Management of Rainwater Resources for Rehabilitation of Degraded Lands in Arid and Semi-arid Region of Southern Pakistan

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Abstract In face of changing climate patterns and increasing livestock population, the pressure on silvopastures in dry lands of Pakistan is increasing, resulting in degradation of natural resources and loss of soil fertility. The Farm Forestry Support Project of the SDC-IC initiated rehabilitation work in 2010 in dry region of Karak using rainwater harvesting and sand dune stabilization techniques. The objective was to recover vegetation and increase land productivity. The activity was carried out jointly with farmers. Results recorded in 2015 showed a profuse plant growth in terms of trees, shrubs and grasses with a potential to provide timber, fuel wood and fodder for livestock. Conservation of moisture also resulted in growth of natural grasses and shrubs. After 5 years, plant growth in height and diameter of 6 m and 20 cm, respectively, was recorded. The vegetation cover of 45% and increase in content of soil organic matter and nitrogen were recorded. All this happened with a cost of US$82 per hectare. Rejuvenation of wells in few cases was an additional positive effect. On the other hand, annual income of US$735 per hectare from *Saccharum spontaneum* planted in sand dunes was a benefit to farmers against the other land uses in sand dunes.

Keywords Silvopasture · Sand dune stabilization · Soil moisture
Annual income

1 Introduction

Dry lands are generally defined as arid, semi-arid or dry sub-humid lands receiving less than 500-mm annual rainfall with an aridity index between 0.05 and 0.65 (the aridity index is the ratio of precipitation/precipitation evapotranspiration) (United Nations Convention to Combat Desertification 1999). There are more than 3 billion

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people globally living in dry lands that cover 40% of earth's surface (Robin 2002). Dry lands are generally defined in climatic terms as lands receiving less than 500 mm of annual rainfall. In Pakistan, the situation is severe with 75% of the country's area receiving less than 250 mm of annual rainfall (Pakistan Meteorological Department 1998). Most parts of Sindh and Balochistan and southern parts of Punjab and NWFP are falling within this dry zone (Government of Pakistan 2006).

Over 30 million people in Pakistan live in dryland areas. Their livelihoods depend heavily on the natural resource base in the form of provision of food for human beings, fodder for livestock, fuel for cooking and heating and water for drinking. Some scanty income from the sale of medicinal plants and herbs, livestock and dairy products and wildlife was also added to the meagre earnings (Fischler and Irfanullah 2006).

The poor in these ecologically fragile marginal lands are increasingly locked into patterns of natural resource degradation (Government of Pakistan 2007). There are many factors responsible for degradation of natural resources, and the climate change promotes the process by limiting the water availability and increasing temperature. Due to the low production and regeneration potential, dry lands are not able to support an ever-increasing population of human beings and livestock. Most of the silvopastoral ecosystems in dry lands are degraded due to overstocking beyond their carrying capacity, whereas rainfed croplands are increasingly being abandoned due to prolonged drought periods. These adverse factors are continuously undermining the livelihoods of poor pastoral and farming families.

1.1 Study Area

The study relates to joint activities of the Farm Forestry Support Project, local NGOs and rural community organizations in Karak, one of 22 districts in the southern part of the Khyber-Pakhtunkhwa Province (NWFP) of Pakistan (Fig. 1). District Karak is situated in southern region of NWFP (Fig. 1), covering an area of 3372 km^2. Total population of Karak is 430,000 heads (Government of Pakistan 1998).

The area comes under tropical and subtropical climatic zone, characterized by arid and semi-arid conditions. It can be divided into three distinct geographical divisions: the dry hilly zone in north, sandy desert in south-west and sandy-loam plains in the eastern part (Irfanullah 2008). The northern hilly zone is famous for mining of various minerals like salt and gypsum. The south-western desert is characterized by shifting sand dunes, very dry and hot winds and subsistence cultivation of gram, mustard, groundnut and wheat. The eastern region is famous for a number of agricultural crops (millets, wheat and maize) and vegetables (chilies, okra, eggplant and tomato) mainly because of availability of some irrigation water. As a whole, 19% of the area is under cultivation out of which water is available for 2% of the area (Government of Pakistan 2006).

Fig. 1 Location map of Karak. *Source* Google Earth

People in this area live on subsistence agriculture, livestock rearing and minor trade of daily use commodities. Literacy rate is surprisingly high (above 50%) as compared to the rate for Pakistan (44%) (Government of Pakistan 1998). Due to harsh living conditions and limited opportunities on land, people prefer to join civil and armed services that are mostly out of the area. The remittances they send back to their families are thus an important source of living.

1.2 The Dryland Ecosystems

The interplay between human beings, land resources, climatic conditions, natural vegetation and livestock constitutes the ecosystem in most of the dry lands in Pakistan. In all these, the climatic factors and availability of water for productive practices are limiting factors. Again, in most of the cases, vast tracts of land are available, but production systems are limited to only a few patches because of climatic conditions that limit the availability of water.

In the study area, mean maximum temperature can reach to 46 °C in summer (May–September). The mean minimum temperature in winter months (November–February) goes down to 3 °C. The extreme arid conditions prevailing in major part of Karak limit agriculture to a profitless rather under-paying activity. Subsistence agriculture is totally dependent on rainfall that is sporadic, uncertain and does not exceed 350 mm per annum (Government of Khyber-Pakhtunkhwa 1998). Livestock rearing (mainly goats and sheep) is thus adopted as major source of livelihood that supports the family in terms of nutrition and income from sale of animals, wool and milk (Fig. 2).

These limitations lead towards a silvopastoral way of living where natural vegetation plays deciding role in the sustenance of the system. Sporadic grasses, shrubs and stunted trees are all what is required for grazing herds (Fig. 2). The local tree vegetation in this area includes *Acacia modesta*, *Prosopis cineraria*, *Capparis aphylla*, *Prosopis glandulosa*, *Tamarix aphylla*, *Zizyphus mauritiana*, *Olea ferruginea* and *Tecoma undulate*. Some of the important shrub species include *Zizyphus numularia*, *Vitex negandu*, *Saccharum munja*, *Callygonum polygonoides*, *Callotropis procera* and *Nannorrhops ritchiana*. Among grasses, *Chrysopogon* spp., *Cenchrus* spp. and *Cynodon dactylon* are important, whereas *Salsola foetida*, *Withania* spp. and *Erva javanica* are common herbs. The natural forest is limited to only 2% of the total area on distant hills (Government of Pakistan 1998), comprising mainly *Acacia modesta* and *Olea ferruginea*.

Availability of water for drinking purpose is also not certain. The water table is as low as 500 ft., and it costs high to drill and pump the water out. There were some natural springs in the hills that were providing drinking water to communities but dried out in recent droughts (1992, 1998 and 2002).

Fig. 2 The dry lands in Karak, Pakistan. *Photograph* Irfanullah Sahibzada

1.3 Statement of the Problem

Most of the people in Karak live below poverty line. Their livelihood is dependent on rainfed subsistence agriculture and livestock. The livestock is then dependent on natural range vegetation in the form of low trees, shrubs and grasses. However, due to increasing drought conditions and scarcity of rainfall, the agriculture is not more a productive activity and croplands are increasingly abandoned. To fill this gap in livelihood, the number of livestock per household is increasing with time. This exerts great pressure on natural vegetation of the rangeland area that gets grazed more intensively and more frequently. This leads to the degradation of ecosystem and depletion of natural vegetation. The scanty rainfall condition, hot weather and sustained grazing pressure restrict recovery potential of natural vegetation. The phenomenon thus adds to desertification that compounds the problem of poverty and makes communities utterly vulnerable to the situation.

The net effect of the problems stated above is observed in the form of increase in poverty and vulnerability of the poor. The droughts leave negative effects on their capacity to survive. In the efforts to survive, they become heavily indebted, their health is badly affected, and most of them migrate to urban areas.

2 Methodology

Keeping in view the importance of natural vegetation and the support it does provide to local livelihoods, the Farm Forestry Support Project (FFSP) funded by Swiss Agency for Development and Cooperation (SDC) and executed by Intercooperation-Pakistan, started the dryland management and rehabilitation programme in District Karak. The purpose was to rejuvenate the productive capacity of degraded lands so that the support these lands were providing to livelihoods previously could be restored (Shah 2011).

Based on the detailed area surveys and consultation sessions conducted in the region by experts from FFSP through the local NGOs and farmers' communities, rehabilitation measures were designed to address the problem. In order to regain the depleted vegetation cover and thereby restore the soil fertility for increased production in silvopastoral lands, the "Hillside Ditch" technique was specifically designed and applied on 5 sites within the district. The technique aimed at taking maximum advantage of atmospheric water (rainfall) for increased biomass production for human and livestock needs (Farm Forestry Support Programme 2015).

2.1 Design Parameters

The hillside ditches were designed for these silvopastoral lands with gentle sloping topography (below 30°) to enable the use of machinery (tractors) for reducing labour cost (Fig. 3).

Continuous ditches along the contour line having plant pits at regular interval were excavated (Fig. 3). The ditches were 66 cm wide and 30 cm deep, with excavated soil from ditch placed on downhill side making continuous ridge of 30 cm. The soil excavated from plant pits was placed within the ditch on one side of plant pit to impound water. Spacing of ditches and plant pits was kept as 7 and 5 m, respectively (Fig. 4). The size of the ditches and spacing of plants and ditches were fixed keeping in view the rainfall of the area.

The plant pits were planted with tree species that were fast growing and having fodder value. The interspaces between plants were sown with seeds of grasses and fodder shrubs to have maximum utilization of space. The species used on different sites included *Acacia albida*, *Dalbergia sissoo*, *Acacia nilotica*, *Melia azadarich* and *Acacia Victoria* in trees; *Dodoneae viscose* and *Acacia modesta* in shrubs; and *Sorgham almum* and *Cenchrus ciliaris* in grasses.

On sites with sand dunes that kept shifting with winds, a sand dune stabilization technique with a local species called "Khana" (*Saccharum spontaneum*) was applied. *Kana* suckers were obtained from an adjacent district at the cost of Rs. 7 per sucker and planted at a spacing of 5 m × 3 m in straight lines (Fig. 10).

2.2 Instruments

The hillside ditches were excavated with the help of a tractor-driven "Ditcher" specially designed for the purpose to reduce cost. The ditcher that was fabricated in a local workshop consisted of a modified form of mouldboard plough commonly used by farmers in hilly areas for cultivating hard gravelly soils. The front two

Fig. 3 Layout site of hillside ditches *Photograph* Irfanullah Sahibzada

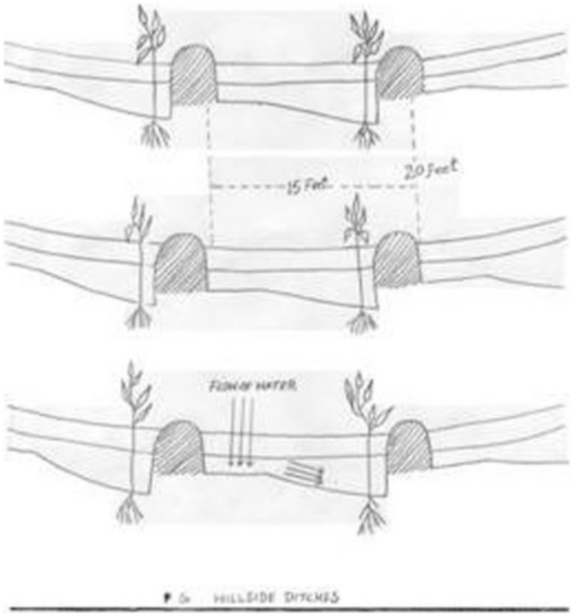

Fig. 4 Design of hillside ditches

Fig. 5 Ditcher, specialized instrument for ditch making. *Photograph* Irfanullah Sahibzada

blades were replaced with strong chisels and the rear blades by enlarging its length to 1 m and depth to 0.6 m (Fig. 5).

For reducing the cost of manually excavated plant pits within the ditches, a pit excavator was designed and used (Fig. 6). The front blade commonly used with tractor was modified to have a top width of 1 m and bottom width of 0.6 m.

The pit excavator was fitted with the tractor in front to excavate pits in hillside ditches. The pit excavator was so used that it produced a gently increasing slope towards the planting point from the middle of the space between two plant pits.

Fig. 6 Pit maker for making pits in ditches. *Photograph* Irfanullah Sahibzada

2.3 Operational Details

Function of the whole arrangement of ditches and pitting was to take maximum benefits of rainwater in arid zones by making maximum rainwater available for plant growth for prolonged period. This was with the purpose to eliminate high establishment costs in arid zones involving labour in plantation and manual watering at frequent intervals. By keeping the depths of ditch, the ridge and pits within the ditch as 30 cm each, a 90 cm deep and 66 cm wide space at each planting site was made available for storing run-off water coming from up-slope side. By keeping the space between ditches and plant pits as 7 m and 5 m, respectively, rainwater falling on 35 m^2 land surface on uphill space was collected at each planting point.

3 Results

3.1 Physical Evidences

The maximum on-site conservation of rainwater and its utilization for plant growth was the major effect visible on these sites. In an area arid to a limit that could not support the slow-growing vegetation produced fast-growing trees and obtained profuse growth of shrubs and grasses within a few years of time (Fig. 7).

According to the data collected from different sites, the average survival rate of trees planted was 40%, the average number of trees growing per hectare becoming 218. This number was manifold more than the number of trees growing on these types of lands without treatment (i.e. 14 trees per hectare) (Pakistan Forest Institute 2005). The height and diameter growth rate on these sites recorded was also considerably higher. Maximum diameter and height growths were recorded in case of *Acacia albida* as 20 cm and 6 m, respectively, followed by *Acacia nilotica* as 15 cm and 5 m, respectively (Figs. 8 and 9; Table 1).

Fig. 7 Growth of grasses after one year. *Photograph* Irfanullah Sahibzada

Fig. 8 6-year-old trees of *A. nilotica. Photograph* Irfanullah Sahibzada

Due to retention of run-off and percolation of run-off water into soil on the site, a profuse growth of local annual and perennial grasses was recorded, in addition to the *Sorgham almum* and *Cenchrus ciliaris* that were sown during plantation activity. The average soil cover on these soils recorded was 45%, considerably high over normal cover on these degraded lands (10–15% on the average). These grasses and shrubs were of high value as a feed for local goats and sheep. The farmers were advised not to allow animals for grazing in initial 2 years. They could, however, cut grasses and stall-feed their animals during these 2 years.

Fig. 9 3-year plants of *A. nilotica. Photograph* Irfanullah Sahibzada

Table 1 Growth data for trees, shrubs and grasses in hillside ditches

S. no.	Parameter	Species	Data recorded
1	Average diameter	*Acacia albida*	20 cm
		Acacia nilotica	15 cm
2	Average height	*Acacia albida*	6 m
		Acacia nilotica	5 m
3	Av. no. of trees surviving/hectare	Overall	218 numbers
4	Average vegetation soil cover	Overall	45%

Source Survey data

The activity also contributed to the overall fertility status of soil. The laboratory analysis of soil samples taken at three sites each from treated and controlled plots showed a higher organic matter content and total nitrogen concentration in treated plots. A slight increase in phosphorus content and decrease in lime content could also be attributed to the treatment of site. No significant change in the electrical conductivity, pH and potassium content was however recorded. The treatment period of 5–6 years was too less to demonstrate any significant change in soil properties, except the content of organic matter that was recorded higher in treated plots (Table 2).

In addition to increase in on-site productivity and soil fertility, the activity also contributed to the recharge of groundwater in down the slope areas. According to information provided by local community, two wells that dried out due to prolonged drought were rejuvenated near to the activity sites.

On the other hand, the Khana belts served the purpose of windbreaks for sandy croplands and contributed to household income in the form of proceeds from sale of its stalks and leaves. The *Saccharum* plant was found most suitable for sandy land as it did withstand against prolonged droughts, lesser cost involved in its establishment and high return for its marketable products (Fig. 10).

Table 2 Soil properties in treated and controlled plots

No.	Parameters	Control plot	Treated plot
1.	Organic matter (%)	0.65	1.01
2.	Total nitrogen (%)	0.13	0.20
3.	Phosphorus (mg/kg)	3.05	3.14
4.	Potassium (mg/kg)	155.13	114.1
5.	Electrical conductivity (dS/m)	0.10	0.13
6.	Lime content (%)	6.96	6.75
7.	pH (1:5)	8.29	8.38

Source Khattak (2015)

Fig. 10 *S. spontaneum* in sand dunes. *Photograph* Irfanullah Sahibzada

3.2 Cost Analysis

Due to use of specialized instruments and machinery, the cost was very low for applying hillside ditch technique to the development of silvopastures. The total cost including use of machinery, planting stock, seeds and labour was calculated as US $82 per hectare (Table 3).

It is important to mention that the extra cost involved in this activity was that of using specialized techniques. This, however, drastically reduced the cost of manual watering as implied in ordinary plantation activities by the Forest Department or other agencies. The usual cost per hectare plantation activity by the Forest Department was Rs. 19,800 or US$330 (as per exchange rate of Rs. 60/USD in 2009) that was considerably higher than the cost on using hillside ditches (Government of Khyber-Pakhtunkhwa 2003; FATA 2015). The additional benefit of this silvopasture development was that it re-established the whole vegetation cover as compared to ordinary plantation work that considered only trees.

Table 3 Cost analysis of silvopasture development per 1 ha of land

Activity	Cost description	Rate (Rs.)	Amount (Rs.)	Amount (US $)
Preparation of hillside ditches with tractor and ditcher	3 h	300	900	Total cost = US$82 @ PK Rs. 60/ $ (2009)
Preparation of pits with tractor and pit blade	2.5 h	300	750	
Planting stock	540 Plants	2/plnt	1080	
Planting with first watering	540 Plants	2/plnt	1080	
Restocking (30%), including cost of plants and planting	160 Plants	4/plnt	640	
Grass seed	3 kg	50/kg	150	
Seed of shrubs	2 kg	100	200	
Sowing of shrubs' and grasses' seeds	1 Labour day	100	100	
Total cost (Rs.)			4900	

Source Sahibzada (2015)

Table 4 Annual cost/benefit per hectare for various crops of sand dunes in Karak

Cost/Benefit	Kanola (Rs.)	Gram (Rs.)	Mustard (Rs.)	*Kana* (Rs.)
Annual cost	6052	9139	10,003	–
Annual income	14,795	53,097	74,055	44,100
Net Profit (Rs.)	8743	43,958	64,052	44,100
Net profit (US$) (@ of Rs. 60/USD of 2009)	USD 146	USD 732	USD 1067	USD 735

Source Agriculture Research Station Karak (2015)

In case of sand dunes, total cost per hectare of *Kana* establishment including the cost of suckers and labour was Rs. 5000 (US$83). The average annual return from *Kana* site was Rs. 44,100 (US$735) that was profitably comparable with other land uses available for sand dunes, except wheat (Table 4).

The investment cost for *Kana* was only one time as this was a perennial plant. It was cut each year and sprouted again (Fig. 11). Both the long stalks and leaves were sold in market (these were used for furniture making, as roofing material, sunscreens and making of decoration items). The outstanding characteristic of *Kana* was that its production did not depend on rainfall and even did well in prolonged droughts when all other crops failed.

Fig. 11 Harvesting of *S. spontaneum. Photograph* Irfanullah Sahibzada

4 Discussion

The study faced all those constraints common in dealing with a common resource in social environment. It could have produced better results if the land resource use patterns were in control of the study team. However, it is a fact that more than 60% land in Karak is treated as wasteland where free and unrestricted herding and grazing of animals is practised. Due to no or lesser productivity of economic goods, the use rights for livestock grazing are not reserved. Free, unrestricted and extensive grazing of animals is thus practiced by local communities, even by those who do not own any land and totally depend on their livestock.

The rehabilitation measures however demand care of the land and protection from grazing for initial two years to provide relief to the recovering vegetation. Due to silvopastoral practices that have become a way of life, it is difficult for landowners to abandon grazing on their land. It is due to this reason that communities usually demand for fencing the area or keeping watchmen to protect the site which enormously increase the establishment cost of the activity.

Without attending to the protection parameters, activity in some places has resulted in no conspicuous results after the planted seedlings and shrubs were completely clean washed by roaming herds of goats and sheep.

On the other hand, it is a common concept among local people that investing on silvopastures is a profitless venture. Failures due to water shortage in past and the lack of protection from free grazing animals have further strengthened this perception. The already marginalized communities therefore find it very difficult to invest on pasture development.

To overcome these constraints, the project used a vigorous campaign to convince the local resource users (herders and farmers) for restricting their herding practices to untreated lands. The project team ensured in return to limit the treatments to a small portion (1/4th) of the grazing lands to provide sufficient grazing fields for the herds. At the same time, a concept of social fencing was used where farmers' associations in the target communities and adjacent villages were taken into confidence for the activity and they were then able to control the unattended grazing practices.

Whereas this paper addresses the problem faced by a wider population of herdsmen and farmers dependent upon farming and livestock resources in a pattern that is common to the dry southern landscapes of Pakistan, India and many other adjacent countries, the land use pattern in dry parts of many these countries may vary and the coping strategies for all those lands will vary accordingly for producing similar results. This study is therefore limited in scope keeping in view the resource use patterns.

The study produced visible effects in terms of revamping the biomass reserves of the area. However, the more desired effect on soil fertility and its organic content was not visible or verifiable in the limited span of this study. For measurable effects in these parameters, a longer period monitoring is required.

5 Conclusions

The interventions in silvopasture development and sand dune stabilization have proved significant in overcoming the water shortage and rejuvenating the vegetation for the benefit of human beings and livestock. The cost of these activities is also very low and within the bearing capacity of farmers. Every effort has been made to make use of local instruments and material like the improvised “ditcher” and “pitter” which were the modified forms of already in-use agricultural implements. The study in the given socio-economic and geophysical environment produced results that could be of use and interest to many scientists and practitioners working in similar environment and dealing with similar problems. Particularly, the subtropical dry lands in many neighbouring countries can be a suitable ground for tackling these problems with these or adjusted techniques.

However, a strategy needs to be worked out beforehand to control the constraints elaborated in the previous section to eliminate or minimize the effects of free grazing. These facts and results need to be spread wide through extension and mobilization of communities at regional level. The mater of free livestock grazing should be managed at regional and not at local level. Communities should be facilitated to reach a mutual consensus for protecting sites under treatment and keeping their animals grazing in other areas. A controlled grazing system in which area is divided into blocks, keeping one block under protection on rotational basis, may also be one of the options.

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The commitment and efforts of local NGOs (*Khwendo Kor* and *Yaraan* in Karak) who were involved in contacting the communities, selection of sites and discussing all the matters with community organizations at grass-roots level are highly appreciable. These organizations and their role are crucially important in the sustainability of the activity on long-term basis.

Technical expertise and support provided by Dr. Bashir Hussain Shah (the FFSP Consultant) in the initial phases of the activity was very much helpful in designing tailor-made interventions for sites in the field. Dr. Shah's knowledge and experience is enlightening many minds in many organizations in many parts of the country because of his dedication to the development.

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