Review Article

Review of Dry Land Afforestation Practices in Pakistan

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Abstract | Dryland afforestation is a primary tool for controlling soil erosion, land degradation, and desertification. Pakistan is predominantly a dry country, where 51.5% of the area is arid and 36.9% is semi-arid. The two-thirds of the livelihood of Pakistan is growing rapidly over a population of 184 million people, who directly depend on goods and services provided by dryland natural resources, especially natural forests. In the dry zone areas, the natural forests have completely disappeared and degraded. The forest cover cannot be regenerated naturally in dry areas with erratic climatic conditions. Several research organizations such as the Pakistan Forest Institute, PARC, IC, FAO, UNDP etc., initiated systematic research in dry areas to combat land degradation and desertification effectively. These research studies focused on the maximum utilization of rainwater to ensure the availability of soil moisture to the plants for a longer period to enhance survival and growth. Various water harvesting techniques such as mud plaster, conservation contour trenches, V-shaped micro-catchments, hillside ditches, roaded catchments, water spreading, and individual basins were investigated to determine their efficiency and effectiveness. Deep planting and plastic mulching were extensively used for this purpose. Several multipurpose tree species were recommended for the desert environmental conditions in Thal, such as *Acacia albida*, *Acacia tortilis*, *Acacia elata*, *Tecoma undulata*, *Acacia victoriae*, *Tamarix aphylla*, *Acacia modesta,* and *Prosopis cineraria*,. For semi-arid areas *Eucalyptus camaldulensis*, *Acacia saligna*, *Acacia elata*, *Acacia albida* and *Leucaena leucocephala* were found to be quite successful. These techniques have shown positive outcomes regarding runoff induction, survival rates, and the growth of tree species. This review recommends adopting specific water harvesting techniques for dry land forestry and range improvement in different geographical areas based on these research findings.

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Introduction

Drylands generally receive annual rainfall of less than 500 mm with an aridity index ranging from 0.05 to 0.653 in arid, semi-arid, or dry sub-humid areas (Kemal, 2004). Any tree planting established with natural rainfall and without the help of artificial irrigation may be termed dry afforestation (Siddique *et al*., 1993). Almost 70% of the total area of Pakistan falls in arid and semi-arid areas, as the northeastern

part of Punjab receives annual precipitation of 800 mm while the southwest part of Balochistan receives less than 80 mm of rainfall. About 75% and 85% of KPK and Punjab respectively while, the whole of Sindh and Baluchistan fall in the dry zone (Shah, 2006). A Desert is an area with moisture deficiency and sparse or absent vegetation in temperate, subtropical, and tropical zones (Stringer *et al*., 2007). Desertifcation, on the other hand, is land degradation in arid, semi-arid, and dry sub-humid areas caused by adverse anthropogenic impacts (UNEP, 1990).

The most limiting factor is water scarcity in dry areas for natural resource development for sustainable livelihoods (Kemal, 2004). Timber and fuelwood production as well as forage, crop and fodder production are the main natural resource development to meet the desires and needs of the local inhabitants. The utilization and consumption of these natural resources lack proper planning and scientific management (Prell *et al*., 2009). Therefore, to enhance these natural resources, rainwater has to be harvested and conserved to produce fodder for livestock and food for humans. Water harvesting technology is cost-effective, as shown by the benefit-cost ratio (Dallman *et al*., 2021).

In the rain-fed dry zone, the productivity of crops is not optimal due to subsistence farming practices. By using rainwater harvesting techniques, the potential of dry areas can be improved (Baig *et al*., 2013). Natural forests and rangelands play an important role in the livelihood of the local communities. Afforestation and reforestation by manual methods of watering, such as hand and tanker, are not feasible given the economic perspective. Due to all of these limitations, reforestation in dry areas is one of the challenging issues in meeting conservation needs as well as sustainable development (Shah, 2006).

In the early 1980s, the Pakistan Forest Institute in Peshawar initiated various research experiments across the country to explore different water harvesting techniques for afforestation in arid and semi-arid areas. The findings of these experiments demonstrated that commercial plantations can be established using water harvesting techniques suit the site and planting tree species in the subtropical broad-leave evergreen and tropical thorn forest zones. Water harvesting technology proved to be the most effective, practical, and cost-efficient technique for planting in Pakistan's arid and semi-arid zones (Sheikh *et al*., 1982).

Table 1: *Land use statistics 2018-19 of Khyber Pakhtunkhwa (area in Hectares).*

S. No	Category	Area	Percentage
1	Cultivated area	1,872,695	22.414%
2	Forest area	1239014	14.829%
3	Non-available for cultivation	3924986	46.977%
4	Cultivable waste	1318462	15.780%

Source: *(Bukhari et al., 2012)*

Background of dryland afforestation in Pakistan

88% of the total area (87.88 million hectares) of Pakistan falls in the arid to semi-arid range. Among the total area, arid, semi-arid, subhumid, and mixed areas are 51.5%, 36.9%, 5.4% and 6.2%, respectively. The solely arid area is 41 million hectares, including about 11 million hectares of hyper-arid climates (PCRWR, 1999). Pakistan is one of the most arid countries with, rainfall of less than 240 mm annually (Farooq *et al*., 2008). The country's population, about 62% resides in rural areas that are directly or indirectly dependent on agriculture for their livelihoods (GoP, 2009).

Land covered by vegetation for more than 10 years is the forest cover (Bodart *et al*., 2013). During the last few decades, human activities have greatly affacted the vegetation cover of the earth (Fang *et al*., 2018). In different parts of the country, productive forestry is sometimes practiced in irrigated plantations and riverine forests. However, government-owned forests can only meet a small portion of the timber and fuel wood demand. Most of the timber demand (35%) and nearly all the fuel wood demand (99%) are fulfilled by private farmlands (Shah, 2006).

In order to meet the demand for fuel wood, and timber in the country, there has been a significant focus on promoting farm forestry. Farm forestry is most viable in irrigated areas where a double cropping system allows continuous cultivation throughout the year. However, the potential for farm forestry is limited in rain-fed agricultural areas in semi-arid or arid regions, where only one crop is grown and a fallow period occurs. This is because, during the fallow period in rain-fed areas, unrestricted livestock grazing poses challenges to protecting seedlings (Shah, 2006).

Table 2: *Growth performance of multipurpose tree species under various water harvesting techniques in 1993.*

Techniques	Surface planting			Pit planting			Trench planting			Roaded catchment and trench planting			Roaded catchment planting		
Specie	Survival	Dia (cm)	Height (m)	Survival	Dia (cm)	Height (m)	Survival	Dia (cm)	Height (m)	Survival	Dia (cm)	Height (m)	Survival	Dia (cm)	Height (m)
Acacia albida	8	4.5	2.2	10	8.1	3.3	14	9.4	5.2	13	9.8	4.9	14	10.8	5.3
Acacia aneua	5	3.9	4.2	6	3.8	3.8	8	2.9	3.8	4	2.9	4.4	7	2.6	3.5
Acacia tortils	10	4.5	5.4	7	11	5.7	12	12.2	5.7	8	11.7	5.8	12	12.2	6.1
Acacia modesa	12	3.9	3	16	4.3	3.5	14	4.9	3.7	12	4.4	3.4	16	5.1	3.8
Acacia victora	10	5.5	3.5	10	7.1	4.3	5	4.6	4	2	5.1	5.1	5	6.9	4.2
Prosopis cinerara	11	5.3	3	12	5.3	3.6	12	5.9	3.6	11	5.9	3	12	8.5	4.6
Tecoma unduala	14	5.6	3.3	15	6.4	3.2	13	5.5	3.3	15	6.1	3.5	16	5.1	3.1
Parkinsona	4	3.3	3.4	1	3.3	3.9	2	3.6	3.9	7	3.2	3.3	7	2.8	2.9
Ave Survived plants	9	5.2	3.5	9	6.2	3.9	10	6.3	4.2	9	6.2	4.2	11	6.8	4.2

Source: *(Saddiqui et al., 1993).*

A choice is to utilize the dry zone regions to produce timber, fuel wood, and fodder. As mentioned earlier, due to limited rainfall, only irrigated plantations were deemed financially viable. However, the focus on food production has rendered the establishment of new irrigated plantations impossible. Even the existing irrigated plantations are being questioned, as using irrigation water and valuable land for forest trees is not feasible. The only possibility lies in promoting dry land forestry through the implemention of dry land plantation techniques (Shah, 2006).

Over the past two decades, efforts have been made to expand forest coverage in the dry zone to fulfill the demand for fuel wood, timber, and fodder. Extensive research and development activities have led to the development of water harvesting techniques for planting in arid regions. Furthermore, suitable tree and shrub species have been identified and tested for planting in various ecological zones. Selection of appropriate techniques and native species for the establishment of fuelwood plantations in the subtropical thorn forest and dry temperate zones to provide timber, fuelwood, and fodder.

Pakistan forest institute (PFI) research findings regarding dry land afforestation

In early 1980, the Pakistan Forest Institute Peshawar began a research project for dry land afforestation throughout the country. In light of the research experiments, water harvesting is recommended as the most cost-effective and practicable method for reforestation in the arid and semi-arid zones of Pakistan. A few research findings from the research experiments are given below:

During 1980, water harvesting techniques were compared with pit and surface planting to raise multipurpose tree species at Dagarkotli and Bhabarband. (1) Roaded catchment, one-meter slope (1:3) with a trench: 0.3 meter deep. (2) Roaded catchment, one-meter slope (1:3) without trench. (3) Trench 0.3 meters wide and 0.3 meters deep. (4) Pits 0.3 meters deep with a 0.3-meter diameter. (5) Surface planting (control). Four different tree species were planted in the experiment. Growth data, as shown in (Table 2) was collected in April 1993.

In 1984, 15 multipurpose tree species were planted using water harvesting techniques. The preliminary results recorded the survival and height of tree species (Table 3 and Figure 1).

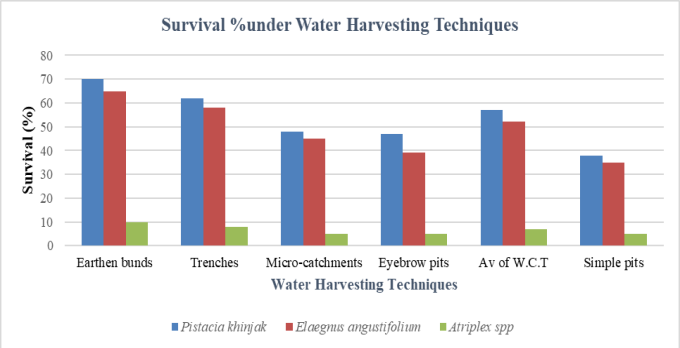

Figure 1: *Survival percentage of plants under various water harvesting techniques at Mianghundi, Quetta (survival of 60 plants).*
Source: Shah, 1992.

Table 3: Survival and height of multipurpose tree species at Bhabarbund, Sindh, in 1984.

S. No		Deep planting (30 cm)		Shallow planting (18cm)	
		Survival %	Height (cm)	Survival %	Height (cm)
1	*Acacia aneura*	30	102	30	79
2	*Acacia tortilis*	66	298	45	290
3	*Tecoma undulata*	60	156	35	104
4	*Acacia modesta*	47	45	43	52

Source: *(Sheikh et al., 1984)*

In August 1992, an experimental investigation was initiated at Ratta Kulachi in D.I. Khan to explore the potential for afforestation of *Acacia nilotica* in loamy-clay soil in rain-fed conditions. The study utilized a randomized complete block (RCB) layout and four different intervention methods. Each method involved planting twenty tube seedlings that were one year old. The four methods tested were catchment areas with basic holes, catchment areas with soil enhancements, isolated planting basins, and conventional dug pits, as shown in Table 4.

Table 4: *Effect of water harvesting and soil amelioration on survival, height, and diameter of Acacia nilotica at D.I. Khan.*

S. No	Treatment	Survival %	Diameter (cm)	Height (m)
1	Roaded catchment and soil amelioration	86	4.6	2.17
2	Roaded catchment	95	4.7	2.2
3	Individual Basin	97	4.9	2.32
4	Pits	81	2.5	1.41

Sheikh (1988) different plots were established in Kharian, employing a split-plot experimental design and featuring three repeated measures. Each plot contained twenty specimens of various multi-use tree species. Four water conservation strategies were assessed: V-shaped micro-catchments, gradonii systems, conservation furrows, and traditional pit-based planting methods. Metrics on tree survival rates and growth heights were documented in 1991, as summarized in Table 5.

In 1982, a research study was conducted at Rakh Dagar Kotli Bakhar to assess the efficiency of different treatments of the catchment plots to induce maximum runoff. A total of 30 catchment plots were prepared and treated with (i) coal tar cover, (ii) cement and sand, (iii) lime concretion, (iv) soil plus wheat straw, (v) mechanical stabilization, (vi) sodium carbonate spray, (vii) natural grass cover (viii) polythene sheet cover. The most effective and economical treatment for rainwater harvesting was plastermud (Soil + wheat straw), which induced an average maximum runoff of 11.03 m^3/catchment sample plot, receiving 78.14% of the total rainfall. While cement plaster, coal tar cover, lime concretion, mechanical stabilization and natural grass cover were found ineffective (Sheikh *et al.*, 1982).

In 1987, a distinct study was undertaken in Hangu, located in the Kohat district of KPK. The primary goal was to evaluate the effectiveness of three specific water harvesting and conservation methods: V-shaped micro-catchments, contour trenches designed for conservation, and ditches tailored for hillside terrains. These methods were tested in conjunction with planting four tree species: *Acacia modesta*, *Acacia nilotica*, *Eucalyptus camaldulensis*, and *Leucaena leucocephala*. The detailed outcomes of the study can be found in Table 6, as documented by (Shah, 1987).

Table 5: *Survival and height of plants under various water harvesting techniques at Kharian in 1991.*

S. No		Species							
	Water conservation techniques	Eucalyptus camaldulensis		Leucaena leucocephala		Acacia nilotica		Acacia modesta	
		Survival %	Ht (cm)	Survival %	Ht (cm)	Survival %	Ht (cm)	Survival %	Ht (cm)
1	Conservation trenches	72	206	65	172	45	108	36	48
2	Micro catchments	55	169	65	168	40	132	39	59
3	Gradonii	38	177	62	189	48	135	40	49
4	Simple pits	25	59	59	122	23	60	26	46

Table 6: *Testing of water harvesting techniques at Hangu (Kohat).*

Water harvesting techniques	Tree species	Results % (Survival & Growth)
V-shaped micro-catchments	Acacia modesta, Acacia nilotica, Eucalyptus camaldulensis Leucaena leucocephala	Techniques with 80-100% survival and good growth.
Conservation contour trenches		
Hillside ditches		

Source: Shah, 1987.

Table 7: *Results of different water harvesting techniques at Quetta and Loralae.*

S. No	Water harvesting techniques	Tree species	Results % (Survival)
1	V-shaped micro-catchments	Pistacea khinjuk, Fraxinus xanthxyloids, Prunus eburnean, Prosopis juliflora	All the four species gave 50-65% survival with water harvesting techniques, while there was no survival in case of planting in the simple plant pits.
2	Conservation contour trenches		
3	Hillside ditches		
4	Simple plant pits		0% Survival

Source: Shah, 1987.

However, in 1987 three indigenous species *Pistacea khinjuk, Fraxinus xanthxyloids, Prunus eburnean* and one exotic tree species *Prosopis juliflora* were planted in V-shaped micro-catchments, conservation contour trenches, and hillside ditches. An experiment was laid out in Quetta and Loralae to investigate water harvesting techniques. The results of the research study are shown in Table 7.

According to Shah (1991), a study was conducted in Loralai, Baluchistan, to assess management systems suitable for the dry zone area. Five catchments were chosen and treated with different water conservation techniques. Three plant species were planted: *Acacia modesta, Tecoma undulate,* and *Eucalyptus camaldulensis*. The results of the study are shown in Table 8.

Table 8: *Suitability of different management systems for dry zone area (Loralae Baluchistan) (1990).*

S. No	Water harvesting techniques	Tree species	Survival Percentage
1	Contour trenches	*Acacia modesta, Tecoma undulate Eucalyptus camaldulensis*	82%
2	Simple conventional pits		
3	Hillside ditches		78%

Similarly, another study was conducted in Vehar District Loralae, to determine the effect of water spreading on the establishment of trees. Two catchments were selected and treated with and without water spreading. The plant species *Leucaena leucocephala* was planted in both catchments. The results of the study are shown in the Table 11 88% and 78% survival of seedlings in plots with and without water spreading (Table 9) (Shah, 1991).

Table 9: *Effect of water spreading on the establishment of trees at Loralae Baluchistan.*

S. No	Treatment	Tree species	Survival percentage
1	Water spreading	*Leucaena leucocephala*	88%
2	Without water spreading		78%

Source: *(Shah, 1991).*

Shah (1992) carried out a study to develop an agroforestry system using water harvesting techniques in a semi-arid zone at Kharian. 2 slope lengths of 4m and 5m and 3 slope gradients of 7%, 10% and 15% of roaded catchments were tested to determine the optimum slope length and gradient. The results of the study are shown in Table 10.

Table 10: *Effective slope length vs slope gradient by using water harvesting techniques in semi-arid zone (Kharian).*

S. No.	Slope length	Slope gradient	Result
1	4 m	7%, 10% and 15%	A 4-meter slope length with 7% gradient is more effective in increasing the runoff and is economical to construct.
2	5 m		

During 2018, a similar study was carried out to evaluate the effect of different water conservation techniques on the growth and height of different tree species in the Karak and Mianghundi (Quetta) and Mastung districts of Baluchistan. Data on the survival and height of all species was recorded and analyzed (Tables 11 and 12), according to (Siraj and Baloch, 2018).

Table 11: *Survival percentage of plants under different water conservation techniques (WCT) at Mastung (survival of 60 Plants).*

S. No	Water conservation techniques	*Tamarix gallica*		*Calligonum* spp.		*Saccharum* spp.		*Arundo donax*		Average %
		Survival %		Survival %		Survival %		Survival %		
		No	%	No	%	No	%	No	%	
1	Trenches	49	82	39	65	38	63	43	72	70.5
2	Simple pits	35	58	34	57	35	58	36	60	58.0
3	Surface planting	25	42	17	28	23	38	23	38	36.5
	Average	42	70	37	61	37	61	40	66	64.5

Source: *Siraj and Baloch, 2018.*

Table 12: *Average height data of Atriplex canescens under different water conservation techniques (m).*

S. No	Water harvesting technique	Height (m)					Total	Average
		Plant 1	Plant 2	Plant 3	Plant 4	Plant 5		
1	Earthen Bunds	1.46	1.41	1.38	1.42	1.39	7.06	1.41
2	Trenches	1.38	1.35	1.36	1.32	1.34	6.75	1.35
3	Micro-catchment	1.36	1.34	1.35	1.33	1.35	6.73	1.34
4	Eyebrow pits	1.34	1.36	1.33	1.35	1.34	6.72	1.34
5	Av. of W.C.T.	1.38	1.36	1.35	1.35	1.35	6.81	1.36
6	Simple pits	1.28	1.26	1.25	1.29	1.27	6.35	1.27

Source: *(Siraj and Baloch, 2018).*

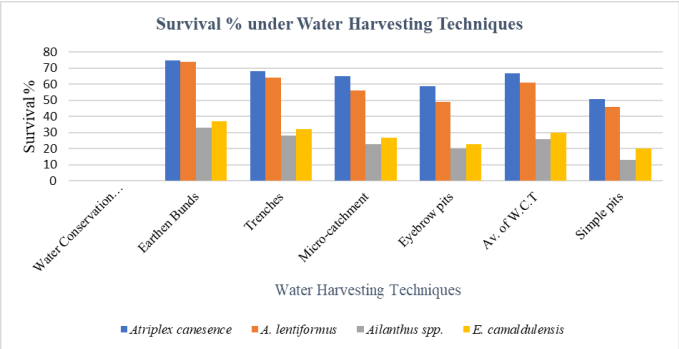

Figure 2: *Survival percentage of plants under various water conservation techniques (WCT) at Karak valley Quetta. (survival out of 60 plants).*
Source: *(Siraj and Baloch, 2018).*

Conclusions and Recomendations

Research findings revealed that boat-shaped sowing pits are effective for sowing indigenous tree species on steep slopes. At the same time, conservation contour trenches are suitable for moderate slopes to trap runoff and conserve water for planting. Similarly, V-shaped micro-catchments are effective and economical techniques for collecting rainwater and concentrating it for planting. Eyebrow plant pits proved helpful in trapping runoff and facilitating grass cover and tree planting, while hillside ditches proved suitable for water storage and tree planting in hilly areas.

Research findings also revealed that saucer-shaped plant pits are effective for runoff collection and plant growth in plain areas. Similarly, individual basins square or rectangular basins with ridges have also proved satisfactory for runoff collection and planting. Roaded catchments are also advisable for rainwater harvesting and successful plantations in plain areas.

Likewise, conservation benches for range improvement in hilly areas proved satisfactory in runoff production for grass sowing. The contour trenches with a length of 3m length and a width of 0.3m and depth are effective for sowing good quality grass on a small scale in hilly areas. Hillside ditches are suitable for developing silvo pastoral systems at a nominal cost for producing forage and fodder for the livestock.

Comparably roaded catchments are a suitable technique for grass sowing in plain areas. Roaded catchments also proved effective for planting fodder trees in the same areas. Water spreading proved a more useful technique for fodder trees and perennial grasses than crops because the deep-rooted trees, bushes, and grasses can extract the moisture in the deeper layers.

By adopting these techniques, Pakistan can enhance water resource availability, improve tree survival rates,

and promote sustainable land use practices. To fully realize the benefits of water harvesting, it is essential to integrate these techniques into policy frameworks, provide necessary support and training, and foster collaboration among stakeholders. Implementing these recommendations will contribute to sustainable land management, water conservation, and improved livelihoods in arid and semi-arid areas of Pakistan.

It is therefore recommended to promote the adoption of suitable water harvesting techniques for dry land forestry and range improvement in different geographical areas based on these research findings.

Novelty Statement

The paper reviewed past dry afforesation tecniques which will contribute to enhance forest cover and dry land management as well.

Author's Contribution

Qazi Bilal Ahmed: Wrote the manuscript and reviewed.
Nowsherwan Zarif: Investigation
Anwar Ali: Conceptualization
Faizan Ahmed: Resources Software
Asim Karim: Visualization
Ali Nawaz: Edited and corrected manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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