.
- The project components should be broad based, including alternative income generating activities and should not be restricted to the development of rainfed agriculture.
- Institutional development at the level of community-based organizations should be given top priority and should precede the project identification and implementation.
- Complementarity should be established between the various agencies (Government, donors, NGOs) implementing the project in the same area/district/state to avoid unhealthy competition.

ENDNOTES

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2 Workshop organized by MORAE, GOI and World Bank - Brainstorming session on Watershed Development - Nov.20, 1997; and National workshop on Watershed Approaches for Managing Degraded Lands in India: Challenges for 21st Century - April 27-29, 1998 organized by MORAE and ODI at New Delhi.

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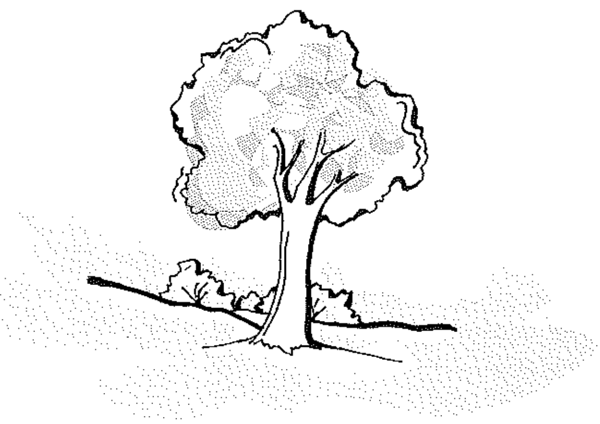


SOIL AND LAND RESOURCE DATABASE FOR INTEGRATED WATERSHED MANAGEMENT

S.N. Das • All India Soil & Land Use Survey • New Delhi

INTRODUCTION

The ethos of India is born out of diversity. The diversified terrain and climate are responsible for occurrences of different genera in plant, animal and human population. The diversification, however, led to the development of a stronger cultural heritage of the country through integration. Such integration is also required when we deal with the management of soil and water resources for sustainable food production. If we look at the geography of the country, it has the snowclad Himalayas in the northern and north eastern regions, the Deccan plateau in the central region, coastal plains along east, west and southern regions and desert in the western region. Both interior and exterior drainage drain the country. Such diversified terrain needs an integrated approach for scientific management of soil and water resources.

It is estimated that out of the 329 m ha of total geographical area of the country, 313 m ha area is drained by major rivers and their tributaries across the country whereas 16 m ha has ephemeral drainage (Anon 1990). India being a riverine country, the drainage system is more pronounced and water induced soil erosion is a menace. Owing to this very fact, the soil and water conservation planning and measures in the country have been conceptualized on watershed basis. Since the early 1970s, concerted efforts have been made to promote conservation of soil and water resources considering watershed as the basic unit of treatment.

Watershed management (WM) has been defined as the rational utilization of land and water resources for optimal and sustained food production with minimum hazards to natural resources. It essentially relates to soil and water conservation which means proper land use, protecting lands from all forms of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of water for drainage, flood protection, sediment reduction and increasing productivity from all land uses (Tejwani, 1984 and Tideman, 1996). Watershed management should have a multidisciplinary approach where scientists from various disciplines, viz., soil science, agronomy, soil conservation, forestry, veterinary science, sociology and environment are involved for scientific evaluation of the soil and land resources potential, optimal utilization and planning. Unless an integrated approach is followed, the goal of WM cannot be achieved.

In India, WM is being promoted with more emphasis on participation of the local community which is termed as Participatory Watershed Management. It is stated to be managed by the farmers in place of the executives of the Government machinery and is aimed towards holistic human development. It is defined as utilization and conservation of land, water and forest resources at farm, household and community or given watershed levels for overall human development (Anon, 1997).

The Government of India launched a number of schemes adopting watershed as the basic unit of treatment (Das, 1998). The Centrally Sponsored Scheme on Soil and Water Conservation in the Catchments of River Valley Projects was launched during 1961-62. Subsequently, a similar scheme was introduced for Flood Prone River catchments during 1980-81. The objectives of these schemes are aimed at soil, water and forest conservation and implemented through technocrats following

extension methods of transfer of technology (Anon, 1997). These schemes have been visualized for long term benefits. The modern participatory watershed management paradigm is aimed at natural resource management for poverty alleviation and overall human development. It is a farmer-driven approach based on indigenous technology, tradition, culture and cosmic vision of the local people (Sharma, 1997). More emphasis has been given to people's empowerment and vegetative measures as a means of conservation of soil and water resources.

The modern approach is quite in line with the objectives projected in the National Watershed Development Programme for Rainfed Areas.

Need for Watershed Management

Watershed Management is essential to address various issues like

- Food security.
- Ecological balance.
- Optimal utilization of natural resources.

The challenge before the country is to ensure food security to the ever-increasing population. As of date India supports over 15% of the world's livestock and 18% of the world's population while sharing 2% of the world's geographical area (Katyal, 1997). The most disturbing factor in Indian agriculture is the declining trend in food production despite same levels of input management (Deb, 1994). The pace of the green revolution seems to have started slowing down due to falling responses of cereal crops mainly rice and wheat to NPK fertilizers (Katyal, 1997). Thus crop management commensurate with soil, water and nutrient management could resolve the burning issue.

In India 65% of the agriculture is rainfed and 109 m ha area is drought prone, (Katyal, 1997). Agricultural statistics indicate that net sown area is 142.8 m ha of which 89.8 m ha is rainfed and 53.0 m ha is irrigated (Sharma, 1998). Thus efforts are on to bring more area under irrigated agriculture to enhance crop production. The conservation of rainwater through watershed approach in the rainfed areas would be a viable strategy to ensure food security to the country.

According to the national forest policy resolution of the Government of India adopted in 1952, the country should maintain one third of its land under forest to maintain ecological balance between agriculture and forestry. (Melkania et al, 1989). The land use statistics in India (1994-95) indicate 68.3 m ha area is under forest which constitutes about 22.4% of the total geographical area of the country (Sharma, 1998). In order to maintain the ecological balance, area under forest cover needs, to be increased to 33.3%. The degraded forests need to be regenerated through watershed management programmes.

One of the biggest threats to sustained foodgrain production, the country is facing today, is the menace of land degradation. Land degradation due to water and wind erosion, waterlogging, salt affliction and biotic interference has put up a tremendous challenge to mankind in its quest to attain sustainability in crop production. In India, 175 m ha of land has been estimated as problematic land, suffering from various kinds of degradation (Anon, 1987). It is reported that 150 m ha is affected due to water and wind erosion, 6.0 m ha is waterlogged, degradation due to salinity accounts for 5.5 m ha, 4.4 m ha and 3.9 m ha area are affected due to shifting cultivation and ravines respectively. An area of 2.7m ha is also affected due to riverine and torrents (Deb, 1994). Besides, nutrient loss to the tune of 5.37 to 8.4 m occurs due to soil erosion per year (Anon, 1987); 85.65 m ha of cultivated land is affected due to soil physical constraints (Yadav, 1996), 0.38 m ha area is disturbed by mining per year (Dadhwal et al, 1996), etc. This indicates the seriousness of the problem and decline in the productive potential of land.

Impact on socio-economic conditions

The loss of soil and land resources has put tremendous pressure on land and its consequential impact on the socio-economic conditions of the people in the country.

The loss of fertile top soils, sedimentation of reservoirs and canals, loss of water resources and their quality resulting in poor crop yield, non-availability of land for cultivation or other land use practices have led to unemployment and poverty. It is estimated that the per capita availability of land for cultivation has declined from 0.43 to 0.19 ha/person during 1951 to 1992 (Ghosh, 1994). People from rural areas are migrating to the cities in search of jobs due to non-availability of cultivable land. According to Bowonder et al (1985), the storage capacity of the Tungabhadra reservoir has been lost due to a higher rate of sedimentation as against that projected at the time of construction. Similar observations were made in respect of Nizamsagar, Ramganga and Mayurakshi dams (Bali, 1994).

To understand the nature and degree of severity of degradation vis-á-vis watershed environment, it is essential to study and analyze the various soils and land attributes

Environmental impact

The depletion of soil moisture, occurrence of drought and floods, reduction in the biomass production and land cover condition, enhanced weed growth, etc. are the resultant impacts of the degradation of soil and water resources. Besides, over exploitation of land resources and accumulation of contaminants in environment as waste are posing serious threats to the ecology. Shrinkage of biodiversity and ecological imbalance may lead to environmental hazards.

IMPORTANCE OF SOIL AND LAND RESOURCE DATABASE

A database on soil and land resources is a prerequisite in watershed management planning and implementation. To understand the nature and degree of severity of degradation vis-a-vis watershed environment, it is essential to study and analyze the various soils and land attributes. The importance of soil and land resource database in watershed management is well known. The database should suffice to derive the inputs for soil management, land management, water management, nutrient management and crop management. These inputs will help in developing a scientific plan for watershed management (Das, 1998). International Crop Research Institute for the Semi Arid Tropics (ICRISAT) found that the application of improved soil and water management techniques coupled with soil, water, crop and nutrient management strategies could optimize the use of natural resources (Virmani, 1998).

The impact of various land and soil parameters on degradation of watershed and environment has been illustrated in Figs. 1 and 2 for better understanding of the importance of database.

Figure 1: Land and environment

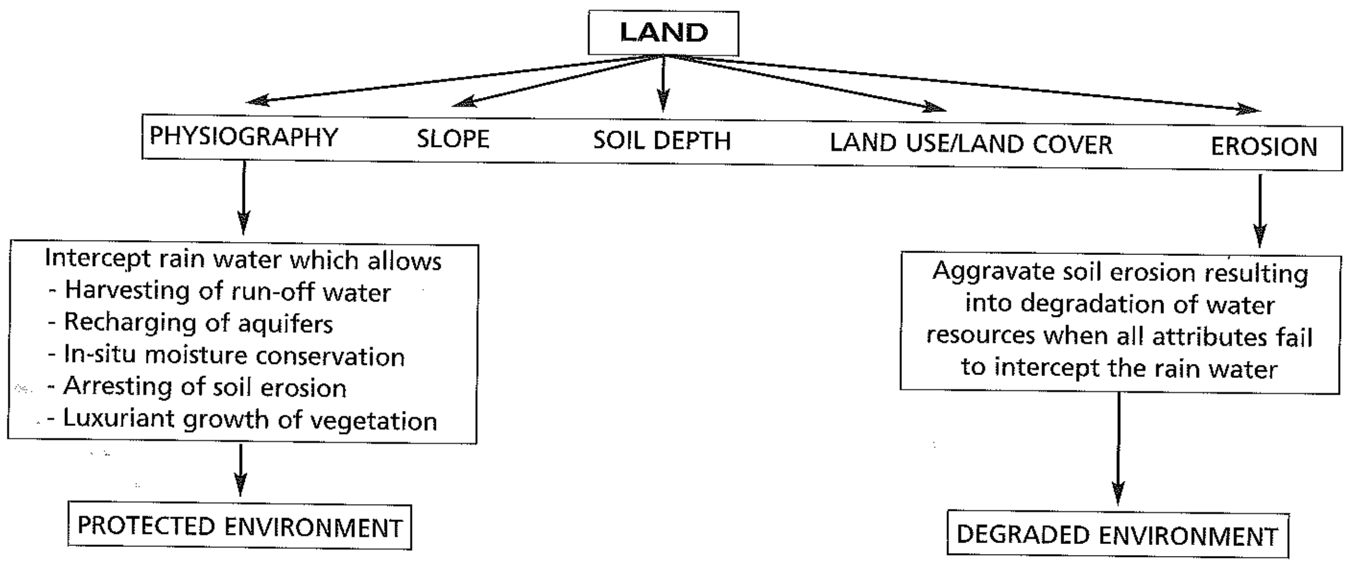
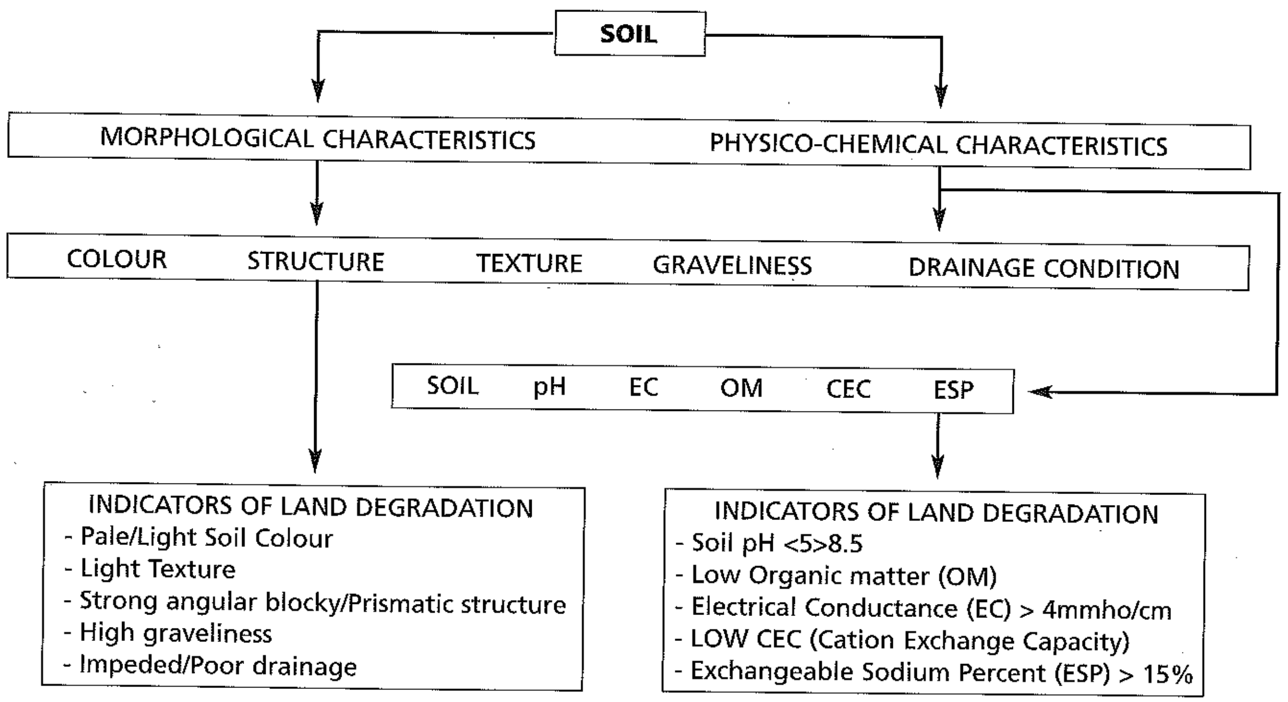


Figure 2: Soil and environment



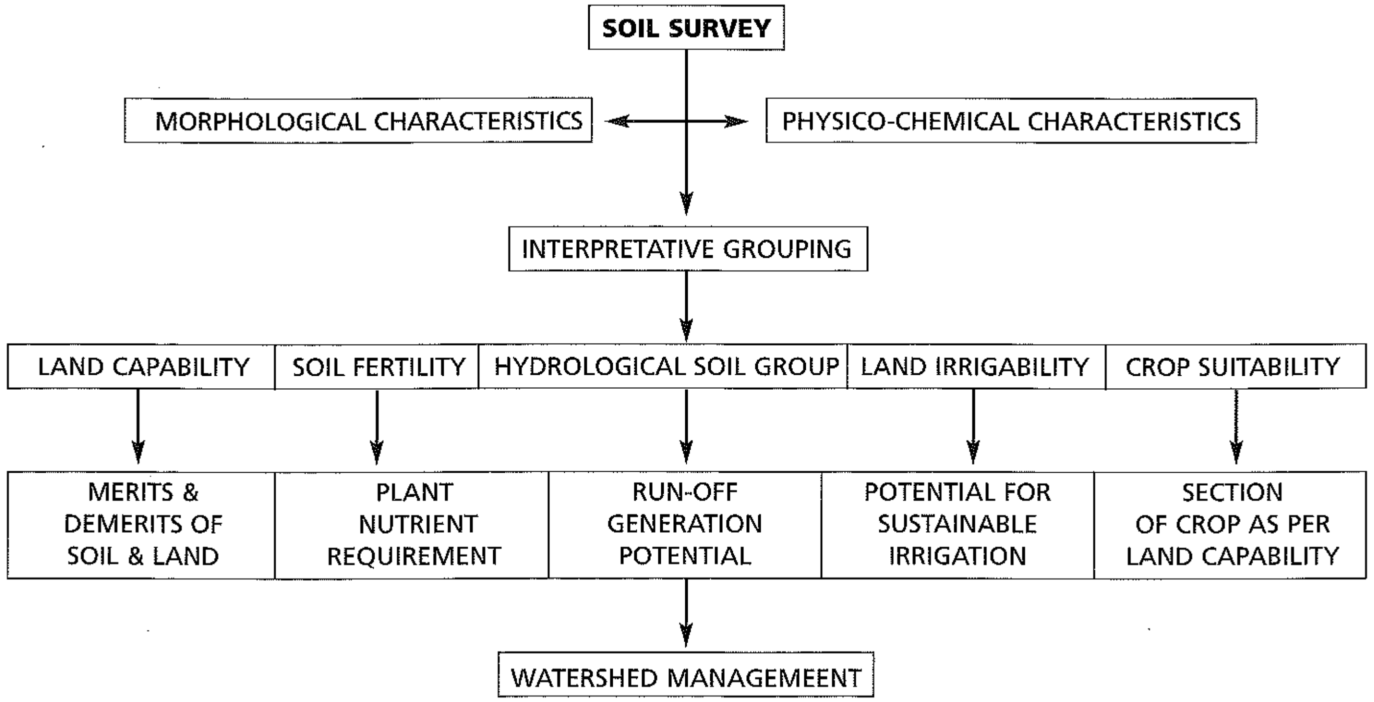
Need for soil survey

Land use planning, land treatment and watershed management all need basic information about land for scientific planning, i.e., land capability classification (LCC) map of the watershed (Johnson, 1998).

To generate land capability classification map, soil survey is essential. Once soil map is generated after a detailed soil survey using large scale base map it could be translated into LCC map based on the standard criteria (Anon, 1970).

Besides, soil survey is an established tool to generate various morphological, physical, physico-chemical and mineralogical properties of soils in a systematic way through examination of soils in the field and laboratory. The information that are useful in watershed management planning have been schematically explained in Fig.3.

Figure 3 Soil survey and Watershed Management



Conceptualization of catchment area treatment

The vastness of the catchment, constraints of funds and manpower and urgency of database on soil and land resources led to the conceptualization of priority approach in catchment area treatment in the country. To suit the needs of the country, AISLUS developed a methodology for prioritization of watersheds based on sediment yield index and runoff potential index in the catchment of River Valley Projects (RVP) and Flood Prone Rivers (FPR) respectively.

Database generation

To provide the scientific database on soil and land resources to the planner and policy makers for soil and water conservation planning both at macro and micro levels in the catchment area, AISLUS employs the following working models to generate the database.

- Rapid Reconnaissance Survey using 1:50,000 scale topographical map for identification and demarcation of priority sub-watersheds in the RVP/ FPR catchments based on Sediment Yield/Run-off Potential Index.
- The detailed soil survey using 1:15,000 scale aerial photograph or cadestral map in the selected priority sub-watersheds for generation of detailed information on soils and land characteristics.

Rapid reconnaissance survey for watershed prioritization

The level of mapping extends up to phases of soil series where the different phases namely effective soil depth, surface texture, stoniness and rockiness, slope and erosion are used and depicted in respect of each soil series on the soil map

Watershed prioritization comprises delineation and codification of watersheds in the catchment following stream hierarchy and its categorization based on the sediment yield or runoff generation potential index. The steps involved in the methodology are as follows (Anon, 1991).

- Generation of drainage map on 1:50,000 scale using Survey of India topographical map.
- Delineation and codification upto sub-watershed level following stream hierarchy.
- Rapid reconnaissance of the area to formulate erosion intensity mapping unit legend followed by mapping.
- Generation of map showing the spatial distribution of different erosion intensity mapping units.
- Assignment of weightage and delivery ratio to each erosion intensity mapping unit.
- Computation of area of each mapping unit and sub-watershed plannimetrically and calculation of sediment yield index following the empirical formula.

$$SYI = \frac{\sum_{i=n}^{i=1} (Aei \times Wei \times Dri)}{Aw} \times 100$$

SYi = Sediment Yield Index
Aei = Area of the ith erosion intensity mapping unit
Wei = Weightage value of the ith mapping unit
Dri = Delivery ratio of the ith mapping unit
Aw = Total area of subwatersheds
n = Number of mapping unit

- Categorization of sub watersheds into very high, high, medium, low and very low priority categories with respect to sediment yield indices. The database on priority watersheds thus generated for each and every catchment could be utilized to carry out strategic planning for catchment area development in a phased manner.

Detailed soil survey

It deals with the systematic examination of soils in the field and laboratory, delineation of soil boundary on map with thorough traversing, classification and interpretation of soils for utilitarian purposes and documentation of findings in the form of reports. Detailed soil survey is carried out using 1:15,000 scale aerial photographs or cadestral map as base map (Anon, 1970). The level of mapping extends up to phases of soil series where the different phases namely effective soil depth, surface texture, stoniness and rockiness, slope and erosion are used and depicted in respect of each soil series on the soil map. The soil map is translated as Land Capability Classification map based on the standard criteria (Anon, 1970) which is an essential input for micro level or village level planning. Besides, soil information could be analyzed and interpreted to derive a thematic map and information regarding soil irrigability class, land irrigability class, hydrologic soil group, soil fertility, crop suitability and engineering purposes.

Evaluation of database

The data on soil and land resources needs to be evaluated to derive the following information that are essential to prepare scientific watershed management plans:

- Land management.
- Soil management.
- Water management.
- Crop management.
- Nutrient management.

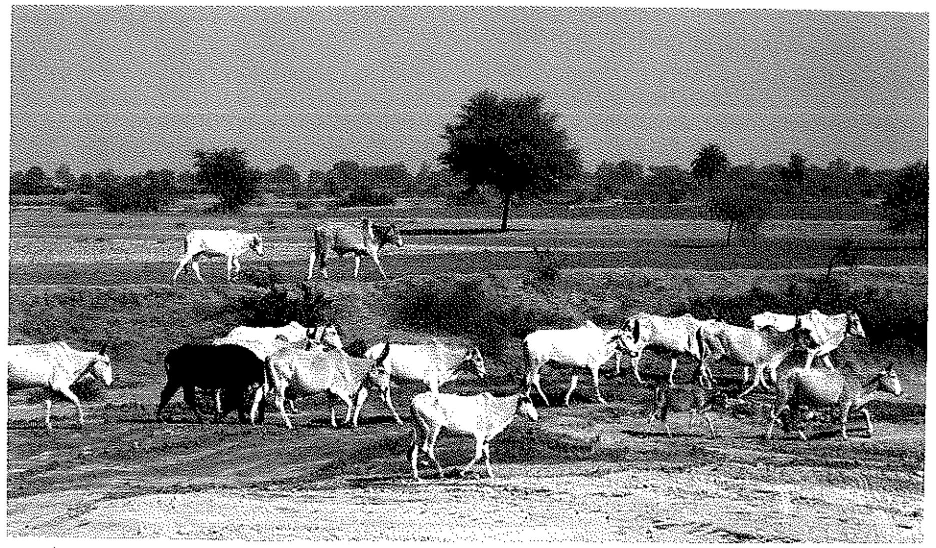
The database must contain detailed information on soil and land characteristics so that lands can be classified on the basis of their merits and demerits and management plans can be chalked out based on land capability classification. Based on land capability, class, subclass and unit, suggestive treatment measures could be derived that will act as guides to the development of watershed management plans.

The detailed characteristics of soils will allow diagnosing the soils not only for optimal use but also for any corrective measures towards maintenance of soil health

The detailed characteristics of soils will allow diagnosing the soils not only for optimal use but also for any corrective measures towards maintenance of soil health. The presence of any hard pan in sub-soils, the information on soil physical condition, soil acidity, salinity and alkalinity certainly will allow planners to have an in-depth idea of the watershed area for preparation of an effective plan.

The detailed land characteristics such as, topography, relief, slope, land use, erosion condition and drainage network could be utilized to derive the water harvesting potential of the watershed, identification of sites for water harvesting structures, percolation tanks, layout for disposal of runoff water and drainage treatment plan. Land irrigability classification of the watershed and information on hydrological soil grouping will certainly act as a guide for irrigation water management and conservation of surface runoff at appropriate locations. The information on contour, hydrological soil grouping and slope length could be examined to plan the harvesting of surface runoff towards management of soil moisture condition of the watershed. Both land and soil management aspects of the watershed should be considered for effective water management.

The detailed soil characteristics alongwith the knowledge of available nitrogen, phosphorous and potash and some micronutrients shall be required for scientific nutrient management in the watershed. Besides, the knowledge of fertility status, the information on soil physical condition, soil reaction, hard pan in the sub-strata and cation exchange capacity will help in the planning for judicious use of chemical fertilizers, and the loss of fertility due to leaching could be minimized.



The existing land use practice, local needs, soil and land potential and climatic environment are required to be studied for crop management in the watershed. The cropping pattern, inter cropping and selection of species should be commensurate with watershed

environment, which will allow better crop management. The references of all the management aspects are required to be taken into consideration for scientific cropping system in the watershed.

Soil and water conservation

Watershed management relates to soil and water conservation in the watershed. The basic factors involved in the soil conservation strategies are:

- Protection of soil from raindrop impact.
- Increasing the infiltration capacity of the soils to reduce the volume of runoff.
- Improving the aggregate stability of soil to increase its resistance to erosion, and.
- Increase the roughness of the ground surface to reduce the velocity of runoff and wind (Kirkby et al, 1980).

Water conservation is inseparable from soil conservation, which also includes:

- Rainwater conservation.
- Land management and.
- Runoff conservation.

Some of the activities under rainwater conservation could be

- Exercising strict control on deforestation.
- Afforestation of bare hills and.
- Promoting in-situ conservation of water through proper selection of crops and cropping pattern.

To understand the basic principles of soil and water conservation and to undertake planning and implementation measures in the watershed, the knowledge of soil science is essential.

Study of soil resources

Soil is one of the vital natural resources for sustenance of mankind. The detailed study of soils is a prerequisite not only for sustainable agriculture but also for optimal use of the precious resources and maintenance of soil health (Tideman, 1996). Soil is generally defined as the upper part of the earth's crust developed as a result of inter play of five factors, viz., climate, parent material, relief, vegetation and time. It supports all living beings on earth. To understand soils properly it is necessary to know about the primary constituents of soils, i.e., mineral matter, organic matter, soil water, soil air and soil temperature. All these parameters govern the nature and properties of soils. Variations of these parameters give rise to different kinds of soils. The mineral matter of soil comprises sand, silt and clay, which are differentiated on the basis of size fractions. The clay fraction is the core constituent of any soil that determines the various physical, physico-chemical and chemical properties of soils. The nature of clay mineral of soils holds the ultimate key for nutrient reserve and soil fertility. Kaolinite, Illite and Montmorillonite are the major clay minerals generally found in soils of which montmorillonite possesses relatively higher retention capacity of holding plant nutrients in exchange sites. Kaolinite has the least capacity owing to the fact that it is non-expandable clay mineral while montmorillonite is a 2:1 expanding clay lattice mineral. The other size fractions of mineral matter also play vital roles in modifying the physical condition of soils and supplement the nutrient requirements of plants.

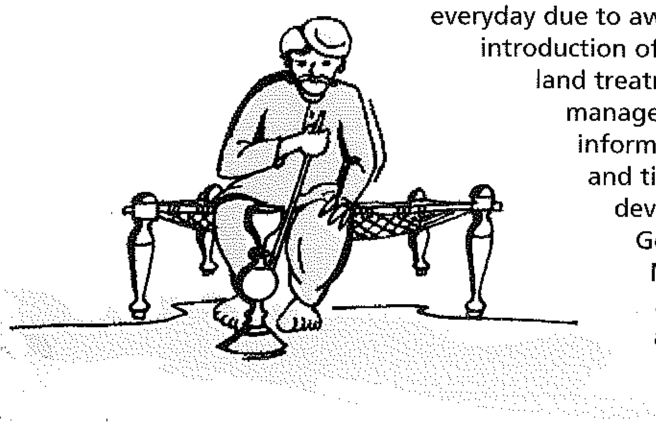
The organic matter is an important component of soils as it modifies the physical condition of soils and also acts as a buffer to maintain optimum soil pH to enhance the availability of nutrients to plants. Besides, organic matter also releases plant nutrients through the process of decomposition and mineralisation. The nature and content of organic matter in soils has immense importance in maintaining soil productivity. Its depletion results in the degradation of soil structure, porosity and bulk density that is ultimately responsible for poor physical soil condition and poor soil productivity.

Soil water is another important constituent. Survival of plants is dependent on it. The water retained by soils against gravitational force is termed as soil water. It's quality, quantity and availability depends on the nature and content of mineral and organic matter of soils. The physical properties of soils play a great role in retention capacity of soil water and their availability to plants. Soil air and temperature have a direct bearing on plant growth in supplying oxygen and maintaining optimum temperature.

While studying soils it is essential to know about their origin, formation and classification. The soil formation is defined as a function of five factors and expressed as Soil = f (C, P, R, V & T) where climate, parent material, relief, vegetation and time are the five soil forming factors. The development of various kinds of soils is the resultant action of climate on parent material under different topographical situations and vegetation conditions over a period of time. The physical, chemical and biological weathering of rocks responsible for the development of soil also give rise to the different soil characteristics such as colour, texture, structure, consistency, soil reaction, etc., besides accumulation of silicate clays, humus, sesquoxides, bases, etc, down the profile. The relative impact of one soil forming process over the other is reflected in soil properties. Based on the properties of soils, soils could be placed under different soil taxa as per the USDA key to soil taxonomy (Anon, 1998). The importance of soil lies in the fact that it supports plants that supply food, fibres, drugs and fulfills other needs of mankind besides filtering water and recycling waste. Soil is not statistic. The pH, soluble salt contents of organic matter, carbon-nitrogen ratio, microbial population, temperature and moisture all change with the seasons as well as over a more extended period of time. Thus soil must be viewed from short term and long term perspectives towards optimal utilization and management.

Management of database

It is often difficult to manage and handle the voluminous database in conventional mode, resulting in delay in quick transmission of desired information to the planner as it involves compilation of information from different sources, manually. Besides, the demands of soil and land resources data base are increasing everyday due to awareness among the planners and policy makers, introduction of Panchayati Raj, watershed-based land use planning and land treatment and people's participation in the watershed management programmes. Thus quick dissemination of information to the users in the desired format is also a laborious and time taking job. To overcome this difficulty, it is essential to develop a digital database on soil and land resources using Geographic Information System and Relational Data Base Management System. It will facilitate the storage, editing, analysis, manipulation and retrieval of the desired database accurately and in time. The updating of existing database with real time data using remote sensing techniques can only be possible once digital database is developed.



An integrated system comprising Geographic Information System for map data, Image Analysis System for remote sensing data and Relational Data Base Management System for statistical data could be developed for automated data base on soil and land resources. Once the automated spatial data base is developed, it will be a database of tremendous potential for land resources development to cater to the needs of the country in a sustainable manner.

Awareness campaign

One of the components of watershed management is to generate awareness among the people living in the watershed. The prime focus during awareness campaigns should be given on the importance of soil and land resources, their management and soil health. The database should suffice to undertake effective measures on soil physical condition, enhancement of buffer capacity and corrective measures for optimal soil reaction. Such information needs to be disseminated to the farmer in the form of soil health card for proper diagnosis of soils. In fact, in India no such medium exists, which could bring together all the people dealing with watershed management, especially the planners, policy makers, researchers, soil scientists, soil conservationists and farmers.

Once basic soil and land information with limitations and treatment measures are documented in the form of soil health card and provided to the farmers, it could act as a communication linkage amongst all. Such a venture will not only allow taking up diagnostic measures on soils to enhance food production but also bring awareness among the whole spectrum of society involved in watershed management. Besides, distribution of relevant literature in the local language, organization of camps and workshops, use of electronic media and other means could act as tools for promoting awareness among all concerned.

People's participation

The success of any watershed management programme is in the hands of the people living in the watershed. It is thus very essential to motivate the community living within the watershed to conserve the soil and water resources for sustainable land use practices in order to earn their livelihood from the assets being created in the watershed area. The Government of India identified community participation as a thrust area in the entire watershed-based soil and water conservation programme and made an attempt to mobilize them in watershed management. The strategy so far adopted in participatory watershed management is resolving the immediate needs of the community living in the watershed to motivate them in the land-based programme. Once people are sensitized, land management aspects with harvesting of runoff water and conservation of soil moisture are given utmost priority to enhance land productivity. As of date, watershed management is limited to land and water management. These are certainly of prime importance but no emphasis has been laid on soil management. To achieve optimal land productivity and to maintain soil health, basic information on soils is required. The information on various soil parameters that are necessary to evaluate the potential and problems in different soils is indicated in the format of soil health card (Fig. 4). Once the community is motivated enough in the watershed management programme they may show interest in soil management to obtain maximum output. The soil health card will allow undertaking scientific and judicious nutrient and crop management in the watershed. It is necessary to nurture this philosophy of watershed management with all scientific inputs to ensure food security to all and work towards making a green and healthy nation.

Figure 4: Soil health card

Serial No. ....

General Characteristics

- Name of Farmer: ....
- State: • District: • Taluk: • Block:
- Village: • Plot No.:

Soil & Land Characteristics

- Slope: • Relief: • Erosion: • Depth: • Drainage:
- Present Land Use/Crop
- Level of Management
- Surface Texture: Gravel % Sand % Silt % Clay %
- Sub Surface Texture: Gravel % Sand % Silt % Clay %
- Soil pH:
- Electrical Conductance (m mho/cm):
- Organic Matter (%):
- Cation Exchange Capacity (me/100g):
- Calcium Carbonate (%):
- Exchangeable Sodium Percent:
- Presence of Hardpan in Sub-soil:
- Available Water Holding Capacity:
- Available Phosphorus (Kg/ha):
- Available Potash (Kg/ha):
- Soil Fertility Status:
- Micro nutrient Status (Available zinc, iron, boron):

Signature of Issuing Authority

Seal: ....

Date: ....

Principles and Practices of Integrated Watershed Management in India
Soil and Land Resource Database for Integrated Watershed Management

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INTEGRATED WATERSHED MANAGEMENT IN THE INDIAN ARID ZONE

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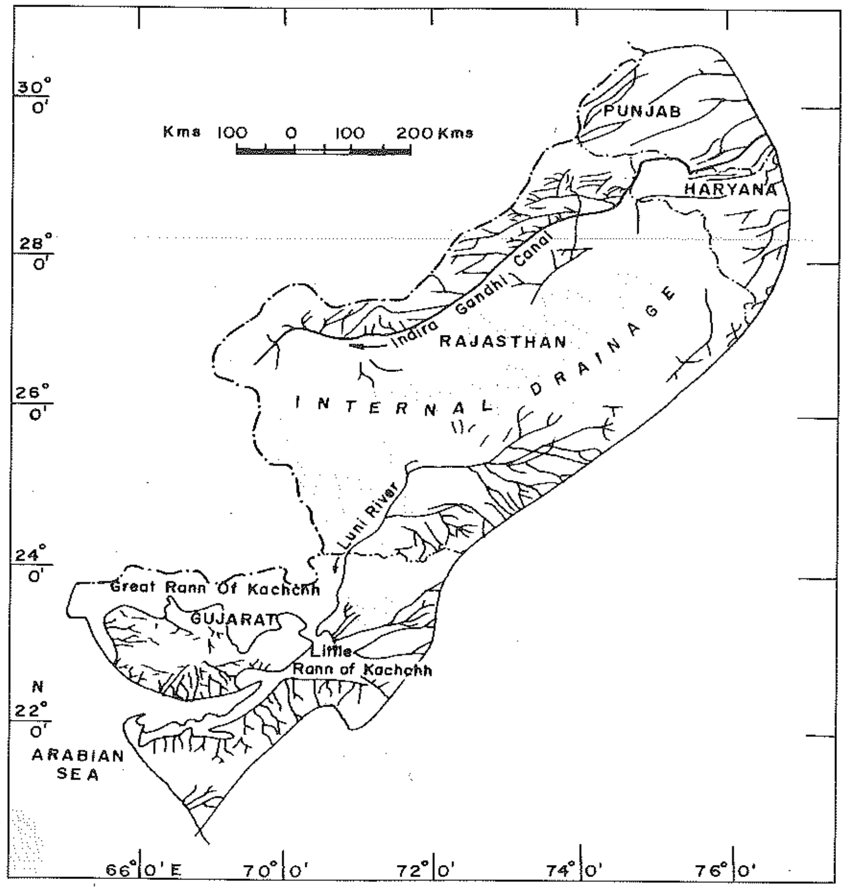
INTRODUCTION

Watershed management for agricultural development is an integrated and interdisciplinary approach. The long term objective of integrated watershed management is the rational utilization of natural resources of soil and water for increasing and stabilizing the productivity of drylands on a sustainable basis. The end aim is improving the quality of life of the people living in the arid region at a great disadvantage caused by high natural variability of rainfall resulting in frequent droughts, aridity and continued depletion/degradation of resources.

A watershed-based approach often fails to take into account the disastrous consequences of climatic and environmental variability when combined with the stresses on natural resources due to overexploitation. In arid regions the focus of integrated watershed management is on increasing the productivity concurrently integrating rainwater management with the entire system of production including both the crop as well as the animal components.

Figure 1: Extent of the arid zone in northwest India



The key components of integrated watershed management programmes in the arid regions are:

- Soil and water conservations
- Ecological restoration

Extent

The hot northwest Indian arid zone occupies 285,680 sq. km and is spread over the states of Rajasthan, Gujarat, Punjab and Haryana. About 52% area in the arid zone comprises of sandy plains, dune systems, eroded rocky/gravelly surfaces and isolated hillocks (Fig.1). The channels emanating from these hillocks and rocky/gravelly pediments get suffocated in deep alluvium and blown sand in the down valley and form internal drainage basins/watersheds.

Another 33% area is occupied by the Luni Basin, the Sahibi Basin and a few smaller river basins. These are ephemeral drainage systems and convey runoff only in direct response to torrential rainfall during the monsoon season. Thus, nearly 85% area, i.e. about 243,000 sq. km within the Indian arid zone is in need of integrated watershed management.

Climatic features

The Indian arid zone is characterized by low annual precipitation varying from less than 100 mm to 450 mm in the arid zone of Rajasthan, from less than 300 mm to 500 mm in the arid zone of Gujarat and from 200 to 450 mm in the arid part of Haryana and Punjab (Sharma and Vangani, 1992). The high inter annual variability in rainfall is the single major factor influencing water supplies, crop and pasture yields and instabilities in agricultural productivity. The coefficient of variation of the annual rainfall ranges from 37 to 59% in western Rajasthan, 50% in Punjab and from 60 to 70% in Gujarat. Agricultural drought is a common feature, its frequency being once in two years (Ramakrishna, 1997). A significant feature of the distribution of the rainfall is that the major part of the rainfall is received in the southwest monsoon period during June to September. The contribution of this rainfall to the annual rainfall is quite high, varying from 78% in Punjab to more than 85% in Rajasthan.

Apart from the low precipitation, this region experiences extreme variations in diurnal and seasonal temperatures. May and June are the hottest months with mean air temperatures in the range of 40 to 43°C. However, on individual days temperatures of the order of 47 to 49°C are also recorded in the region when heat wave conditions prevail. In winter, the minimum temperature varies from 3 to 10°C with occasional periods of below-freezing surface temperature and frost in the wake of cold wave conditions associated with passing western disturbances and snowfall in the sub-Himalayan region.

Strong hot winds associated with dust storms is a characteristic feature of the Indian arid zone; mean daily wind speeds of the order of 20 to 30 km/h are recorded during April to June. The prevalence of clear skies and high isolation, strong wind regimes and high temperatures, the annual potential evapotranspiration exceeds 1500 to 2300 mm.

Hydrology

The runoff rates rise and fall rapidly in the region due to high rainfall intensities, steep slope gradients and sparse vegetative cover. However, because of the often short, sharp and intense bursts of rainfall, and variations in slope gradients and surface type along flow lines, runoff is not generated uniformly

The runoff rates rise and fall rapidly in the region due to high rainfall intensities, steep slope gradients and sparse vegetative cover. However, because of the often short, sharp and intense bursts of rainfall, and variations in slope gradients and surface type along flow lines, runoff is not generated uniformly (Sharma, 1992). The local population has a good insight and knowledge of the hydrological characteristics and, therefore, is a very important source of information to assess local conditions. River flow is ephemeral and almost all surface flow is storm water that rushes off the land during and immediately following rain storms. However, in the river bed itself there is a slow, subsurface flow of water, which depends on the porosity, the continuity of the pores and the hydraulic gradient.

The availability of groundwater is characterized by deep water tables, high salinity, negligible recharge and uneconomic cost of exploitation. About 65% of the area has more than 15 m depth water table, or contains more than 3 g/l salts, or has discharge potential of less than 1 l/s (Das, 1994). Besides, the utilizable groundwater is being exploited at a faster rate than the recharge and thus the groundwater reserves are being depleted at an alarming rate.

Soils

The quaternary alluvium and aeolian sand have mainly served as the parent material of dominant dune, interdune and sandy soils (64.9% area). These are coarse to fine, sandy to loamy sand, structureless soils prone to wind erosion, crusting, high infiltration rates and low water holding capacity (Kolarkar et al., 1997). About 13.5% of the area is occupied by medium to fine textured alluvial plains. Miscellaneous soils such as gypsid, rocky/gravelly and salt affected soils occupy 15.7%s of the area. The rest of the area has indurated hard pan at 30-50 cm depth. Thus, high salinity and root zone limitations are major constraints of these soils. The arid zone soils are low in organic carbon, low to medium in available phosphorus and high in available potassium.

SOIL AND WATER CONSERVATION

Diversions are designed to keep the flow velocity within the permissible limit. This limit ranges from 0.5 to 0.6 ms^{-1}

In the Indian arid zone, erosion by water is a dominant form of land degradation in the ephemeral river basins, along the isolated hillocks and in the foothills. Torrential and sporadic rainfall, erodible soils, sparse vegetative cover and biotic interference cause high soil erosion rates by water. The mean sediment transport rate in the ephemeral channels range from 12 to 54 gl^{-1} (Sharma, 1996). In western Rajasthan the area affected by water erosion and gully formation has increased at the rate of 0.71% per annum between 1958 and 1986. In the year 1986, 355 sq. km was affected by such degradation. If the same rate of water erosion continues then by the year 2020, 441 sq. km will be affected by erosion. The more prevalent soil and water conservation measures in the Indian arid zone are discussed here :

Diversion

A diversion is an independently designed channel constructed across the slope alongs foothills for diverting concentrated runoff to other locations within the watershed. In the arid regions the diversion channels are used either to control gully erosion or to store runoff in reservoirs/recharging aquifers.

Diversions are designed to keep the flow velocity within the permissible limit. This limit ranges from 0.5 to 0.6ms^{-1} for most arid zone soils. The cross sectional area of the channel equals the expected peak rate of runoff divided by the permissible velocity of flow.

Figure 2:
Half-moon terraces

Half-moon terraces

Half-moon terraces are widely used as soil and water conservation measures in the region for large scale afforestation programmes (Fig. 2). Staggered half-moon terraces are constructed on the contours across slopes at 3-5m spacing; the loose earth/rock fragments are used to form bunds towards the downstream side. Sharma et al., (1998) recorded 52-59% higher soil moisture storage in the half-moon terraces compared to control; resulting in the better establishment and growth of plants. A majority of trees and shrubs recorded 17-27% higher growth in half-moon terraces as compared to control within a period of three years.

Contour bunding

Contour bunding is done with two objectives: the rainfall received in the field is stored in situ, and the runoff that causes soil erosion and loss of water is checked due to compartmentalization of the field by earthen bunds. In the arid region the contour bunding with broad based considerations are preferred.

Contour bunds having 170 cm base, 61 cm height and 15 cm top widths were constructed at a vertical interval of 61 cm across 2.0-2.5% slope. Each bund was provided with a random rubble dry stone masonry spillway having crest length of 3m and still height of 30 cm to permit the overflow of excess runoff without breaching the earthen bunds.

Forage yield in contour bunded fields was significantly higher over control (Table 1). The mean increased forage yield was 154% over control; it ranged between 15 and 2696% among different years in response to the annual rainfall (Wasi Ullah et al., 1972).

Table 1: Air dried forage yield in contour bunded fields in different years.

Forage yield (kg ha^{-1})			
Year	Contour bunding	Control	Increase(%)
1961	2321	83	2696
1962	2183	413	429
1963	1547	288	437
1964	1967	497	296
1965	1716	1068	61
1966	1685	1463	15
1967	1100	822	34
1968	64	21	205
1969	1196	769	56
Mean	1531	603	154

Table 2: Air dried forage yield under contour furrows in different years.

Forage yield (kg ha^{-1})			
Year	Contour furrowing	Control	Increase (%)
1961	796	257	210
1962	2297	212	983
1963	647	66	880
1964	1951	110	1674
1965	2293	234	880
1966	2328	255	813
1967	1741	434	301
1968	372	28	1229
1969	1670	328	409
Mean	1566	214	632

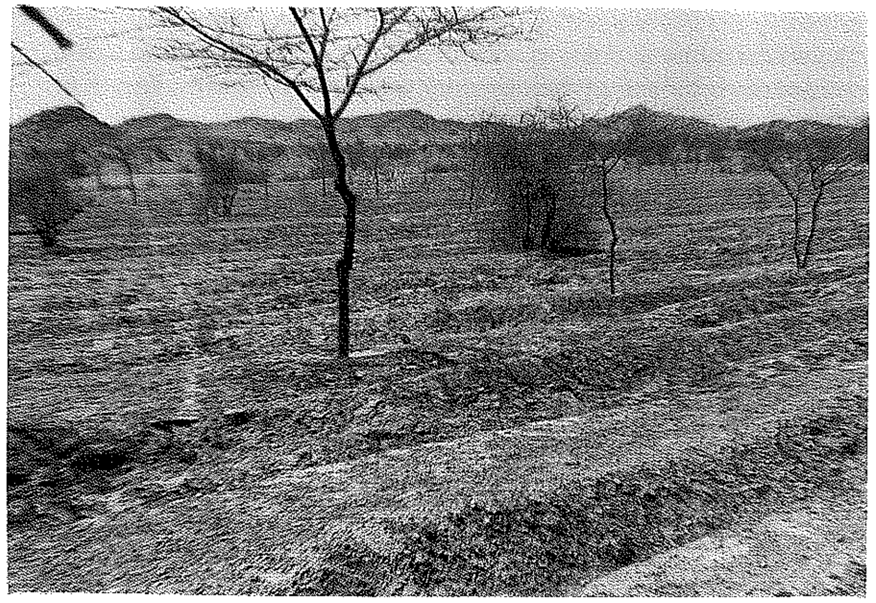


Figure 3: Contour furrowing

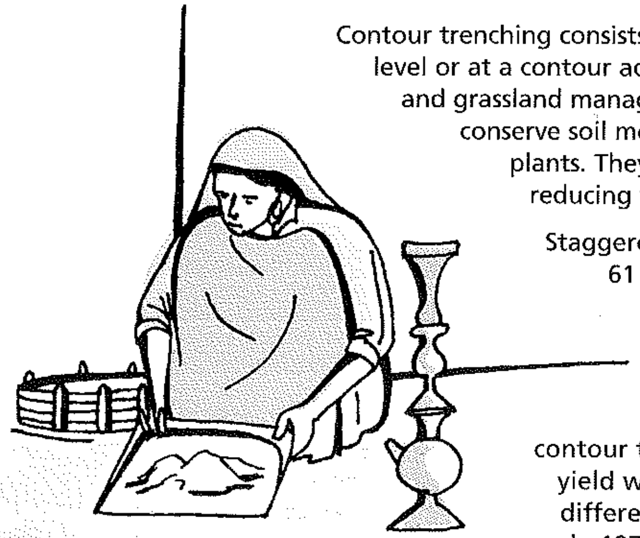
Contour furrowing

Contour furrows have been extensively used in the integrated watershed management programmes in the region as a measure of moisture conservation as well as economical and quick alternative of soil preparation for better establishment and growth of grasses (Fig. 3). Contour furrows having parabolic cross sections of 23 cm depth and 61 cm width were excavated and the earth was formed into a mound on the downstream side. These were spaced 8-10 m apart.

Verma et al. (1997) recorded the highest soil moisture storage at the centre of furrow throughout the growing season. The mean soil moisture storage at the middle of ridge, top of mound and at centre line of horizontal spacing followed a similar pattern of accretion and depletion, and were non-significantly different among themselves. Similarly, Sharma et al. (1983) recorded the significantly higher soil moisture storage at the centre of furrow and at the middle of ridge compared to the top of mound and the centre line of horizontal spacing. Also the highest soil moisture depletion and low peak retention were observed at the centre of furrow and the top of mound, respectively. On an average the contour furrows stored 39% additional soil moisture compared to control.

The better soil moisture regime under contour furrows resulted in higher plant population, dry matter production and precipitation use efficiency in the arid regions (Wasi Ullah et al., 1972). The air dried forage yield under contour furrows was 632% (ranging from 210 to 1674%). The forage yield increased dramatically for five continuous years during 1962 to 1966 in response to the better rainfall regime ranging annually between 280 and 478 mm.

Contour trenching



Contour trenching consists of excavating trenches and forming bunds along a uniform level or at a contour across the slope in uncultivable steep slopes for afforestation and grassland management programmes. Contour trenches reduce runoff and conserve soil moisture, thus helping in the establishment and growth of plants. They also protect the structures in the lower reaches by reducing the volume and discharge of runoff.

Staggered contour trenches having a depth of 30 cm and width of 61 cm were dug at 61 cm vertical interval in 61 m long sections across the slope. An unexcavated portion of 1.5 m was left between the trenches to serve as spillway during periods of heavy runoff.

Forage yield was significantly higher over control in contour trenching fields (Table 3). The mean increased forage yield was 165% over control; it ranged between 48 and 434% in different years in response to the annual rainfall (Wasi Ullah et al., 1972).

Table 3: Air dried forage yield in contour trenching fields during different years.

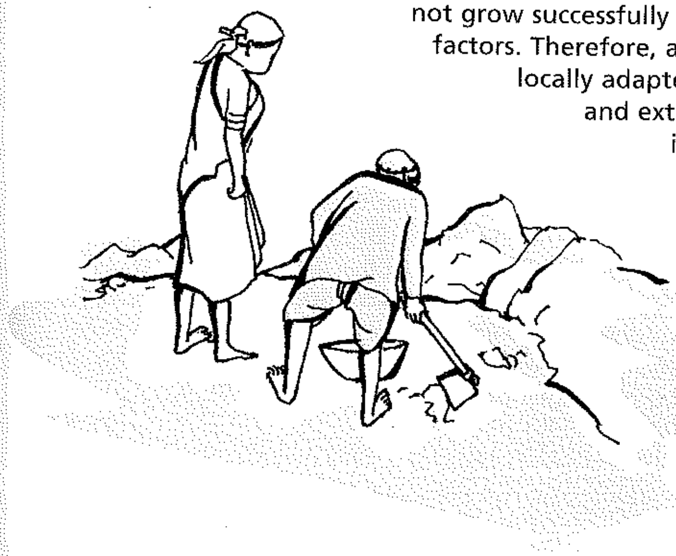
Forage yield ($kg\ ha^{-1}$)			
Year	Contour furrowing	Control	Increase(%)
1961	724	258	181
1962	1468	275	434
1963	864	184	370
1964	1839	598	208
1965	1550	906	71
1966	1791	908	97
1967	1285	867	48
1968	74	19	289
1969	2295	472	386
Mean	1321	499	165

Contour vegetative barriers

A need was felt to evaluate suitable plant species from the locally adapted, native, fast growing, perennials having stiff erect stems and extensive root systems, that form a dense hedge when planted in rows

Watershed management traditionally had a strong hydrological focus, based particularly on structural engineering approach. However, with a growing interest in the protection of environment the focus of soil and water conservation programmes now shifted to how the farmers can manage their lands and maintain or restore the productivity of their soils. For this they need non-structural considerations such as vegetative practices to control the quantity, quality and timing of runoff.

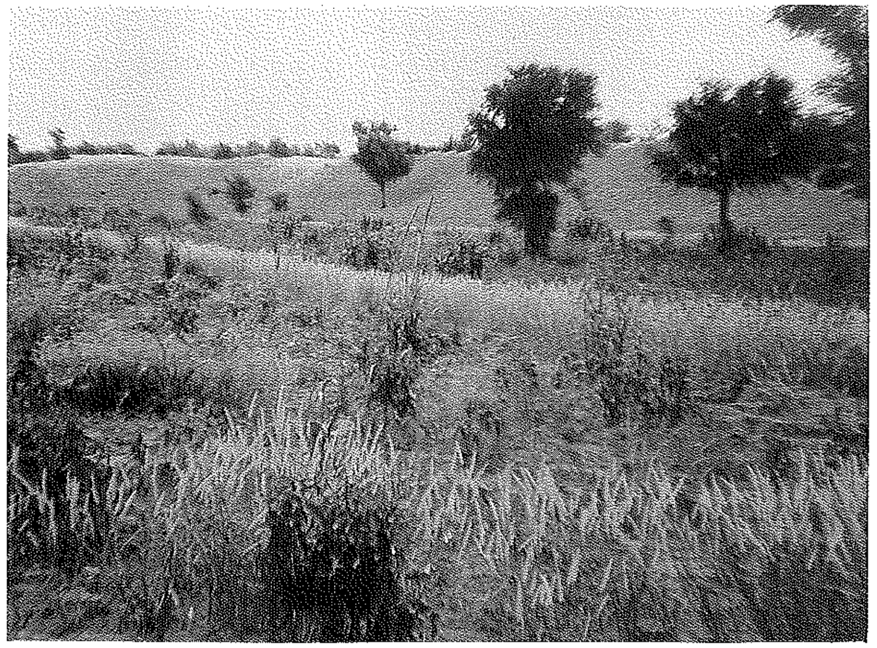
Contour Vegetative Barriers (CVB) are hedgerows of perennial grasses or shrubs planted at regular intervals on contours for conserving soil and water in sloping rainfed crop-fields. These barriers could be planted with or without support of the earthen embankments. The selection of species is based on the morphological and physiological characteristics that are ideal for the purpose of soil and water conservation i.e., the ability of the vegetation to perform the required engineering role and acceptability to the region (Morgan and Rickson, 1995). The World Bank in the last 10 years has promoted the vetiver (Vetiveria zizanioides) grass as a simple, practical, low-technology and low-cost substitute for soil and water conservation in developing countries (World Bank, 1990). However, vetiver does not grow successfully in the Indian arid zone due to adverse climatic and edaphic factors. Therefore, a need was felt to evaluate suitable plant species from the locally adapted, native, fast growing, perennials having stiff erect stems and extensive root systems, that form a dense hedge when planted in rows. The hypothesis is that sloping crop-fields with CVB store greater soil moisture, both during and after a rain storm, than crop-fields without CVB. An experiment on the performance of CVB as soil and water conservation measures was conducted in about a 50 ha during 1992-94 at village Bujawar near Jodhpur (26.5°N, 73.1°E). Clusterbean (Cyamopsis tetragonoloba) and pearl millet (Pennisetum typhoides) were grown during June-September in 19 farmers' fields ranging in area from 0.8 to 3.8 ha The 105 year average rainfall is 366 mm per annum in 17 rainy days;



90% of which occurs during the monsoon season. The soil is sandy loam and is deep to very deep. The experimental fields have a mean slope of 3% and are subjected to sheet and rill erosion.

Rooted slips of 8 species of perennial grasses: Cenchrus ciliaris, Cenchrus setigerus, Cymbopogon jwarancusa, Lasiurus sindicus, Panicum antidotale, Panicum turgidum, Saccharum bengalense and Vetiveria zizanioides and seedlings of 6 species of shrubs: Agave americana, Aloe barbedensis, Barleria prionitis, Euphorbia antisyphylitica, Ipomoea carnea and Leptadenia phyrotechnica were transplanted 0.30 m apart on 1m contour intervals and clusterbean/pearl millet was grown in between the rows of CVB. There were 14 fields with CVB each having different species of plants and 5 fields as control. The fields were bounded by earthen bunds. Data on rainfall, runoff, soil loss, soil moisture storage, growth and performance of barriers and crop production were recorded.

Figure 4: Contour vegetative barriers



Refinement of the selected plant species which can form an effective CVB against soil erosion comprised a critical evaluation of the vegetation on site by recording the survival rates, and the rates and characteristics of growth of plant roots and canopies. The rooted slips of grasses developed at the farmers' fields and transplanted on contours at 1m vertical interval had 92% survival rate. The grass species such as Cymbopogon Jwaracusa, Cenchrus ciliaris and Cenchrus setigerus developed into clumps of 10-15 cm diameter in the first year and 20-30 cm diameter in the second year, thereby closing completely (Fig. 4). The plants grew to an average height of 50 cm with an average number of 25 tillers per clump. Thus, these grasses performed well and formed effective CVB in a span of two years compared to 4 years for the vetiver grass to grow effectively. The shrubs, raised during the rainy season, performed well until the subsequent winter season. However, only 50% shrubs survived through the next year and could not form an effective CVB.

The area received between 280 and 544 mm annual rainfall during the study period. Fourteen rainfall events generated runoff during this period. The rainfall events varied from 8 to 94 mm with duration ranging from 20 minutes to about 11 hours. The rainfall intensity for a 5 minute duration ranged between 3 and 150 mm/h.

The CVB did not channelise runoff but allowed surface runoff to slowly flow through the hedge resulting in greater opportunity time for rainwater infiltration

Reduction in runoff volume and peak flow was recorded in the CVB fields over control. The runoff volume was reduced by 28 to 97% and the specific peak discharge was reduced by 22 to 96% (Table 4). The vetiver CVB reduced runoff volume by 30 to 47% only. Also the CVB fields stored 2.5 times greater soil moisture than control. The CVB did not channelise runoff but allowed surface runoff to slowly flow through the hedge resulting in greater opportunity time for rainwater infiltration. Infiltration reduces the volume of potentially erosive surface flow. Hence, the CVB could be named as 'flow-through' system in contrast to the conventional diversion system used in contour bunds (Sharma et al., 1997).

Principles and Practices of Integrated Watershed Management in India
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Table 4: Summary of mean observed rainfall, runoff, soil loss and soil moisture storage data.

S. No.	Date	Rainfall (mm)	With CVB: Rainfall (mm)	With CVB: Specific peak dis-charged ($l\ s^{-1}\ ha^{-1}$)	With CVB: Soil loss ($kg\ ha^{-1}$)	With CVB: Soil moisture storage ($cm\ m^{-1}$)	Without CVB: Runoff (mm)	Without CVB: Specific peak dis-charged ($l\ s^{-1}\ ha^{-1}$)	Without CVB: Soil loss ($kg\ ha^{-1}$)	Without CVB: Soil moisture storage (cm m-1)
1.	19 July '92	8.0	0.4	1.2	1.59	10.6	2.1	7.5	504.00	4.3
2.	2 Sept '92	11.9	2.7	13.2	8.91	11.4	4.7	27.2	310.20	4.3
3.	3 Sept '92	37.5	5.1	23.1	5.09	13.8	8.0	39.3	528.23	7.3
4.	4 Sept '92	93.5	17.7	32.6	32.75	24.6	24.6	92.6	1196.74	9.9
5.	10 Sept '92	40.8	3.5	15.3	7.68	15.5	7.3	22.2	630.72	7.6
6.	26 June '93	71.0	3.8	3.3	6.50	16.2	7.5	11.6	378.75	8.9
7.	12 July '93	52.4	2.5	1.8	2.51	14.9	5.3	2.3	457.92	8.7
8.	16 July '93	8.7	0.8	1.1	2.12	10.8	4.7	18.6	406.08	5.2
9.	17 July '93	83.5	14.2	10.3	14.69	23.1	20.9	18.2	689.70	9.9
10.	18 July '93	79.1	14.8	14.2	9.80	17.7	23.1	24.9	473.29	9.8
11.	19 July '93	21.2	0.2	0.2	7.29	12.4	1.1	0.4	273.46	6.0
12.	30 July '94	13.7	0.1	1.1	3.98	11.2	3.0	31.8	869.55	6.8
13.	1 July '94	77.1	1.9	12.4	7.03	16.6	4.9	22.7	193.06	9.2
14.	13 Aug '94	10.0	0.4	6.5	3.00	10.3	8.5	19.9	487.05	4.9

The CVB fields lost on an average 8 kg/ha soil as compared to 527 kg/ha for the control; well within the tolerance limit of 5-10 kg ha^{-1} for sandy soils. Also the sheet and rill erosion were checked to a greater extent in these fields.

The better moisture regime in CVB fields resulted in higher growth and yield of clusterbean and pearl millet crops (Table 5). The seed grain yields of clusterbean and pearl millet increased between 14 and 61%, and 19 and 40%, respectively over control. These yield averages were significantly higher than only 6 to 26% increase with the vetiver CVB. Also, the seed grain yield production was the highest during 1994 due to a better moisture regime as a result of higher rainfall.

Table 5: Yield (kg/ha) of clusterbean and pearl millet as influenced by contour vegetative barriers (CVB).

Year	Annual rainfall (mm)	Clusterbean: With CVB	Clusterbean: Control	Pearl millet: With CVB	Pearl millet: Control
1992	387	637	496	2108	1573
1993	280	431	378	991	832
1994	544	246	772	3700	2638
Mean	404	771	549	2266	1681

The CVB of indigenous species of economic importance, were found to be the most acceptable by the farmers. The farmers believe that these CVB are less expensive, easy to raise, less labour intensive and provide fodder during the lean periods. The CVB technology is being implemented on a large scale by the Rajasthan state departments in watershed development programmes in the region.

Gully control structures

Depending upon the degree of degradation and expected peak discharge, both the temporary as well as the permanent gully control structures are used to reclaim gullies and regulate flow in the ephemeral streams. In many watersheds in the arid region, the temporary checks would be adequate; in general, the locally available materials such as earth, loose stones, brushwood, stone slabs, polybags filled with earth, etc. are preferred. The life of these structures ranges between 3 and 8 years. This period is generally adequate to realize the desired objectives of gully plugging and stabilization of ephemeral channel courses. Bhati et al. (1997) recorded a mean rate of sediment deposition behind these temporary checks as 11.5 t/annum over a period of seven years (range 3.9-18.0 t/annum).

Small earthen dams

When water flows regularly into small valleys such as springs, earth dams are built to retain water on site. Small earthen dams are raised bunds of compacted soil, 2-5 m in height; they often include a clay core with stone aprons and a spillway to discharge excess runoff. In the Indian arid zone several small earthen dams have been constructed on ephemeral channels to cater to the drinking water and irrigation requirements. The runoff in the catchment area can be estimated by:

Runoff = Rainfall x Runoff coefficient x Catchment area.

The runoff coefficient is the proportion of rainfall that will result in runoff. For different types of catchments, different coefficients apply (Table 6). The materials to be used are mainly clay for the core wall and large stones for protection against erosion. Standard guides are available for designing and construction of various components of the small earthen dams in the arid region and must be adhered to (Fowler, 1977).

Figure 5: Anicut/Check Dam

Anicut/check dam

These structures are constructed across ephemeral streams with fill section, to intercept the runoff from local catchments and store it for optimum utilization (Fig. 5). The stored water behind the structure is used for drinking, irrigation, recession farming and recharging the downstream wells. The anicuts/check dams are widely adopted in the arid parts of Rajasthan and Gujarat under hilly and uneven topography, where ephemeral streams are present and good runoff production catchments are available.

In general, the anicut/check dam is designed on the basis of 50 years recurrence interval of the rain storm. Basically, there are two components of the system - earthen embankments and masonry spillway. The design parameters are catchment area, expected runoff, designed storage as well as the area to be benefited. A thorough and detailed knowledge of geological, hydrological, and morphological features of the area is necessary for selecting the sites. Local guidelines and design parameters have been developed for their construction by the Soil Conservation/Irrigation Departments. These guidelines are region specific and must be adhered to as per the site conditions.

The anicut/check dam enhances the groundwater recharge. In a case study, the groundwater recharge enhanced up to 35% over a period of three years in sandstone terrain by the construction of anicuts on three ephemeral streams in western Rajasthan (Bhati et al., 1997). The quality of groundwater was also improved as evidenced by reduction in EC and pH by 25.2 and 13.6%, respectively. In general, the average recharge is 50%s of the storage in any normal year and the zone of influence ranges from 1.5 to 2.0 sq. km.

Khadin

Khadin is a system of growing crops on harvested and stored water in the farm soils by constructing an earthen bund across the gentle slope in the valley bottom. This practice dates back to the 15th century and is being followed in the < 200 mm rainfall zone of the Indian arid zone.

Table 6: Runoff coefficient in the Indian arid zone.

Rainfall zone (mm)	Terrain	Runoff coefficient
<200	Rocky/gravelly eroded surface	0.2-0.3
	Interdunal plain	0.1-0.15
200-400	Rocky surface with gravel mantle	0.2-0.3
	Rocky surface without gravel	0.3-0.4
	Sandy loam to loamy sand	0.15-0.2
	Above with compaction	0.3-0.4
>400	Hills and uplands	0.4-0.6
	Sandy/alluvial plain	0.2-0.4
	Compacted and smoothed soil	0.3-0.5
	Soil on <10% slope	0.0-0.3
	Rocky natural surface	0.2-0.5

In the extreme western arid tract in India many large rocky areas, rugged hillocks and plateau form the runoff producing catchments for the adjoining flat valley bottoms which are the main farming lands in the region. A large earthen bund is constructed across the gentle slope of the valley bottom to facilitate the spreading of harvested runoff. Water thus accumulates to a depth of 60 to 90 cm, gradually seeps into the ground and recharges the soil profile. If the accumulated water persists longer, it is drained out through the sluice before sowing the crops. The soils in Khadin are very fertile due to frequent deposition of fine sediments. Depending upon the type of catchment, the ratio of farm to catchment area varies from 1: 12 to 1: 15 (Kolarkar et al., 1983). There is considerable scope to improve upon the productivity of Khadin systems through agroforestry and agrohorticulture systems.

Operation and maintenance

The soil and water conservation measures discussed above are essentially site specific. The choice of measures for a given watershed depends upon its hydrological characteristics and intended land use. Indepth and precise characterization of the watershed has, therefore, a significant role in the preparation of the management plan and its execution.

Vegetative reinforcement of the control structures such as bunds, check dams, channel/reservoir embankments, etc. can increase their longivity considerably and supplement fuel and fodder production. Perennial grasses can be planted on all earthen bunds. This will not only make the bunds stable against wind and water erosion but also provide a permanent source of fodder which is always in short supply in the region.

ECOLOGICAL RESTORATION

Adoption of need-based soil and water conservation measures besides controlling erosion, results in spectacular regeneration of natural vegetation in the severely eroded areas of the region. In Jhanwar watershed near Jodhpur, the tree and shrub density around check dams increased by 188 and 813%, respectively, between 1987 and 1994 (Bhati et al., 1997). Amongst the trees, the highest increase in plant density was observed in case of Commiphora wightii followed by Acacia jacquemontii and Prosopis cineraria (Table 7). These tree species are of high economic, medicinal and social value. The increase in shrub density during the same period was in the order: Maytenus emarginata >Lycium barbarum >Capparis decidua > Grewia tenax.

Table 7: Plant population in the study area during the project period.

Plant species	No. of plants		Increase (%)
	Initial-1987	Final-1994	
Acacia jacquemontii	10	76	650
Capparis decidua	103	315	206
Commiphora wightii	15	137	813
Grewia tenax	8	23	188
Lycium barbarum	36	193	436
Maytenus emarginata	41	221	439
Prosopis cineraria	9	65	622

CONCLUSIONS

Integrated watershed management aims at optimizing the use of land, water and vegetation in the arid regions, so as to mitigate the effects of droughts, flash floods and soil erosion. In the arid regions the conservation of soil moisture is more important which not only conserves the soil but also increases the availability of fuel, fodder and agricultural production on a sustained basis.

The engineered structural soil and water conservation measures such as bunding, furrowing, terracing, etc. are too expensive and difficult to maintain as arid areas are prone to excessive wind erosion and occasional flash floods. With the growing interest in the protection of environment and perennial shortage of fodder,

vegetative measures of soil and water conservation gained importance in the region. However, indepth studies are warranted to develop solutions with regard to various plant species that can sustain land and water and are also economical to the community.

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