INDIGENOUS WATER HARVESTING SYSTEMS IN PAKISTAN

MOUNTAIN IRRIGATION SYSTEMS
- **Snowmelt Irrigation in Northern Areas**
- **Streamflow Irrigation in Wet Mountains**

RUNOFF FARMING SYSTEMS
- ***Barani* Tract in NWFP and Punjab**
- ***Abraize* in Punjab**
- ***Khuskhaba* in Balochistan**

TORRENT-SPATE-IRRIGATION SYSTEMS
- ***Rod-Kohi* in NWFP, Punjab and Sindh**
- ***Sailaba* in Balochistan**

PERENNIAL-SPATE-IRRIGATION SYSTEMS
- ***Kalapani* in NWFP and Punjab**
- **Minor Irrigation Schemes in Balochistan**

RIVERFLOOD-SPATE-IRRIGATION SYSTEMS
- ***Kachi* Tract in NWFP and Punjab**
- ***Sailab* and *Gharkab* Tracts in Punjab**
- ***Kacha* Tract in Sindh**

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1. Introduction

1.1. Description and Classification of Water Harvesting Systems

Indigenous water harvesting systems of Pakistan differ significantly from modern irrigation systems, where flows of indigenous systems fluctuate widely in space and time. Prediction of flows is difficult as floodwater is coming from large catchments. Landholders are at the mercy of extreme events of floods and droughts. Indigenous water harvesting systems commonly found in Pakistan can be characterised in the following five major categories:

- Mountain irrigation system is based on snowmelt or streamflow or springwater, which is diverted along the mountain slopes through channels to foothills. Snowmelt systems are located in Northern Areas, whereas streamflow or springflow systems are located in wet mountains of NWFP.
- Runoff farming system is based on incident rainfall and supplemented by surface runoff, which is harvested from adjacent hillsides and run-on in the fields. This system is named as *Abraize* in Punjab and *Khuskhaba* in Balochistan. These systems are more sustainable compared to *Barani* farming.
- Torrent-spate-irrigation system is based on floodwater. This is named as *Rod-Kohi* in NWFP, Punjab and Sindh provinces and *Sailaba* in Balochistan. *Daman* area in D.I.Khan, *Pachad* in D.G.Khan, *Sailaba* in Loralai, Barkhan and Musa Khel are few examples of plains where floodwater farming is practised.
- Perennial-spate-irrigation system is based on surface or subsurface flows and located within the torrent-spate-irrigation tract. This is named as *Kalapani* in NWFP and Punjab province.
- Riverflood-spate-irrigation system is based on river floodwater peaks. This system is named as *Sailaba* in the Riverine areas, where recession agriculture is practised. *Kachi* tract in NWFP and Punjab province and *Kacha tract* in Sindh province are good examples.

Mountain irrigation systems are reliable than any other water harvesting systems, whereas reliability in spate irrigation systems is higher than *Barani* and *Khuskhaba* systems. These systems differ widely. The main parameters are hydrological (catchments characteristics, rainfall pattern), geographical (location and level), hydraulic (type of diversion and size of command area) and sociological (land tenure, social structure and degree of public intervention).

1.2. Historical Perspective of Water Harvesting Systems

There is evidence that indigenous water harvesting systems have been practised in Pakistan since 3000 BC (Dennell, 1982; Jarrige, 1985; Meadow, 1991). In the beginning, only the narrow

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strips of land along banks were irrigated. With the passage of time, irrigation was extended to nearby areas by breaching the banks or natural levies of rivers to bring water to the low-lying areas. This was done only during high flood periods.

First evidence of perennial irrigation on any of the Indus system rivers dates back to early 17th century. When 80 km long canal was constructed by the Mughal Emperor Jahangir (reigned 1605-27) to bring water from right-bank of Ravi to pleasure gardens near Lahore. Irrigation system, which exists today, was started in 19th century under the British administration. In the early 19th century, there were numerous inundation canals leading from River Indus and its tributaries. These were remodelled and fitted with permanent headwork and new canals with weir controlled supply were constructed during the middle of the 19th century.

Historic development of canal system illustrates that mountain and spate irrigation systems were the most important agricultural system until the end of the 18th century. Systematic canal development in Indus basin shifted focus from mountain and spate irrigation, when large number of inhabitants were settled in canal commands to earn better and sustained livelihood.

In the early 20th century, the British administration appointed first administrator in district of spate irrigation D.I.Khan, after completion of land settlement and establishment of water rights. Similar activities were undertaken in D.G.Khan and Zoab. Management of these systems was improved after fixing operational procedures, which were printed and named as *'Kulliat-a-Rod-Kohi'*. These procedures were followed strictly until late 60s of the 20th century. Participatory actions were much more common during the tribal system, which was abolished during mid 70s. Later interference of large and politically influenced water users has resulted in increased number of diversion structures and violation of water rights. Co-ordination among water users was also less effective compared to the tribal system.

1.3. Farming System

In perennial (mountain irrigation and *'Kalapani'*) systems, high value crops including fruits and vegetables are grown in addition to food grains. In the torrent-spate-irrigation, wheat, gram, rape and mustard are grown in *Rabi* season. Whereas in *Kharif* season, farmers try to have dual purpose mix cropping system i.e. sorghum mixed with mashbeans and mungbeans to have both grain and fodder. Yields are normally low but some of the progressive farmers are getting more than 3 tons of wheat without any fertilisation in a wet year, due to deposition of fertile sediments with irrigation. Fodder is a priority in these areas because they contribute significantly towards livestock production.

Watersheds and rangelands constitute about 65 to 70 percent of the country's area (Ashraf 1987). These areas are in depleted condition and far below their productive potential. This is because of continued misuse through deforestation, unchecked grazing and lack of appropriate management of steep slopes for cultivation. Watersheds have been severely damaged with the result that agricultural productivity has been considerably decreased.

1.4. Institutional Change

In the local water resource management of the indigenous water harvesting systems, the public-sector is considered as an external player. Indigenous systems are being managed completely by

3

the local water users' institutions. Therefore, for any change, there is a need to have clear focus on resource users' institutions itself and see what factors influence change, stagnation or sustainability. Furthermore, it is also useful to define role of public-sector in setting more transparent conditions for change, stagnation or collapse.

Transaction costs are the cost of arranging, monitoring and enforcing contracts. In local water resource management these are often social contracts, regulating access and usage of the resource within group of resource users. This is referred to first order transaction costs related to management of the indigenous systems in traditional framework. The second order transactions costs deal with institutional or technological change.

Second order transaction costs are generally high in comparison to first order transaction costs. Institutional change requires learning rather than information collection, and bargaining rather than contract preparation. Moreover, institutional change is not repetitive, but incidental. Its outcome is uncertain and the behaviour of various actors can not be predicted. Whereas at the level of institutional management interests are often defined by the institutions and a status quo exists, in institutional change interests are open. They may differ and conflict and complicated negotiation is necessary. The costliness of institutional change explains why some changes – although they could improve resource utilisation – do not take place at all. There are several examples of institutional stagnation in local water resource management in Pakistan that can be attributed to high second order transactions costs. The failures of groundwater management regimes in most valleys of Balochistan, the inability to reach agreement on water rights in new agency-developed systems, and the lack of adjustment in water delivery schedules in perennial-spate-irrigation systems are the few examples (Steenbergen, 1997).

1.5. Future Prospects

Importance of agricultural sector in economy of Pakistan results from the fact that it accounts for 25 % of the gross domestic product and provides job opportunities to 55 % of the labour force. It also accounts for 80% of the total export earnings. Within the agricultural sector, irrigation plays a predominant role in industrialisation process of Pakistan with production of cash crops (cotton, sugarcane, citrus, mango) and dairy cattle.

With a population estimated at more than 132 million inhabitants today that is likely to reach 171 million by the year 2010, the demand for food products is expected to continue to grow. Thus, unless there are significant improvements in agricultural productivity and total production, imbalance between supply and demand of basic agricultural goods is expected to increase in future, and to threaten self-reliance objective of Pakistan.

Country's food imports are currently around US$ 2.0 billion. Government is now seriously thinking to accord priority to spate irrigation for both torrent and riverflood systems, to launch a concerted effort for production of wheat and oilseeds in these marginal ecologies for attaining self-reliance in food security. Poorest-of-the-poor live in these ecologies and thus demand high priority in initiating poverty alleviation programmes. Furthermore, it is not economical to grow wheat and oilseeds under tubewell irrigation, and these crops have to compete for water in the Indus basin with other cash crops like cotton, sugarcane, fruits and vegetables.

4

2. Background of the Country

2.1. Physiography

Country's geographical area is 88.2 million hectares (ha) including Northern Areas. It shows a great diversity of bio-climates, vegetation types and fauna. Major habitats consist of: a) flood and arid plains, sand and piedmont deserts and a variety of forests; b) grassy tundra and cold deserts; and c) lakes, rivers, swamps, and coastal marine habitats (GOP and IUCN, 1991; GOP, 1992). Country can be divided broadly into three major regions and plateau:

- High northern mountains; with 50 peaks of over 6,700 m at confluence of three world's highest mountain ranges – Himalayas, Karakoram, and Hindu Kush. These mountains occupy area in a wedge bordered by imaginary lines running due west and due north of Islamabad.
- Indus plain; drainage basin of River Indus and its tributaries – Kabul, Swat, Haro, and Soan in the west, and Jhelum, Chenab, Ravi, and Sutlej in the east. Plain consists of fine alluvium deposits by the river system; it lies to the east of an imaginary line running roughly north-east to south-east from Islamabad to a point slightly west of Karachi.
- Lower and more arid western highlands, with highest peak of 3374 m, which lie to the west of same imaginary line.
- In addition, a relatively small area in Northwest of Indus plain comprises Pothwar plateau and Salt range, with elevations ranging between 450 to 600 m. The plateau has topography dissected badly by water and wind erosion.

2.2. Agro-ecological Regions

Country is divided in to 10 broad agro-ecological regions (Figure 1) considering physiography as basis for characterisation (PARC, 1980). Ecology and resources in these regions vary considerably. Main limitation for agriculture is water shortage because of arid climate. Development of agriculture is; therefore, dependent mainly on development of water resources which, in turn, is more capital intensive than any other development. Sedimentation in rivers and channels, erosion of soil, waterlogging and salinity, desertification and over-grazing are examples of leaky agricultural systems. This requires an ecological approach for agricultural development rather than a factory approach presently being followed.

Country's cultivable area is 24.6 million ha. Around 12 million ha are under forage and forests (GOP, 1998). This makes 36.6 million ha suitable for agriculture and forestry. Rest 43 million ha is not suitable for agriculture and forestry within existing framework except for rough grazing in certain places. Sustainable development of water in this area is one of the major limitations for expansion of agriculture and forestry.

Out of cultivable area of 24.6 million ha, 18 million ha are under irrigation from canals, tubewells, wells, springs, streams, etc. Rest 6.6 million ha is under *Barani* and indigenous water harvesting systems. Out of this, 2.0 million ha are under torrent-spate-irrigation system (Khan, 1987; PARC, 1995). In addition to this, there are around 1.25 million ha under riverflood-spate-irrigation in the country. This leaves around 3.35 million ha, which solely depend on rainwater and/or runoff.

Indigenous water harvesting systems are mostly located in Northern Dry Mountains, Wet Mountains, *Barani* tract, Sulaiman Piedmont, Western Dry Mountains and Dry Western Plateau (Figure 1). The water harvesting systems include mountain irrigation, runoff farming, torrent-spate-irrigation and perennial-spate-irrigation. The riverflood-spate-irrigation systems are located along the River Indus (Figure 2). These systems provide livelihood for a large number of ecologically and economically marginal people in Pakistan.

2.3. Agro-climatic Zones

Agro-climate was characterised based on seasonal aridity index. Maps of seasonal aridity classes of *Kharif* and *Rabi* seasons were superimposed to prepare one map representing the seasonal aridity for both the seasons. Eighteen aridity zones were identified based on both *Kharif* and *Rabi* seasons (Figure 3 and Annex. I).

Humid and sub-humid *Kharif* zones have 3 and 5 *Rabi* zones, respectively, to illustrate the variability in *Rabi* season. Variability in *Rabi* season for humid *Kharif* zone ranges from humid to semi-arid, whereas for sub-humid *Kharif zone* it ranges from humid to hyper-arid.

Semi-arid *Kharif* zone shows four combinations in *Rabi* season namely humid, semi-arid, arid and hyper-arid. For arid and hyper-arid *Kharif* zones, *Rabi* season is either arid or hyper-arid.

2.4. Rainfall

Mean annual rainfall varies from less than 100 mm in Sindh province to more than 1500 mm in foothills and northern mountains (Figure 4). About 60% of this rainfall is received during the monsoon period (July to September). Much of summer rains are not available for crop production because of rapid runoff due to torrential showers. On other occasions, rain may be so light that it evaporates before it can penetrate in the root zone. *Barani* areas are completely dependent on rainfall for agricultural production and 50-60% of annual rainfall is lost through surface runoff (Ahmad, 1993a).

There is extreme variability in rainfall both temporally and spatially in locations, where indigenous water harvesting systems are practised (Table 1). The maximum annual rainfall is four to five times the minimum rainfall. The variability also exists among *Rabi* and *Kharif* seasons. In most of the country except Balochistan province and Northern Areas, about 60% rainfall is received in *Kharif* season. Northern Areas and Balochistan receive winter rainfall, whereas summer rainfall is almost insignificant except in few areas (Ahmad, 1993a).

2.5. Surface Water

Glacier melt, snowmelt, rainfall and runoff constitute the river flows. Western rivers provide 170 billion m^3 of surface water in an average year. Bulk of the river flows is in *Kharif* season, which are around five times the flows in the *Rabi* season. The variability in flows of eastern rivers is even higher than western rivers. At the commissioning of Tarbela, eastern rivers at upper most barrages in Pakistan contributed about 7.9 billion m^3 of water to the Indus River System in an average year of which about 75% was in *Kharif* season.

Table 1. Rainfall probabilities of selected locations of indigenous water harvesting systems in Pakistan.

Station	Annual Rainfall (mm)				
	Rainfall Probability (%)				Average
	95	75	50	5	
Murree	1221	1501	1695	2170	1695
Abbotabad	-	937	1164	-	1200
Jhelum	697	861	989	1353	1002
D.I.Khan	114	178	234	418	246
D.G.Khan	-	86	135	-	151
Zoab	102	182	257	522	277
Barkhan	-	231	317	-	337
Quetta Cant.	116	174	225	385	234
Mastung	-	105	160	-	177
Kalat	72	124	174	346	187
Dalbandin	26	51	74	161	82
Panjgur	33	64	94	206	103
Bela	-	147	213	-	231

Variability in river flows is a major limitation in development of run-of-river type irrigated agriculture in the Indus Basin, to meet crop irrigation requirements during the low flow period of *Rabi* season and early and late *Kharif* season. In spite of construction of two major storage (Mangla and Tarbela), about 126 billion m^3 are currently diverted to the Indus basin in an average year, of which 63 % is in *Kharif* season (Ahmad, 1993a). Quality of surface water varies from 150 to 250 ppm in the Northern upper Indus plain compared to 250 to 350 ppm in the lower Indus plain (Ahmad, 1993b).

In highland, snowmelt, springwater and streamflow are diverted to provide irrigation in foothills and mountain valleys. Flow of these streams varies from 0.1 to 0.5 m^3/sec and covering a command area of 10 to 250 ha. These schemes are in thousands in the country.

Hill-torrents in western ranges contribute floodwater to a potential area of 2.0 million ha. At least, 50% of this area is watered in an average year. Exact amount of torrent water is not known but varies considerably as yearly fluctuations are high. However, the catchment area receives rainfall of around 80 billion m^3 in an average year.

Indus River and its tributaries during the peak flow season inundate the Riverine tract in the Monsoon season and after flood recedes recession agriculture is practised in this potential area of around 1.25 million ha.

2.6. Groundwater Resources

Indus basin represents an extensive groundwater aquifer covering a gross command area of 16.2 million ha. Before the development of canal irrigation system, water table was well below the surface and aquifer was in state of hydrological equilibrium. Recharge to aquifer from rivers and rainfall was balanced by outflow and crop evapotranspiration. When canal irrigation system was introduced, percolation to the aquifer was greatly increased in Indus basin resulting in twin menace of waterlogging and salinity (Ahmad, 1993a).

Investments in drainage have been significant in Pakistan during the last three decades under the Salinity Control and Reclamation Projects. Even then, high water table still affects large tracts of land, with more than 22% of the gross command area of the Indus basin having water table within 1.5 m from the surface (World Bank, 1994). Groundwater in around 60% area of the Indus basin is marginal to brackish in quality (WAPDA, 1979).

Although, there are disadvantages in having a high water table, it is, at present, being used for irrigation by about 484,000 tubewells in fresh groundwater areas of the country. The present groundwater contribution for irrigation is one-third of the total water available for agriculture (GOP, 1998; Zuberi and Sufi, 1992; NESPAK, 1991).

Groundwater aquifer in mountain valleys, *Barani* tract and torrent-spate-irrigation tract is limited. Deep groundwater is available in localised basins. Shallow seepage water is also available in areas closer to recharge sources and farmers do exploit this resource for supplemental irrigation or to raise high value crops. In the riverflood-spate-irrigation tract, shallow fresh groundwater is available due to seepage from river system. Farmers have installed shallow wells and tubewells in the Riverine tract.

3. Indigenous Water Harvesting Systems

3.1. Mountain Irrigation Systems

Indigenous perennial irrigation systems are of two types -- mountain and spate irrigation systems. Mountain irrigation systems are located in Northern Areas and NWFP. These depends on diversion of snowmelt, spring or stream water to grow crops, fruits and vegetables in valleys.

3.1.1. Era, Location and Extent of the Systems in Northern Areas

Northern Areas consist of Gilgit, Baltistan, Chitral and Dir. High mountains of Himalayan, Karakoram and Hindukush ranges are located in this region, which carried a large number of peaks of over 8000 m high. Tops of these mountains are covered with snow. Summer is mild and winter is cold. Soils are generally deep, clayey and are formed in colluvial material accumulated on lower parts of mountain slopes and in alluvial deposits in narrow valleys. Soils above 2100 m are characteristically non-calcareous and acidic, with pH 5.5-6.5, whereas these are calcareous at lower altitudes.

Most of the area is used for grazing and a part is under scrub forest. Deep soils of valleys and lower parts of the mountain slopes are used for cultivation of cereals, vegetables and fruits by diverting the snowmelt through contoured channels. Mountain water harvesting systems of this region are unique in the world. Each channel commands a scheme, which is maintained through active participation of water users. Interventions of the public-sector institutions are minimal.

Potential area under mountain irrigation schemes is around 0.125 million ha, out of which 50% is presently being irrigated by diverting the snowmelt.

8

3.1.2. Era, Location and Extent of the Systems in Wet Mountains

Topography of wet mountains is characterised by a series of ranges, which are intervened by wide and narrow plain valleys. Swat-Kohistan area in the north is highly mountainous and much of it has not been mapped geologically. Most of the area is comprised of steep mountain slopes covered with forests. Altitude ranges between 1000 and 5000 m. Swat valley, which in its lower reaches becomes wide, has thin deposits of alluvium range from coarse to medium grades.

Hazara-Kohistan is a mountainous country and known for its picturesque Kaghan valley, which is a narrow valley covered with forests. Inter-mountain areas of varying extent are generally filled with alluvium.

Extreme eastern part could be classified as humid, with mild summers and cold winters, without any pronounced dry season. Tops of the mountains are covered with snow during winter and spring seasons. Broadly, the western parts could best be described as sub-humid Mediterranean, with dry summer having rainfall confined to winter and spring seasons only.

Soils are formed in celluvium on lower parts of the mountain slopes, and in alluvium and loess materials in valleys. These range in texture from silt-loam to silty-clays and are either non-calcareous or slightly calcareous with pH ranging from 5.5 to 8.1.

Wheat and maize are grown under rainfed environment. Rice is grown in small areas, which are irrigated with water from springs and streams. Fruit orchards are grown in areas having altitude of more than 1500 m. Irrigation system is unique, where water is diverted from streams through contoured channels to irrigate small terraced fields.

3.1.3. Issues

Variability in allocation and availability of perennial water supplies has implications on area commanded by a scheme and cropping pattern, which is subject to wide fluctuations (spatial and temporal) due to lack of weir-controlled regulation. Interests of management of mountain irrigation are not uniform, because availability of irrigation water varies throughout command area primarily due to higher diversion and conveyance losses.

Water users at head and middle reaches grow high value crops due to relatively assured water supply. Whereas at the periphery of the command area crops that grown are normally of low value as there is higher risk of crop failure. Net benefits of mountain irrigation management are higher under any circumstance. In contrast to the non-perennial systems, for most of the users the returns are normally higher that they will not give up their entitlement. Technical, social, institutional and economic issues related to past and present use of mountain irrigation systems are:

Technical

- Mountain irrigation systems are reliable during spring and summer seasons. Discharge is reduced in winter due to reduced snowmelt; therefore, it is hard to predict the land that will be commanded during *Rabi* season.

- Risks in mountain irrigation are not equally distributed throughout the command area. There may be land with high, medium and low probability of irrigation based on location and level of the command area.
- Stability of water conveyance system due to heavy breaches and landslides is a major concern.
- Water losses are common due to ineffective and inefficient diversion and conveyance of water. This has caused inequity in distribution of allocated share of water to different water users. Tail-end water users are adversely affected.

Social and Institutional

- Water rights in mountain irrigation systems are not sharply defined. Water distribution is based on allocation rules rather than alienable property rights. Lack of improvements in water rights and water distribution rules is a major limitation to make these more responsive to have equitable distribution of water.
- Co-ordination among farmers is limited due to lack of appropriate organisation, which can ensure operation of the system in accordance with the established water rights and norms.
- Lack of public-sector institutional support to water users in provision of technical backstopping and to resolve conflicts was a major constraint in improving the system's operations. Co-ordination among various public-sector institutions is non-existent.

Economic

- In mountain irrigated areas, high value horticultural crops are grown. These systems are still dominated by cereals, fodder and oilseeds. Even if optimal conditions were to prevail, crop returns would have difficulty competing with alternative sources of income.
- Lack of capital with farmers and limited joint action is a constraint in adoption of high efficiency orchards farming and vegetable production. Limited access to market is another reason.
- Despite the marginal returns from mountain irrigation, there has been some public investment in these systems in the last three decades. Failure rate of schemes built by the public sector was high. The overriding factor behind the high rate of failures was the inappropriateness of the prevailing engineering concept. The technical designs for mountain irrigation systems resembled those for perennial flow systems, and did not accommodate the nature of the mountain ecology. Therefore, these systems have to be designed and constructed with active participation of water users.

3.1.4. Potential Use and Imperatives

Mountain irrigation systems of Northern Areas are relatively most structured compared to the wet mountains. These systems have to be protected to avoid damages caused by breaches and landslides.

There are opportunities for further development and improvements. Command area and watering intensity can be improved by reducing the outflow through diversion of additional water to the existing or new commands. Moreover, new water resources can be made available by reducing the existing losses within the conveyance network and thereby reducing the incidence of breaches and tail-water problems. Excess water can be stored in earthen reservoirs as silt is much less in the snowmelt compared to torrents water. Stored water can be used for carryover to subsequent months to ensure sustainability of high value horticulture.

Presently, cereals, fodder, vegetables and fruits are normally grown. There is a potential to grow high value horticultural crops. Farmers are also interested to grow multi-cut varieties of fodder, as livestock provide a source of livelihood. The imperatives for improving mountain irrigation systems are:

- Institutional changes are required in local management of mountain irrigation systems through changing net benefits of resource use and to ensure direct participation of water users through co-management. Direct participation of water users should be ensured at all levels to achieve financial sustainability.
- A paradigm shift is necessary for development and operation of the mountain irrigation systems different from canal irrigation. This requires improvements in water rights and allocation rules as water is at premium. Farmers are still trying, if possible, to extend their command area through clearing of un-commanded land having mutual agreement with the community. Thus, there is a potential to add more lands under command where additional water and land are available.
- Strengthening capacities of public-sector institutions should be given priority in provision of technical backstop support to water users.
- Ensure more reliable water supply by reducing risk of failure in conveyance network and by increasing deliveries to various commands. On-farm water management should be given high priority for diversion, distribution and application of water for high value crops, forestry and fodder.
- Introduction of micro-water development schemes should be encouraged for conjunctive use of water through exploitation of springwater and storage of excess surface water in small ponds for multiple water use (domestic, stockwater and irrigation).
- Use of improved seed and fertilisers helped farmers to increase productivity of their lands. Further, through land forming and development by removing stones, crop stand has been increased tremendously. Therefore, both extensification and intensification strategies are being adopted by the farmers. Development of reserves should be encouraged for high value fruit progeny gardens and forest nursery, forages, and multiplication of promising crop cultivars for transfer of production technology.

3.2. Runoff Farming Systems

3.2.1. Era, Location and Extent of the Systems in *Barani* Tract

Runoff farming systems go back as early as the period before the Christ and provided economic basis for some of the early Hindu civilisations. *Barani* tract covers Salt range, Pothwar plateau and Himalayan piedmont plain. Salt range separates Pothwar plateau from Indus plain. In the Pothwar plateau, a series of hills often rising 700 to 1000 m run in an east-west direction, forming a loop which bends in the centre towards Thal Doab. Pothwar plateau is generally open and undulating country developed mainly on sandstone and is mantled by loess deposits. A large area has developed severe gully erosion in the soft loess deposits, rendering the land mostly unfit for agriculture.

Tract could be best described by dividing it in to two regions. A small narrow belt lying along the foot of the mountain is nearly humid, with hot summer and cold winters and has only a short dry season in early summer. Southwestern part of the tract is semi-arid and hot.

Soils of eastern part are dominantly silt loams, silty-clay loams and clay loams with weak sub-angular blocky structure and good porosity. These soils occupy un-eroded or partly eroded parts of land. A large proportion of the area comprises gullied, bad and rock lands. Foothills and hillsides receive runoff from steep lands and thus add to water availability. These areas are receiving supplemental runoff over and above of the incident rainfall.

These areas are located in foothills, where runoff from adjacent slopes is received and stored in fields. These areas are located in *Barani* tracts of NWFP and Punjab. Wheat, oilseeds, maize, millets and sorghum are grown in this tract. Yields are normally higher than *Barani* tract.

There are around 3.35 million ha under *Barani* and runoff farming in the country. Out of this, only 0.35 million ha have potential for runoff farming in the *Barani* tract. However, there is a potential of around 0.40 million ha of additional command area, if water is made available.

3.2.2. Era, Location and Extent of the Systems in Highlands of D.G.Khan

Punjab's Runoff farming systems go back as early as the period before the Christ and provided economic basis for some of the early Hindu civilisations. Heavy rains in mountainous areas result in surface runoff, which run-on to the adjacent fields.

Runoff farming is not developed in a system's approach and is a function of individual efforts. However, there is potential to develop these systems. Smaller size of the command area is a comparative advantage as these are easy to manage. The exact area under this system is not known. However, potential areas are located in highlands of various torrents and mountainous watersheds.

3.2.3. Era, Location and Extent of the Systems in Balochistan

In Balochistan, Runoff farming system is named as *Khuskhaba* and it goes back as early as 3000 BC and provided economic basis for some of the early civilisations. These systems are located in highlands of Khurasan Range, on eastern slopes of Sulaiman Range and Central Brahui Range. These are characterised as temperate, where precipitation is gentle and spread over a longer period.

Streamflows are crucial in *Khuskhaba*, which rise primarily because of rainfall in adjacent mountains. The diversion of small runoff streams is spectacular, as flow in many cases last between a few hours and a day, and an entire season's supplemental water supplies may pass in a very short time span only.

Several indigenous techniques have been developed to divert small temporary flows. In general, their occurrence depends on local topography. Where, land gradient is relatively steep and streamflow is of shallow depth. Runoff flows at high speed, and is best diverted through free offtakes, from one field to another through gravity.

12

Most interesting indigenous *Khuskhaba* system is that prevailing in highland of Balochistan, where water users, under an organised action, streamline the runoff. Most of these systems are small and owned by an individual or by few farmers. Still, much water runs to waste due to lack of appropriate system development and management.

Potential area of *Khuskhaba* is around 0.20 million ha, which is commanded by runoff in an average year.

3.2.4. Issues

Variability of runoff supplies has direct implication on individual or groups of landholders that receive run-on to various fields. Interests of management of runoff farming are not uniform, because probability of run-on varies throughout the command area.

Crops that grown are of normally low value and risk of crop failure, particularly at periphery of the command area, is significant. Net benefits of runoff farming system are small under any circumstance. In contrast to the large perennial systems, for some of the users the returns to runoff farming may be so marginal that they will voluntarily give up their entitlement. Technical, social, institutional and economic issues related to past and present use of runoff farming system are:

Technical

- Because of the inherent uncertainty of runoff, it is hard to predict the land that will receive additional water as run-on during a particular storm or within a season.
- Risks in runoff and run-on system are not equally distributed throughout the system. There may be land with high, medium and low probability of run-on. Thus, there exists internal differentiation based on location and level of the command area.
- Erosion is common due to inherent erodible lands. Runoff farming is subject to process of active land formation, due to both scour and siltation. The impact of these processes differs between various systems. Farmers, however, are not passive actors in these scour and siltation processes, but often actively manipulate land formation.
- Inadequate and inappropriate diversion of runoff caused inequity in distribution of water to different fields. Loss of water is common due to inefficient spreading of runoff within the field.

Social and Institutional

- Water rights in runoff farming systems are reactive and are not sharply defined. They cope not only with the unknown proportions of the next runoff but also with the medium-term changes in the field morphology, due to scour, siltation and change of runoff course.
- Co-ordination among farmers is limited due to lack of appropriate organisation, which can ensure operation of large system in accordance with established water rights and norms.
- Out-migration is a common response to a period of dry years. In good years, the parameters are different and demand for labour will peak, in particular, during land

preparation and harvest. Again this gives rise to flexible markets for labour and in the recent years mechanical traction.
- Lack of public-sector institutional support to water users in technical backstopping and to resolve the conflicts was primarily due to low priority assigned to runoff farming. Furthermore, co-ordination among various public-sector institutions is non-existent.

Economic

- In runoff farming system, subsistence and low-value cash crops prevail. It is still dominated by drought resistant crops like sorghum, millet, pulses, wheat, gram, guar and oilseeds. Most of the land is under local cultivars. Even if optimal conditions were to prevail, crop returns would have difficulty competing with alternative sources of income.
- Due to the small scale of the system, there have been no investments by the public-sector. Investments in other systems by public-sector institutions tempted farmers to leave runoff farming in search of getting irrigated lands or access to irrigation facility.

3.2.5. Potential Use and Imperatives

Runoff farming (*Khuskhaba*) systems of Balochistan are most structured compared to Punjab and NWFP. However, there are many opportunities for further development and improvements.

Command area and run-on intensity of runoff farming system can be improved by reducing the outflow to the tail end through diversion of additional runoff to the existing or new fields. Excess water in wet season can be stored in earthen ponds for carryover to subsequent months to ensure sustainability of runoff farming.

Presently, wheat, oilseeds, sorghum, millets, pulses, guar and cumin are normally grown in these areas. Farmers are interested to grow multi-purpose varieties of fodder, as livestock provide a source of livelihood in years, when there are no crops due to droughts. There is a potential to focus this system to achieve self-sufficiency in wheat and edible oils. The imperatives for improving runoff-farming systems are:

- Within the framework of inherent uncertainty, at the most, probabilities can be established and the area that has a reasonable chance of being run-on in, for instance, a ten-year period may be determined. This area may even be defined formally as an entitled run-on area.
- A paradigm shift is necessary for development and operation of the runoff farming system different from *Barani* farming. This requires direct participation of water users' at all level to ensure economic sustainability.
- Ensure more reliable run-on by reducing the risk of failure in conveyance of runoff from one field to another. On-farm runoff-runon management should be given priority for integrated land use (crops, livestock, forestry, pastures and arid horticulture). This will ensure risk aversion due to droughts and floods, as the tail-water can be ponded in low-lying areas to grow forest plants and forages.
- Introduction of micro-water development schemes is needed for conjunctive use of water through exploitation of shallow groundwater and storage of excess surface water in small earthen ponds for multiple water use (domestic, stockwater, and irrigation).

14

➢ Development of reserves should be initiated for high value arid fruit progeny gardens and forest nursery, forages, and multiplication of promising crop cultivars for dissemination and transfer of production technology.

3.3. Torrent-Spate-Irrigation Systems

3.3.1. Era, Location and Extent of the Systems in D.I.Khan

In NWFP, torrent-spate-irrigation systems go back at least as early as 330 BC and provided economic basis for some of the early civilisations. Alexander the Great, according to *Arrians*, sailed down the river Jhelum to its junction with River Indus. His land forces marched in two bodies on either side of the river. They noticed some form of torrent agriculture although in a very poor state than present but exists in few locations of the Sulaiman piedmont (Figure 2). Heavy rains in the catchments, which extend up to Balochistan, Afghanistan, Sulaiman Range, Shirani Hills and Bhattani Range result in water rushing into various torrents in the foothill plains, named as *Daman* area, where torrent agriculture (*Rod-Kohi*) is practised.

Large and major torrents in D.I.Khan Division are named as *'Zams'*. Principal *Zams* include Tank, Gomal, Choudhwan, Daraban and Shaikh Haider. Takwara is the principal hill-torrent, which collects floodwater from Tank *Zam* and some other passes, and irrigates northern portion of the tract. Luni hill-torrent, which is the largest of all, and which, issuing from Gomal Pass, takes a southeasterly course, and fall into Indus some 24 kms below the town of D.I.Khan. Vihowa hill-torrent waters southern portion of *Daman,* around the towns of Dera Fateh Khan and Vihowa (Figure 5). Few of these streams have a clearly marked channel of their own for any distance from the hills. Owing to the irrigation system in force, waters of one are thrown into another, until channel form a complete network. Because of this, original name of a stream is, as a rule, very soon lost. Its waters get sub-divided and carried off in different channels, where they mix with those of other hill streams, and each of these channels gets a local name of its own. The nomenclature, therefore, becomes somewhat confusing. Hardly, a single stream is known by the same name for its whole course from hills to River Indus (PARC, 1990; GOP, 1884).

This system is mainly practised in D.I.Khan Division by five *Zams* and twenty nullahs. *Zams* are perennial streams in a limited context as they provide '*Kalapani'*, while nullahs receive water only during the flood season. Seasonal hill-torrents result from two-peaked rains of almost 125-mm each in spring and summer. Probability of torrents is also two-peaked, one from mid-February to mid-April and other from mid-July to late August. Summer torrents are the major ones (Khan, 1990).

These hill-torrents result from rains on Sulaiman Range in the west of Marwat Range on the north. The catchments of these ranges are without vegetation and steep slopes exist upstream and downstream of gorges from where torrents emerge. These hill torrents have steep gradients and high velocity. A large amount of sediment is picked up and deposited on flatter slopes. These hill torrents often change their course when in piedmont or flood plains and are thus likely to damage lands.

Each *Zam* and nullah commands a scheme. In total, there are 25 major schemes covering a potential command area of around 0.52 million ha, out of which around 0.26 million ha are normally commanded in an average year in D.I.Khan, Tank and Kulachi.

3.3.2. Era, Location and Extent of the Systems in D.G.Khan

In Punjab, torrent-spate-irrigation systems go back as early as the period before the Christ and provided economic basis for some of the early Hindu civilisations. At the time of the first Muhammadan invasion, Elphinstone says " the mountains of Mekran were inhabited by Balochis, and those of the Sulaiman by Afghans. With respect to the plain, if we may judge from present state of population, those between Sulaiman and Mekran Mountains and River Indus were occupied by Jats or Indians." The first appearance of the Mohammadans in India was in the year 44 of the Hijri (A.D. 664). These civilisations were dependent on spate irrigation for their livelihood (GOP, 1898).

Heavy rains in catchments of the west of Sulaiman Range result in water rushing into three large torrents. These torrents rising far to the west of the Sulaiman Range pierce through them from west to east through narrow and tremendous gorges. Most northerly, Vihowa, emerges from them into D.I.Khan but its floodwater reaches villages in the north of Sanghar. Sanghar emerges near the village of Mangrotha at the centre of the western boundary of Sanghar, and third, Kaha, near Harrand, which is similarly situated in Jampur. The details of other major torrents are given in Table 2.

Table 2. Major hill-torrents of spate-irrigation system in D.G.Khan.

Location	Name of Torrent
Sanghar	Bhati, Kanwan, Mahoi
D.G.Khan	Sori, Vador, Sakhi Sarwar, Mithawan
Jampur	Khasra, Chachar
Rajanpur	Chezgi, Pitok, Northern Shori, Southern Shori

With the exception of Vihowa, Sanghar and Kaha, one of the other torrents flows except when fed by rain in summer and autumn. They then come down in flood heavily laden with detritus washed from slopes of hills, which deposited year after year over space between base of hills and Indus has formed tract called '*Pachad'*, where torrent farming (*Rod-Kohi*) is practised.

Pachad is continuous from north to south of the district, and slopes vary gently from pebble-covered base of hills eastward to the river. From the method of its formation, it follows that soil is a rich loam, but rainfall outside hill tract is so small that cultivation is only possible with the aid of torrent-spate-irrigation. To catch water, embankments, sometimes of earth, sometimes of loose stone, are made in torrent bed, a little below the place where torrent issues from hills. Held up water is led by a system of distributary channels to fields. Each of which is surrounded by strong bunds, so as capable of taking a depth of 0.5-1.25 m of water, to thoroughly saturate and receive a good deposit of silt (GOP, 1898).

Each torrent commands a scheme. In total, there are more than 17 major torrents commanding torrent-spate-irrigation schemes and smaller nullahs covering a potential command area of around 0.41 million ha. Out of which around 0.20 million ha are normally commanded in an average year in D.G.Khan, Sanghar, Jampur and Rajanpur.

16

3.3.3. Era, Location and Extent of the Systems in Balochistan

In Balochistan, torrent-spate-irrigation systems go back as early as 3000 BC and provided economic basis for some of the early civilisations. These systems are located in both the highland and lowland ecologies.

In highland, these systems are located in Khurasan Range, on eastern slopes of Sulaiman Range and Central Brahui Range. Lowland systems are located in vast Kacchi plain, Las Bela and Kharan basin. The distinction between highland and lowland systems is not absolute. Lowland systems with smaller catchments and in the upper reaches of flood rivers on the plain, in particular share many characteristics of the highland systems. On the other hand, highland systems are located in more temperate climatic zones, where precipitation is gentle and spread over a longer period, conform in some respects to the description of the lowland systems (GOI, 1920).

Floods are crucial in torrent-spate-irrigation, which rise primarily because of rainfall in mountainous watersheds. Their diversion is spectacular, as floods in many cases last between a few hours and few days only, and an entire season's irrigation supplies may pass in a very short time span only.

Several indigenous engineering techniques have been developed to divert the temporary flow. In general, their occurrence depends on local topography. Where, land gradient is relatively steep and channel bed is shallow. Floodwater flows at high speed and is best diverted through free intakes. These intakes are generally higher than riverbed, and water starts to flow in channels, as soon as flood has reached a certain level. Where gradient is less steep, a second type of diversion is found. It consists of deflectors, made of brushwood and stones, to guide water to the off-take channels. A third type of diversion structure is found on alluvial plains of lowlands, which are created at tail of the flood rivers. Slopes are flat and water flows slowly. These conditions allow construction of barrages, make up of fine material of riverbed on the plains, called Ghanda in Balochistan and Ghandi in D.I.Khan. The barrages block flow completely and pond-up water which then flows into a number of flood channels, upstream of the diversion structure (GOI, 1920).

Most interesting system of indigenous spate-irrigation is that prevailing in Kacchi plains, where water users, under an organised action, construct annually immense earthen dams in the Nari River for raising water to the surface. An expert water user, known as '*Raza',* is selected to superintend the work, and water users' living for many kilometres along bank of the river are called in with their bullocks to construct the dam. Some of these dams are over 300-m long, 60 m wide at bottom, and 20 m in height. Every village has to supply its quota of men and bullocks/tractors, or, should it fail to do so, has to pay a proportionate amount in cash. There are many of these dams in the Nari river, and in July and August, when the flood come, the upper dams are broken as soon as sufficient water for the area irrigable by each has been received. Still, much water runs to waste due to lack of appropriate system development and management.

Potential area of torrent-spate-irrigation is around 1.07 million ha. Out of which, around 0.20 million ha are commanded in an average year.

17

3.3.4. Issues

Variability of flood supplies has a number of implications. One implication is that area cultivated is subject to wide fluctuation. The consequence is that the groups of landholders that receive irrigation supplies differ from year to year. The interests of management of spate irrigation are not uniform, because probability of irrigation varies throughout command area. Because of these different probabilities of irrigation, not only will the interest in spate irrigation vary between different parts of the command area, but the economic capability of landholders in different parts of the command area will vary too (Steenbergen, 1997).

Another implication is that agricultural production follows limits of what is productive and what is not productive. Crops that grown are of normally low value and risk of crop failure, particularly at periphery of the command area, is significant. Net benefits of spate water management are small under any circumstance. In contrast to the large perennial systems, for some of the users the returns to spate irrigation may be so marginal that they will voluntarily give up their entitlement. Bargaining of accessed rights will be relatively relaxed (Steenbergen, 1997). Technical, social, institutional and economic issues related to past and present use of torrent-spate-irrigation system are:

Technical

- Because of the inherent uncertainty of torrent-spate-irrigation, it is hard to predict the land that will be irrigated. Furthermore, it is also not possible to predict how much land will be irrigated during a particular storm or within a season.
- Risks in torrent-spate-irrigation are high, but they are not equally distributed throughout the system. Within a command area, there may be land with high, medium and low probability of irrigation. Thus, there exists internal differentiation based on location and level of the command area.
- Gully formation is common due to inherent erodible lands, and silting of nullahs leading to flood hazards. Spate-irrigation schemes are subject to process of active land formation, due to both scour and siltation. The impact of these processes differs between the various systems. One variable is the amount and composition of the sediment load that a river carries which depends on rainfall pattern and characteristics of catchment area; its geology, morphology, and vegetation cover. Farmers, however, are not passive actors in these scour and siltation processes, but often actively manipulate land formation. However, in the public-sector initiatives these processes were not understood clearly and resulted into hydrological imbalance.
- Inadequate and inappropriate diversion of floodwater caused inequity in distribution of sanctioned capacity or share of water to different nullahs. Loss of water is common due to inefficient conveyance, distribution and spreading of water within the system. The tail-end water users are affected in both the extremes of flood and drought.

Social and Institutional

- Co-ordination among farmers is limited due to lack of appropriate organisation, which can ensure operation of the system in accordance with the established water rights and norms. Furthermore, deterioration of the system due to influence of large water users and notables, and lack of discipline enforced by the Provincial Irrigation and Drainage

Authorities has reached to a level, where system could not be operated in accordance with established water rights as per *'Kulliat-a-Rod-Kohi'* in NWFP and Punjab.

- Water rights in torrent-spate-irrigation systems are reactive and are not sharply defined. They cope not only with the unknown proportions of the next flood, but also with the medium-term changes in the river morphology, due to scour, siltation and change of river course. Water distribution in the floodwater irrigation systems is based on allocation rules rather than alienable property rights.
- Out-migration is a common response to a period of dry years. In good years, the parameters are different and demand for labour will peak, in particular, during land preparation and harvest. Again this gives rise to flexible markets for labour and in the recent years mechanical traction.
- Depopulation is a constant threat to the farming communities. In particular, where farmers depend on each other in reconstructing large barrages, population figures might drop below the point where it is not possible to mobilise sufficient labour for these recurrent works. Similarly, a large landlord may be unable to find tenants to work on his land and help in the upkeep of the hydraulic structures.
- Lack of public-sector institutional support to water users in technical backstopping and to resolve the conflicts was primarily due to low priority assigned to torrent-spate-irrigation system. Furthermore, co-ordination among various public sector institutions is non-existent.

Economic

- In torrent-spate-irrigated tract, subsistence and low-value cash crops prevail. It is still dominated by drought resistant crops like sorghum, millet, pulses, wheat, gram, guar and oilseeds. Most of the land is under local cultivars. Even if optimal conditions were to prevail, crop returns would have difficulty competing with alternative sources of income. Therefore, returns are marginal, as optimum conditions do not occur.
- Despite the marginal returns from spate irrigation, there has been substantial public investment in these systems especially in Balochistan in the last three decades. The failure rate of the schemes built by the public sector was high (Groundwater Consult, 1991). The overriding factor behind the high rate of failures was the inappropriateness of the prevailing engineering concept, which was based on controlling the flow at a single point rather than managing the inherently varying flood rivers. The technical designs for spate irrigation systems resembled those for perennial flow systems, and did not accommodate the capricious nature of the spate systems. Some of these structures were not able to withstand the force of the violent peak floods. In other cases, headworks were by-passed by the braiding river that they tried to control. Moreover, the provision for sediment transport was insufficient and intakes silted up. Trying to avoid these pitfalls would have required substantial investments in large headworks, complex silt excluding devices and long marginal bunds. Though with these investments, it would have been possible to control the rivers at a single point, the low returns ruled against such high investments.

19

3.3.5. Potential Use and Imperatives

Torrent-spate-irrigation system of D.I.Khan is the most structured system compared to systems in D.G.Khan and Balochistan. However, there are many opportunities for further development and improvements.

Command area and watering intensity can be improved by three ways. Firstly, it can be achieved by reducing the outflow to the River Indus and/or Arabian Sea through diversion of additional water to the existing or new commands. Secondly, new water resources can be made available by reducing the existing losses within the conveyance network and thereby reducing the incidence of breaches and tail-water problems. Thirdly, the excess water in flood season especially in wet years can be stored in storage dams for carryover to subsequent months to ensure sustainability of torrent floodwater agriculture. The third option is capital intensive and has limited life of the storage dams due to heavy load of sediments in the floodwater, which will silt-up the dam quickly. In addition to these three options, there is a limited scope of groundwater exploitation in areas, where water of useable qualities is available.

Presently, wheat, gram, oilseeds, sorghum, millets, guar, and melons are normally grown in these areas. Farmers are interested to grow multi-purpose varieties of fodder, as livestock provide a source of livelihood in years, when there are no crops due to droughts. There is a potential to focus this system to achieve self-sufficiency in wheat and edible oils. The imperatives for improving the torrent-spate-irrigation systems are:

- Within the framework of inherent uncertainty, at the most, probabilities can be established and the area that has a reasonable chance of being irrigated in, for instance, a ten-year period may be determined. This area may even be defined formally as an entitled command area. The fringe of the entitled command area can be defined in two ways and that the institutionalised relationship between the distribution of water and the cost contributions to maintenance is determined by how this fringe is defined.
- Institutional changes are required in local management of spate irrigation system through; a) changing the net benefits of resource use; b) subsidising the first and second order transactions costs; and c) direct participation of water users through co-management. The first order transactions costs are higher, but they are only partly born by the water users themselves. The second order transaction costs have to be subsidised from outside. Capacities of public-sector institutions should be strengthened for provision of technical backstop support in design, construction and operation of the system.
- A paradigm shift is necessary for development and operation of the torrent-spate-irrigation systems different from the modern irrigation schemes. This requires acceptance of water logic, which demands a flexible approach with direct participation of water users' to achieve economic sustainability.
- Ensure more reliable water supply by reducing the risk of failure in conveyance network and by increasing deliveries to various nullahs and commands. On-farm water management should be given priority for diversion, distribution and application of water for integrated land use (crops, livestock, forestry, pastures and arid horticulture). This will ensure risk aversion due to droughts and floods, as the tail-water can be ponded in low-lying areas to grow forest plants and forages.

20

- Introduction of micro-water development schemes is needed for conjunctive use of water through exploitation of shallow groundwater and storage of excess surface water in small earthen ponds for multiple water use (domestic, stockwater and irrigation).
- Development of reserves should be initiated for high value arid fruit progeny gardens and forest nursery, forages, and multiplication of promising crop cultivars for dissemination and transfer of production technology.

3.4. Perennial-Spate-Irrigation Systems

The perennial spate-irrigation systems are located in Western Dry Mountains and Sulaiman Piedmont. The perennial supply spate-irrigation system is known as *'Kalapani'* or black water, on account of its clear colour, to distinguish it from the '*Sufaidpani'*, or white water, the later being the discoloured silty water that issues after rain.

3.4.1. Era, Location and Extent of the Systems in D. I. Khan

Kalapani systems exist in the area before the introduction of torrent-spate-irrigation. There is an evidence that these systems exist in the area much before 330 BC. Large hill-streams have a small perennial flow, which is expended long before it reaches River Indus. These perennial springs are known by the local name of *'Zam'*. There are five *Zams* in the Division (Figure 5). The cold weather flow of these springs varies from about 6 m^3/sec in the Gomal *Zam* to from 0.6 to 1.2 m^3/sec in the Draban and Chaudwan *Zams*. Like floodwater, this *Kalapani* also, if left to it, would run to waste in torrent bed, leaving surrounding area as dry as before (PARC, 1990; GOP, 1884).

Dreary appearance of country is to some extent broken, wherever a perennial stream issues from the hills. Cold clear water running over its shingle bed is caught in small embankments of stones and brushwood, and led away from stony torrent bed to the side. Where cutting in clay soils bring it down to the cultivated fields. Heads of these channels are generally bordered with *'Shisham' (Dalbergia sisso)* trees, which grow to a fair size, and here and there are little water mills with a row of willows along each side of the millrace. Recently, some of the diversion structures have been built with stone/brick masonry.

Kalapani cultivation is of two sorts – '*Tand'* or '*Tandobi'* and '*Vichobi'*. In *Tand* cultivation, water is laid on to open fields divided into strips and plots with small ridges between, like those used in well cultivation. *Vichobi* cultivation resembles ordinary hill-torrent cultivation, to which expression is often applied. Embankment fields are filled up with water, which is allowed to soak in, after which field is ploughed and sown. As a rule, *Tand* cultivation is only carried on near the head of a stream. It gives less trouble, but requires more water, as crop has to be irrigated every 10-14 days. Where water of a stream belongs to a tribe or shares, bulk of *Kalapani* is used in *Tand* cultivation, whereas surplus being employed in *Vichobi* cultivation. Often after rain, amount of *Kalapani* increases greatly. Though the water can still be kept in hand and distributed in ordinary *Kalapani* fashion, but there is a point when it is impossible to distinguish *Kalapani* or dry weather flow, from *Rod-Kohi* or torrent flow. When the torrent come down in force, they usually carry all the little embankments for diverting *Kalapani*, and the whole water supply sweeps away through the main channel. By cutting deep heads, however, to their side channels, *Kalapani* proprietors can generally ensure a sufficient and sometimes an over-abundant supply, even during the continuance of a flood (GOP, 1884).

21

Laths (bunds) around the fields used in *Vichobi* cultivation are generally smaller than in torrent cultivation, but fields are watered oftener. *Kalapani* water brings little or no silt. While, the *Rod-Kohi* lands can be cultivated continuously, without any deterioration in the natural luxuriance of crops. *Kalapani* lands, especially when cultivated in *Tand* fashion, require constant falloffs. As a rule, people in the past try to leave *Tand* land fallow for two years out of three. In consequence of this, even the *Kalapani* irrigated tract do not look as green as might be expected, and country, owing to large amount of fallow, has a half-cultivated look.

Now farmers use chemical fertilisers in *Kalapani* system to ensure continued cropping. Vegetables are commonly grown on *Tand* irrigated *Kalapani* lands. Crops grown on *Vichobi* lands as much more same as *Rod-Kohi*.

3.4.2. Era, Location and Extent of the Systems in D. G. Khan

In Punjab, perennial-spate-irrigation systems go back as early as the period before the Christ and provided economic basis for some of the early Hindu civilisations. *Kalapani* tract comprises land, which at the point of issue from hills of the Kaha torrent in the Jampur receives perennial irrigation from that stream. It is led away from torrent by water-cuts at a point considerably above the place, where embankments are made to guide autumn *Rod-Kohi* in to distributaries. Crops grown in *Kalapani* are: a) rice of a superior quality in *Kharif;* b) wheat in *Rabi;* and c) fallow. *Rod-Kohi* water does not reach this tract. Date trees flourish on this soil, and bearing fruits. Vegetables, oilseeds, cotton and fruits are also grown (GOP, 1898).

Other isolated locations, which exist in the Division, are found in Vihowa and Mithawan commands. Mithawan *Kalapani* command is located in the highland. Highland systems are small and much easier to manage but terrain is very rugged. These isolated highland systems are subjected to damage during summer season by *Rod-Kohi* floods, and water users have to rebuild these systems almost every year.

Most of the small-scale *Kalapani* systems can be regarded as a case, where potential for expansion of command area is limited. Thus, these systems can be viewed as an example with adequate availability of water. If water is in excess, then no rotation is practised at the diversion structure, which provides water to more than one channels serving various sub-commands. However, a rotation is practised for each of the sub-commands to provide water to the water users. Therefore, these systems are described as continuous flow, non-rotational channel diversions, rotational for distribution to users, and water rights based on prior appropriation.

Large-scale continuous flow systems are being operated under a fixed rotation of 7 to 10 days interval for various sub-commands. The water user can get his turn after a period of 7 to 10 days. The rotation is practised, as there has been many fold expansion of the command area during the last 3 decades. Still there is a potential for further expansion of the command area. The unit discharge available during the dry period varies from 20 to 30 litres per 100 ha, which is almost in line with the allowance of the irrigated areas, especially of perennial canal commands in the Punjab province.

22

3.4.3. Era, Location and Extent of the Systems in Balochistan

In Balochistan, perennial-spate-irrigation systems go back as early as 3000 BC and provided economic basis for some of the early civilisations. These systems are located in both the highland and lowland ecologies (GOI, 1920).

Perennial water systems exist in two forms. Firstly, perennial streams where water is diverted from the riverbed to irrigate the command area. The most modern form of these systems is now referred to Minor Irrigation Schemes. Secondly, perennial springs in highlands, where water is diverted in streams to irrigate the command area. This is accomplished by raising level of water by temporary diversion structures using stones. These schemes are quite established and scattered. High value fruits and vegetables are grown due to comparative advantage of weather. Apples, apricot, pomegranate, almonds are commonly grown fruits, in addition to potato, onions, tomatoes and seasonal vegetables.

3.4.4. Issues

Area commanded by a scheme and cropping pattern over the command is subject to wide fluctuation due to lack of weir-controlled regulation. The consequence is that the areas commanded and cropping pattern followed by groups of landholders that receive irrigation supplies differ from year to year. The interests of management of *Kalapani* spate irrigation are not uniform, because availability of irrigation water varies throughout command area primarily due to higher diversion and conveyance losses.

The water users at the head and middle reaches grow more high value crops due to relatively assured water supply. Whereas at the periphery of the command area crops that grown are normally of low value and there is higher risk of crop failures. In contrast to the torrent-spate-irrigation systems, for most of the users the returns to perennial spate irrigation are normally higher that they will not give up their entitlement. Bargaining of accessed rights will be relatively complex and always linked with the land. Technical, social, institutional and economic issues related to past and present use of perennial-spate-irrigation system are:

Technical

- Perennial-spate-irrigation systems are more reliable during winter season, whereas these systems are affected by torrents during summer season. Because of the inherent uncertainty of these systems in summer season, it is hard to predict the land that will be commanded during *Kharif* season.
- Risks in perennial-spate-irrigation are not high, but they are not equally distributed throughout the system. Within a command area, there may be land with high, medium and low probability of area to be commanded. The tail-end water users are affected in both the wet and dry years. Thus, there exists internal differentiation based on location and level of the command area.
- Stability of water conveyance system due to heavy breaches and landslides is a major concern in highland systems.
- Inadequate and inappropriate diversion of *Kalapani* caused inequity in distribution of sanctioned capacity or share of water to different nullahs. Water losses are common due to inefficient conveyance and distribution of water within the system. Shortage of water

23

availability in dry spells or drought years is common especially in years when groundwater recharge is low.

Social and Institutional

- System deterioration due to influence of large water users and notables, and lack of discipline enforced by the Provincial Irrigation and Drainage Authorities has reached to a level, where system could not be operated in accordance with established water rights.
- Co-ordination among farmers is limited due to lack of appropriate organisation, which can ensure operation of the system in accordance with the established water rights and norms. Water rights in perennial-irrigation systems are not sharply defined. Water distribution is based on allocation rules rather than alienable property rights. Lack of improvements in water rights and water distribution rules is a major limitation to make these more responsive to equitable availability of water.
- Lack of public-sector institutional support to water users in technical backstopping and to resolve the conflicts was primarily due to lack of focus and priority assigned to perennial-spate-irrigation system. Furthermore, co-ordination among various public-sector institutions is non-existent.

Economic

- In perennial-spate-irrigated tract, medium-value crops prevail. These systems are still dominated by cereals, fodder, pulses, cotton and oilseeds. Even if optimal conditions were to prevail, crop returns would have difficulty competing with alternative sources of income.
- Lack of capital with farmers and joint action is a constraint in adoption of high efficiency orchards farming and vegetable production. Limited access to market is another reason.
- Despite the marginal returns from perennial-spate-irrigation, there has been some public investment in these systems in the last three decades. The failure rate of the schemes built by the public sector was high. The overriding factor behind the high rate of failures was the inappropriateness of the prevailing engineering concept. The technical designs for perennial-spate-irrigation systems resembled those for perennial flow systems, and did not accommodate the capricious nature of the torrent-spate-system, which affects *Kalapani* during the summer season. Some of the structures were not able to withstand the force of the violent peak floods of torrents. Therefore, these systems have to be designed and constructed with active participation of water users.

3.4.5. Potential Use and Imperatives

Perennial-spate-irrigation systems of Balochistan are relatively most structured compared to the systems of D.I.Khan and D.G.Khan. Perennial-spate-irrigation systems are similar to the canal irrigation schemes in the Indus basin. Therefore, these systems have to be protected to avoid damages caused by torrents in summer season. If these systems provide assured and continued water supply for both the seasons, then the conveyance system can be remodelled to reduce seepage losses, which are quite high in sandy reaches.

Command area and watering intensity can be improved by reducing the outflow through diversion of additional water to the existing or new commands. New water resources can be

24

made available by reducing the existing losses within the conveyance network and thereby reducing the incidence of breaches and tail-water problems. Excess water in wet season, especially in wet years can be stored in storage dams or earthen reservoirs as silt is much less in the *Kalapani* compared to torrents water. Stored water can be used for carryover to subsequent months to ensure sustainability of the system. Although the construction of reservoir is capital intensive, but due to extremely low level of sediments in the *Kalapani*, life of storage will be sufficient to justify the investments. In addition to these options, there is a limited scope of groundwater exploitation in areas, where water of useable qualities is available.

Presently, cereals, oilseeds, gram, vegetables and fruits are normally grown in these areas. Farmers are interested to grow multi-purpose varieties of fodder, as livestock provide a source of livelihood in years, when the command area is less due to droughts. The imperatives for improving the perennial-spate-irrigation systems are:

- Within the framework of inherent uncertainty and damage caused to the conveyance system by torrents, efforts are needed to isolate the perennial systems from the effect of torrents in the summer season. This would require remodelling of the existing schemes to improve reliability of water throughout the year. This can be accomplished by diverting the perennial flows with layout, which will not be prone to flood damages.
- Institutional changes are required in local management of perennial-spate-irrigation system through; a) changing net benefits of resource use; b) subsidising the first and second order transactions costs; and c) direct participation of water users through co-management. The first order transactions costs are higher, but they are only partly born by the water users themselves. The second order transaction costs have to be subsidised from outside. Direct participation of water users should be ensured to achieve financial sustainability. Capacities of public-sector institutions should be strengthened for provision of technical backstop support to the water users.
- A paradigm shift is necessary for development and operation of the perennial-spate-irrigation systems different from the torrent-spate-irrigation schemes. This requires improvements in water rights and allocation rules as water is at premium.
- Ensure more reliable water supply by reducing risk of failure in the conveyance network and by increasing deliveries to various commands. On-farm water management should be given high priority for diversion, distribution and application of water for high value crops, forestry and fodder. The integration of crop and livestock production system will ensure risk aversion due to droughts and floods as the tail-water can be ponded in low lying areas to grow forest plants and forages.
- Introduction of micro-water development schemes should be encouraged for conjunctive use of water through exploitation of shallow groundwater and storage of excess surface water in small earthen ponds for multiple water use (domestic, stockwater and irrigation).
- Use of improved seed and fertilisers helped farmers to increase productivity of their lands. Further, through land forming and development by removing stones, crop stand has been increased tremendously. Therefore, both extensification and intensification strategies are being adopted by the farmers. The same is true for the *Kharif* season where now farmers started using water for raising of summer crops due to availability of water because of improved management especially at the diversion structure. Development of reserves should be encouraged for high value arid fruit progeny gardens and forest nursery, forages, and multiplication of promising crop cultivars for transfer of production technology.

3.5. Riverflood-Spate-Irrigation System

3.5.1. Era, Location and Extent of the Systems in *Kachi* Tract

In the *Kachi* tract, riverflood-spate-irrigation systems go back as early as 3000 BC and provided economic basis for some of the early civilisations. This system is located along River Indus. Area included in districts of Bhakkar and Leiah, naturally divides into two portions. Thal forming part of the Sind Sagar Doab, and the *Kachi*, or low alluvial lands on River Indus. All the northern part of Thal is high above the reach of inundation, even in the highest floods, but below Leiah, River Indus sometimes over-flows the Thal lands immediately adjoining the *Kachi* (GOP, 1884).

In the past, towards north, Indus has been cutting right into the Thal bank. Cultivated alluvial lands in this part lie mostly in bets and islands in the river. Below Kalur kot, a strip of alluvial land intervenes between Thal and River Indus, the average width of which, from Darya Khan down to Muzaffargarh district, was about 10 kms prior to irrigation development. It is the tract, to which the name '*Kachi'* more properly applies. Like the word '*Nasheb'*, the term *Kachi* is used for all the low-lying lands on River Indus.

Cultivation in *Kachi* tract depends on inundation of River Indus. Only outer villages of the tract are exposed to erosion and dilution. However, whole tract is more or less intersected by streams of River Indus. The principal of these streams is named as *'Puzal'*, known in lower portions of its course by the names of *'Bodo'* and *'Lala'*. The *Puzal* often separates into two or three branches, some of which run back into River Indus, while some fall into other nullahs, or rejoin lower down. In hot weather, these streams form a network all over the *Kachi*, but in cold weather most of them dry up. In the past, the *Puzal* even was readily fordable during the cold weather, but it has deepened of late, and fords on it are rare. A bridge has in consequence been thrown across it on the road between Dera and Bhakkar. In other parts, it is crossed by means of small boats ('*Dundas*').

Bed of the Indus itself is wide and straggling, and all through cold weather, there are broad stretches of barren sand along its course. *Puzal*, however, and most of smaller nullahs intersecting the *Kachi*, have well defined beds of moderate size, and for greater part of the year they flow up to their banks. Wells, Jhalars, and occasional villages are scattered along sides of these streams, and cultivated fields come down to water's edge. The *Kachi* as a whole, is a pleasant country; about half its area is cultivated, the remainder being overgrown with tall *Munj* grass, and near the river with low Tamarix *('Lai'*) jungle. The river islands are often overgrown with a dense grass jungle, which is a favourite cover for wild pig. The grass is locally called *'Kan'* (*Saccharum spontaneum*) and must be distinguished from *'Kana'* or *'Munj'* grass (*Saccharum sara*), which, at a distance, it somewhat resembles (GOP, 1884).

For three or four kms from the Thal bank the country is thickly studded with wells, each well generally forming a little hamlet of its own, with its farm sheds and out-houses. The larger villages are found mostly on the Thal bank, overlooking the *Kachi*. Here they are beyond the reach of floods. People living in *Kachi*, cut their crops and stack them on higher bits of ground near their wells and villages, in consequence of which they suffer heavy loss in years of high flood. The portion of the *Kachi* towards River Indus is generally destitute of wells, cultivation being all *Sailaba*. Here and there, however, as at Mochiwala, where wells extend further than usual from the Thal bank, the Indus has cut into it, and wells are found standing on very edge of the main stream.

All through the inner portion of the *Kachi*, there are almost invariably pleasant clumps of trees around villages and wells. *Sheeshams* and *Bers* predominate, with an occasional *Siris* or *Pipal.* This part of country is fairly wooded. The out-lying tract towards River Indus has few or no trees, though here and there, especially to the south of Leiah town; there are stretches of *Bhani* jungle. The *Bhani* is a sort of poplar (*Populus euphratica*); in the colour of the bark and general appearance, it somewhat resembles the *Birch*. Here and there, as in Khokranwala rakh, where it has been carefully preserved, it grows into trees of moderate size; but as a rule, it does not exceed five or six m in height. There are some groves of date palms in the *Kachi*, generally near the Thal bank.

Cultivation in the *Kachi* is in open fields. There are very few hedges. The crops in the *Kachi* never fail altogether; though, without a certain amount of winter rain, yield is very short. In years of deficient flood, un-irrigated portions which are sometimes as much as a fifth of the entire area remain waste. The part that suffers most readily from deficient floods is inner portion of the *Nasheb*, from above Leiah to Muzaffargarh border. On the other hand, this is the part that suffers least in years of excessive flood. The *Kachi*, uncultivated and not overgrown with jungle, is always grassy.

Kachi tract consists of alluvial land on both banks of the Indus, and includes portions of Dera Ismail Khan, Kulachi, Bhakkar and Leiah (Table 3).

Table3. Potential and cultivable area of the *Kachi* tract.

Name of Tehsil	Area in Hectares		
	Cultivable	Uncultivable	Total
D.I.Khan	36,909	30,823	67,732
Kulachi	7,739	6,349	14,088
Bhakkar	94,033	32,312	126,345
Leiah	94,887	21,766	116,653
Total	233,568	91,250	324,818

Soils of this tract may be classed under two heads, chahi or irrigated, and *Sailaba* or inundated. In its general characteristics, soil all through the *Kachi* is uniform in character though varying in quality. In some places there are deep deposits of rich loam, in others loam is mixed with an excessive amount of sand, or forms a thin coating overlying a bed of pure sand underneath. These differences, however, fade one into another, and same field is in some places rich and in others poor. The quality of soil, too, changes with length of time that land has been under cultivation. A bed of loam newly deposited by the river may be first class, but after ten years of continuous cultivation, it often gets poor and weedy. The presence of *Kallar*, or natural salts, in soil, also affects quality. In some parts of the *Kachi* tract, especially in the case of well-irrigated land, soil, which is naturally good, is quite spoilt by these *reh* exudations. In a country subject to annual inundation, the character of the soil is always more or less liable to change.

The extent of land annually under cultivation, and average yield in this entire *Kachi* tract, varies comparatively little. The Indus inundation usually extends over far greater part of its area, and

27

crops once sown seldom fail altogether. The part most liable to suffer from deficient floods is inner portion of the *Nasheb*, from above Leiah to the Muzaffargarh border. On the other hand, this part suffers least in years of excessive flood. Wheat harvest, even in bad years, is never less than half the average; and the area under wheat is two-thirds of the whole-cultivated area. In ordinary years nearly whole of the arable land is cultivated, proportion of fallow for whole tract being from 5 to 10 percent, on the cultivated area. A year in which 20 percent of area remains fallow is very exceptional.

Cultivation in the *Kachi* tract depends on inundation of River Indus. Only outer villages of the tract are exposed to erosion and dilution. However, whole of the area is more or less intersected by streams of River Indus. To insure irrigation of higher portion of the *Nasheb*, it is customary to throw dams across channels by which it is intersected. The great object is to pass on water from these embankments by side channels, instead of breaking the Bund, and allowing the work to be entirely carried away. With careful management, these embankments are kept up for years. A few small canals too have been excavated for irrigation of higher lands. As a rule, however, people trust to unassisted floods and percolation. It is only the higher lands that require artificial means for their irrigation.

In years of high flood, there is no necessity for dams, as the *Nasheb* gets flooded up to the Thal bank. At such times, people are often tempted to cut embankments, and thus get rid of a portion of water. After two or three years of high flood, they invariably get careless and stop making the dams. Then come two or three years of deficient flood, when lands remain dry, after which dams are reconstructed, and the old watercourses cleared out.

There is some cultivation in *Kharif*. Tobacco and cotton are grown around wells, and in most years, there is certain amount of millets, sorghum and linseed. Main crops are wheat, gram and peas; wheat is grown very extensively, and occupies in most years two-thirds or more of the cultivated area. In years of high flood, there is no *Kharif* cultivation, and when floodwaters remain standing for a long time, they are injurious even to the *Rabi*. What the people like is one good flood in July, just high enough to cover all but higher lands, on which they grow tobacco and cotton. These are sufficiently irrigated by water that percolates through soil from below. The floodwaters should stand three or four days and then go down. This enables the cultivators to sow millets and linseeds, and to get their lands thoroughly ploughed, ready for *Rabi* sowings.

3.5.2. Era, Location and Extent of the Systems in *Sailab* Tract

In the *Sailab* tract, riverflood-spate-irrigation systems go back as early as 3000 BC and provided economic basis for some of the early civilisations. This system is located along River Indus.

Rajanpur *Sailab* tract contains all villages adjacent to River Indus, which are submerged fully or partially by it, when it rises. These lands are liable one year to be rendered uncultivable by a deposit of sand and another year to be enriched by river silt, and also less liable to injury and less fortunate in receiving silt deposits. There are similar tracts in D.G.Khan division. These are much less extensive than that of Rajanpur and have been included in the Sind tract of Sangarh and Jampur and in the *Chahi Nahri* tract of D.G.Khan. Wells are common in the north of the Rajanpur *Sailab* tract, but not in the south, where cultivators, the Mazari tribe is engaged in agriculture; water is met with near the surface, but there are less number of wells. Crops sown on river-flooded land can be watered afterwards from the well, if cold weather rains fail, but on the other hand, there is a constant danger of wells being eroded or choked with river silt (GOP, 1898).

Of the total area of crops annually harvested, wheat occupies 63%, and mash and peas each 9%. There is a large area of wasteland covered with grass and jungle, and affording excellent grazing to large flocks and herds that are kept in the tract. The area harvested depends on nature and extent of autumn floods in River Indus, and fluctuates enormously from year to year.

Cultivation of *Sailab* land is of the simplest order. When water has subsides and surface of soil begins to dry, land is ploughed and seed is sown in October or November. *Kharif* crops of linseed and mash are grown on lands from which floods retire earliest, but *Rabi* crops are grown in most of the lands. Rain in January or February is necessary to secure proper maturing of crops, though a certain proportion of crops sown can be harvested even if cold weather rains fail altogether.

3.5.3. Era, Location and Extent of the Systems in *Gharkab* Tract

In the Gharkab tract, riverflood-spate-irrigation systems go back as early as 3000 BC and provided economic basis for some of the early civilisations. This system is located along River Indus.

Gharkab tract lies between east of Kutb and *Sailab* tract. Most of cultivation is dependent on river flood, which is distributed over it by depressions called *Dhoras.* Water so distributed is less rich in silt than floodwater of *Sailab* tract, and when set of River Indus is towards east only a small volume of water reaches Gharkab tract. Much of the cultivation is secured by wells, but these are used for valuable garden crops, if land attached to them gets a good flooding from the river. Land receiving floodwater and irrigated by wells is called *Chahi-Sailab,* which forms 22 percent of the total cultivated area. There was a tremendous increase in number of wells in this tract. The water level is shallow even to around 5 m in certain areas. The average area commanded by a well is around six ha with an average annual cropped area of four ha (GOP, 1898).

In the past, well is thrown out of work if land attached to it fails for two years running to receive river inundation, as soil in that case becomes infertile. Now some of the farmers are using fertiliser to replenish nutrients. Wheat occupies 64% and peas 15% of the average area annually harvested. The area harvested fluctuates from year to year largely than in the Sailab tract. The effect of eastward set of the river having a more marked impact in this tract compared to the Sailab, where a certain area is always sure of a flooding. There is much jungle affording excellent grazing for buffaloes, cows, sheep and goats.

3.5.4. Era, Location and Extent of the Systems in *Kacha* Tract of Lower Indus

In Sindh, riverflood-spate-irrigation systems go back as early as 3000 BC and provided economic basis for some of the old civilisations i.e. Indus valley civilisation. These systems are located along the River Indus in the flood plains.

Before the introduction of the weir controlled irrigation in the country, this tract used to provide potential productions to support the early civilisations. The extent and area under riverflood-spate-irrigation have reduced tremendously due to the Indus Basin Irrigation systems' developments.

At present before River Indus reaches the province of Sindh, five rivers of Punjab (Jhelum, Chenab, Ravi, Sutlej and Bias) merge below the Panjnad headwork. At Guddu barrage (80-m a.s.l. and 800 kms from sea), River Indus passes into the plains of Sindh. It meanders through a very wide flood plain (several kms wide), flooding is common and its slow speed results in accumulated silt being deposited. The bed is gradually raised so that some Riverine forests now lie high above the regular flooding levels. Most of the plains of Sindh have been built up by alluvium from River Indus.

The climate of the lower Indus plain is arid subtropical with very hot summers and cool winters. The annual rainfall is about 150-200 mm; the minimum temperature in winter is 2 ^{o}C, and the maximum in summer is 49 ^{o}C.

Major barrages have been constructed at Guddu, Sukkur and Kotri enabling water to be abstracted for irrigation throughout Sindh. In order to contain floods, earthen bunds were built up over the years on each side of the river, so that now River Indus is constrained within this bunded flood plain throughout the length of Sindh.

Within the flood bunds, plantations of *Acacia nilotica* now dominate Riverine forest ecosystem. This ecosystem is dependent upon annual out of bank flooding, which occurs when flow at Guddu is more than 8490 m^3/sec. There are total of 161,852 ha of Riverine forest between Guddu and Indus delta, representing about 19% of the total area between the flood bunds. About 30% of the land is cultivated and the rest is uncultivated scrub or water, sand and mudflats.

The potential area under riverflood-spate-irrigation is around 0.85 million ha. Out of which, 0.16 million ha are under Riverine forests, and around 0.26 million ha are under cultivation in an average year, which can be increased to 0.52 million ha in a heavy flood year.

3.5.5. Era, Location and Extent of the Systems in the Indus Delta

The delta water harvesting systems are as old as the Indus civilisation. The construction of Kotri barrage and the associated flood bunds restricted distribution of freshwater in the delta and caused significant ecosystem changes, which have been compounded by increased freshwater abstraction. The active delta is now much smaller than it used to be and dilution effects of freshwater upon highly saline and arid-environment of the delta have been largely restricted to this area.

The sediment brought down to the delta is now estimated at about 60 million tones per year, about one-fifth of original quantities. The balance of sedimentation and erosion may now have been tilted in favour of erosion.

Nutrients carried in freshwater and sediment flows reaching the delta have also been reduced with implications for overall productivity of the delta. Increasingly nutrients are of marine origin, although there is an increasing contribution from wastewater from Karachi, which swept down the coast by the southeast currents.

Reduced sediment transport has reduced the alluvium deposited in the flood plain, causing a reduction in nutrient status of soils. However, reduced flows of water, especially below Kotri barrage, have increased the deposition of sediment in the main channels, causing sandbar formation.

3.5.6. Issues

Upper Indus ecosystem of the Punjab plains has been changed by the construction of barrages. Increased abstraction has reduced the extent of flooding from up to 8 km on each side to only 2 km now. This has had a number of associated effects. It has permitted raising of some small areas of Riverine forest in previously low lying areas where trees would have washed away, but has also allowed the invasion of exotics such as *Prosopis juliflora* in areas no longer flooded. These have replaced the indigenous *Acacia nilotica*. The gradual shrinking of beds of *Typha,* which used to line banks of the main river and increase in *Saccharum* grasses, indicates a drying out of the flood plain. The Riverine forest is drying out and being reduced to a few relict patches. The many-forested islands (*Belas*) used to be refuge for wildlife. Access to these Belas is now easier, many forests have been cleared, and land used for agriculture.

Lower Indus ecosystem of the Sindh plains have also been changed by construction of barrages from meandering lowland river to a series of shallow reservoirs backing up the flood plain. The impoundment has maintained a permanence of wetlands in this arid region. The construction of flood bunds throughout Sindh have constrained flood plain causing changes in habitat, making thorn forest susceptible to degradation or clearance for agriculture.

Variability of river flood supplies affects area under cultivation, which is subject to wide fluctuation. Because of different probabilities of inundation, not only will the interest in riverflood-spate-irrigation vary between different parts of the inundation command area, but the economic capability of landholders in different parts of the inundation command area will vary too.

Crops grown are of normally low value and risk of crop failure, particularly at the remote periphery of the inundation command area, is significant. Net benefits of riverflood-spate-irrigation are relatively small under the present framework. In contrast to the torrent-spate-irrigation, for some of the peripheral users the returns to riverflood-spate-irrigation may be so marginal that they will voluntarily give up their entitlement. Technical, social, institutional and economic issues related to past and present use of riverflood-spate-irrigation system are:

Technical

- Because of the inherent uncertainty of inundation in riverflood-spate-irrigation, it is hard to predict the land that will be inundated. Furthermore, it is also not possible to predict how much land will receive winter rains due to arid environment of the area. Rapid runoff of storm water is another major concern.
- Risks in riverflood-spate-irrigation are high, but they are not equally distributed throughout the system. Within a command area, there may be lands with high, medium and low probability of inundation. Thus, there exists internal differentiation based on location and level of the inundation command area.

- Erosion due to inherent erodible lands, and silting of streams leading to inequity in inundation. Riverflood-spate-irrigation is subject to process of active land formation, due to both scour and siltation. The impact of these processes differs between various systems. One variable is the amount, composition of the sediment load that a river carries which depends on rainfall pattern, and characteristics of catchment area; its geology, morphology, and vegetation cover. Farmers, however, are not passive actors in these scour and siltation processes, but often actively manipulate land formation.
- Variability in inundation of floodwater caused inequity in distribution of the inundated area. Remote peripheral water users are affected in both the extremes of flood and drought. Loss of water due to uncontrolled spreading resulted in too much or too little inundation in the command area;
- Increased use of pumped water for irrigation of high lying Riverine forests has been inadequate to compensate fully for the loss of natural flooding, and adds substantial costs. This has also affected livestock for grazing and browsing opportunities due to reduced Riverine forests.
- Cultivation of agricultural crops in the flood plain has decreased as a result of reduction of flooded area and availability of fresh alluvium. This has been compensated by the increase in irrigated agriculture.
- Red rice cultivation was a principal crop grown within the active delta. This was dependent upon flooding of freshwater, and crop yields met both subsistence and commercial needs. Orchards of banana, papaya and guava also generated income on lands in the delta. All of these have now virtually disappeared. Grazing of buffalo, sheep and goat is now rare in the Indus delta, and camels are only maintained through the provision of boatloads of freshwater through much of the year. Thus fishing is the only source of livelihood in the delta.

Social and Institutional

- Rights in riverflood-spate-irrigation systems are reactive and are not sharply defined. They cope not only with the unknown proportions of the next flood, but also with the medium-term changes in the river morphology, due to scour, siltation and change of river course.
- Co-ordination among farmers is limited due to lack of appropriate organisation, which can ensure farming in accordance with the established rights and norms. Furthermore, deterioration of the system due to the influence of large water users and notables, and lack of discipline enforced by the Provincial Irrigation and Drainage Authorities has reached to a level, where system could not be operated in accordance with established rights of inundation.
- Lack of public-sector institutional support to farmers in technical backstopping and to resolve the conflicts was primarily due to low priority assigned to riverflood-spate-irrigation system. Furthermore, co-ordination among various public sector institutions is non-existent.
- Out-migration is a common response to a period of dry years. In good years, the parameters are different and demand for labour will peak, in particular, during land preparation and harvest. Again this gives rise to flexible markets for labour and in the recent years mechanical traction.
- Depopulation is a constant threat to the farming communities. In particular, where farmers depend on each other in forming lands, population figures might drop below the

32

point where it is not possible to mobilise sufficient labour for these recurrent works. Similarly, a large landlord may be unable to find tenants to work on his land.

Economic

- In riverflood-spate-irrigated areas, subsistence and low-value cash crops prevail. These areas are dominated by drought-resistant crops, which include sorghum, millet, pulses, wheat, gram, guar and oilseeds. Even if optimal conditions were to prevail, crop returns would have difficulty competing with alternative sources of income.
- Despite the marginal returns from riverflood-spate-irrigation, there has been some public investment in these systems through providing loans for installation of tubewells and purchase of tractors. The overriding factor behind the high rate of failures was the inappropriateness of the prevailing development concept, which was based on installation of wells similar to the perennial irrigated areas. Most of these wells were not able to withstand the force of the violent peak floods.
- Loss of infrastructure including wells and pumping systems is a big loss to the poor farmers. This pose serious limitations for systematic development of these areas.

3.5.7. Potential Use and Imperatives

Riverflood-spate-irrigation systems of Punjab province are the most structured systems compared to other provinces. However, there are many opportunities for further development and improvements.

Command area and inundation intensity of riverflood-spate-irrigation can be improved through introduction of appropriate land forming and water spreading techniques. Supplemental water resources can be made available by installing shallow wells in a way that these are not affected by inundation. Excess water in flood season especially in wet years can be stored in natural depressions for carryover to subsequent months to ensure sustainability of floodwater agriculture. Storage of water is capital intensive and has limited life of the storage due to heavy load of sediments in the floodwater, which will silt-up the depression quickly.

Presently, wheat, gram, oilseeds, sorghum, millets, guar, peas, and melons are normally grown in these areas. These areas have more potential to grow drought-tolerant cultivars of wheat and oilseeds. Farmers are interested to grow multi-purpose varieties of fodder, as livestock provide a source of livelihood in years, when there are no crops due to droughts. There is a potential to focus this system to achieve self-sufficiency in wheat and edible oils. The imperatives for improving the riverflood-spate-irrigation systems are:

- Within the framework of inherent uncertainty, at the most, probabilities can be established and the area that has a reasonable chance of being inundated in, for instance, a five-year period may be determined. This area may even be defined formally as an entitled inundation area. The fringe of the entitled inundation area can be defined in two ways and that the institutionalised relationship between the distribution of inundation area and the cost contributions to maintenance is determined by how this fringe is defined.
- Institutional changes are required in local management of riverflood-spate-irrigation system through changing the net benefits of use of the inundated area and direct participation of water users through co-management. Capacities of public sector

institutions should be strengthened to provide technical backstop support in design, construction and operation of the schemes.

- A paradigm shift is necessary for development and operation of the riverflood-spate-irrigation systems different from the dryland farming. This requires acceptance of water logic, which demands a flexible approach with direct participation of water users'. Direct participation of water users should be ensured at all levels to achieve economic sustainability.
- Ensure more reliable infrastructure development including the wells by reducing the risk of failure in inundation.
- Inundated command water management should be given priority for appropriate land forming and integrated land use (crops, livestock, forestry, pastures and vegetable). This will ensure risk aversion due to droughts and floods, as depressions can be inundated in low-lying areas to grow forest plants and forages. Storage of water in depressions will result in recharge to groundwater to avoid intrusion of brackish groundwater in to shallow freshwater.
- Introduction of micro-water development schemes should be encouraged for conjunctive use of water through exploitation of shallow groundwater and storage of excess surface water in small earthen ponds for multiple water use (domestic, stockwater and recharge).
- Development of reserves should be given priority for high value forest nursery, forages, and multiplication of promising crop cultivars for dissemination and transfer of production technology.

4. Conclusions

4.1. Summary of Indigenous Water Harvesting Systems

There is a wide variety of indigenous water harvesting systems prevailing in Pakistan. Indigenous systems differ significantly from the modern irrigation because flows fluctuate widely in space and time. Prediction of flows is difficult. Landholders are at the mercy of extreme events of floods and droughts. These systems are commonly found in Pakistan and can be characterised in five major categories:

- **Mountain irrigation systems** are based on snowmelt or streamflow or springwater, which is diverted from source through channels along the mountain slopes to the foothills. These are perennial systems.
- **Runoff farming systems** are based on incident rainfall and supplemented by surface runoff, which is harvested from adjacent hillsides and then led to run-on in the cultivated fields.
- **Torrent-spate-irrigation systems** are based on torrent floodwater, which is originated from mountain ranges and then channelled to irrigate flood plains.
- **Perennial-spate-irrigation systems** are based on surface or subsurface flows, which are located within the torrent-spate-irrigation tract.
- **Riverflood-spate-irrigation system** are based on river floodwater peaks, which are located along River Indus.

Indigenous water harvesting systems have been practised in Pakistan since 3000 BC. In the beginning, only narrow strips of land along banks were irrigated. With the passage of time, irrigation was extended to nearby areas by breaching the banks or natural levies of rivers or nullah to bring water to the low-lying areas. This was done only during high flood periods.

Out of country's cultivable area of 24.6 million ha, 18 million ha are under irrigation from canals, tubewells, wells, springs, streams, etc. Rest 6.6 million ha is under *Barani* and indigenous water harvesting systems. Out of this, 2.0 million ha are under torrent-spate-irrigation system. In addition to this, there are around 1.25 million ha under riverflood-spate-irrigation in the country. This leaves around 3.35 million ha, which solely depend on rainwater and/or runoff.

Indigenous water harvesting systems are mostly located in Northern Dry Mountains, Wet Mountains, *Barani* tract, Sulaiman Piedmont, Western Dry Mountains and Dry Western Plateau. The water harvesting systems include mountain irrigation, runoff farming, torrent-spate-irrigation and perennial-spate-irrigation. The riverflood-spate-irrigation systems are located along the River Indus. These systems provide livelihood for a large number of ecologically and economically marginal people in Pakistan.

With the introduction of modern weir-controlled irrigation in the Indus basin during the 19th century, the priority was assigned to irrigated agriculture. In the last 30 years, the indigenous water harvesting systems were deteriorated tremendously due to large-scale introduction of modern surface and groundwater schemes. For example, deterioration of runoff and spate irrigation systems in Balochistan is one of the major cause for affecting sustainability of valley based tubewell irrigated agriculture.

Historic development of canal system illustrates that mountain and spate irrigation were the most important agricultural systems until the end of the 18th century. The systematic canal development in Indus basin shifted focus from mountain and spate irrigation, when large number of inhabitants were settled in canal commands to earn better and sustained livelihood.

Country's food imports are currently around US$ 2.0 billion. With a population estimated at more than 132 million inhabitants today that is likely to reach 171 million by the year 2010, the demand for food products is expected to continue to grow. Thus, unless there are significant improvements in agricultural productivity and total production, imbalance between supply and demand of basic agricultural goods is expected to increase in future, and to threaten self-reliance objective of Pakistan.

Government is now seriously thinking to accord priority to indigenous water harvesting systems, to launch a concerted effort for production of wheat and oilseeds in these marginal ecologies for attaining self-reliance in food security. Poorest-of-the-poor live in these ecologies and thus demand high priority in initiating poverty alleviation programmes. Furthermore, it is not economical to grow wheat and oilseeds under tubewell irrigation, and these crops have to compete for water in the Indus basin with other cash crops like cotton, sugarcane, fruits and vegetables.

Major issues faced by the indigenous schemes can be categorised under technical, social, institutional and economic. Major issues faced by these systems are related to predictability, reliability, equity and adequacy of water for irrigation. Other issues are related to productivity and sustainability of farming under different water harvesting systems. Traditional norms and rules for water rights are not being practised in spirit due to broken traditions of the tribal system and lack of joint action. The society is now moving very fast towards complete individualism.

4.2. Recommendations

1. Institutional changes are required in local management of indigenous water harvesting system through; a) changing the net benefits of resource use; b) subsidising the first and second order transactions costs; and c) direct participation of water users through co-management. The first order transactions costs are higher, but they are only partly born by the water users themselves. The second order transaction costs have to be subsidised from outside. Direct participation of water users' should be ensured at all levels to achieve financial sustainability.
2. A paradigm shift is necessary for development and operation of the indigenous water harvesting systems, which are quite different from the modern weir-controlled irrigation schemes. This requires improvements in water rights and allocation rules as water is at premium. In addition to this, capacities of public-sector institutions should be enhanced for design, construction and operation of these schemes.
3. Farmers are still trying, if possible, to extend their command area through clearing of un-commanded land having mutual agreement with the community. Thus, there is a potential to add more lands under command, where additional water can be made available. Use of improved seed and fertilisers helped farmers to increase productivity in mountain and *Kalapani* perennial irrigation systems, where water is silt free. Whereas in *Rod-Kohi* and Riverine systems, farmers are not using any chemical fertilisers. Further, through land forming and development, crop stand has been increased tremendously. Therefore, both extensification and intensification strategies are being adopted by farmers and should be supported by the public sector.
4. Within the framework of inherent uncertainty, at the most, probabilities can be established and the area that has a reasonable chance of being irrigated in, for instance, a five to ten year period may be determined. This area may even be defined formally as an entitled command area. The fringe of the entitled command area can be defined in two ways and that the institutionalised relationship between the distribution of water and the cost contributions to maintenance is determined by how this fringe is defined. This can be accomplished by diverting the flows with layout, which will not be prone to flood damages.
5. Ensure more reliable water supply by reducing risk of failure in the conveyance network and by increasing deliveries to various commands. On-farm water management should be given high priority for diversion, distribution and application of water for high value crops, horticulture, forestry and fodder. Integration of crop and livestock production system will ensure risk aversion due to droughts and floods, as tail-water can be ponded in low-lying areas to grow forest plants and forages.
6. Introduction of micro-water resource development schemes should be given priority for conjunctive use of water through exploitation of groundwater and storage of excess surface water in small earthen ponds for multiple water use (domestic, stockwater, irrigation).
7. Development of reserves should be encouraged for high value fruit progeny gardens and forest nursery, forages, and multiplication of promising crop cultivars for transfer of production technology.

36

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38

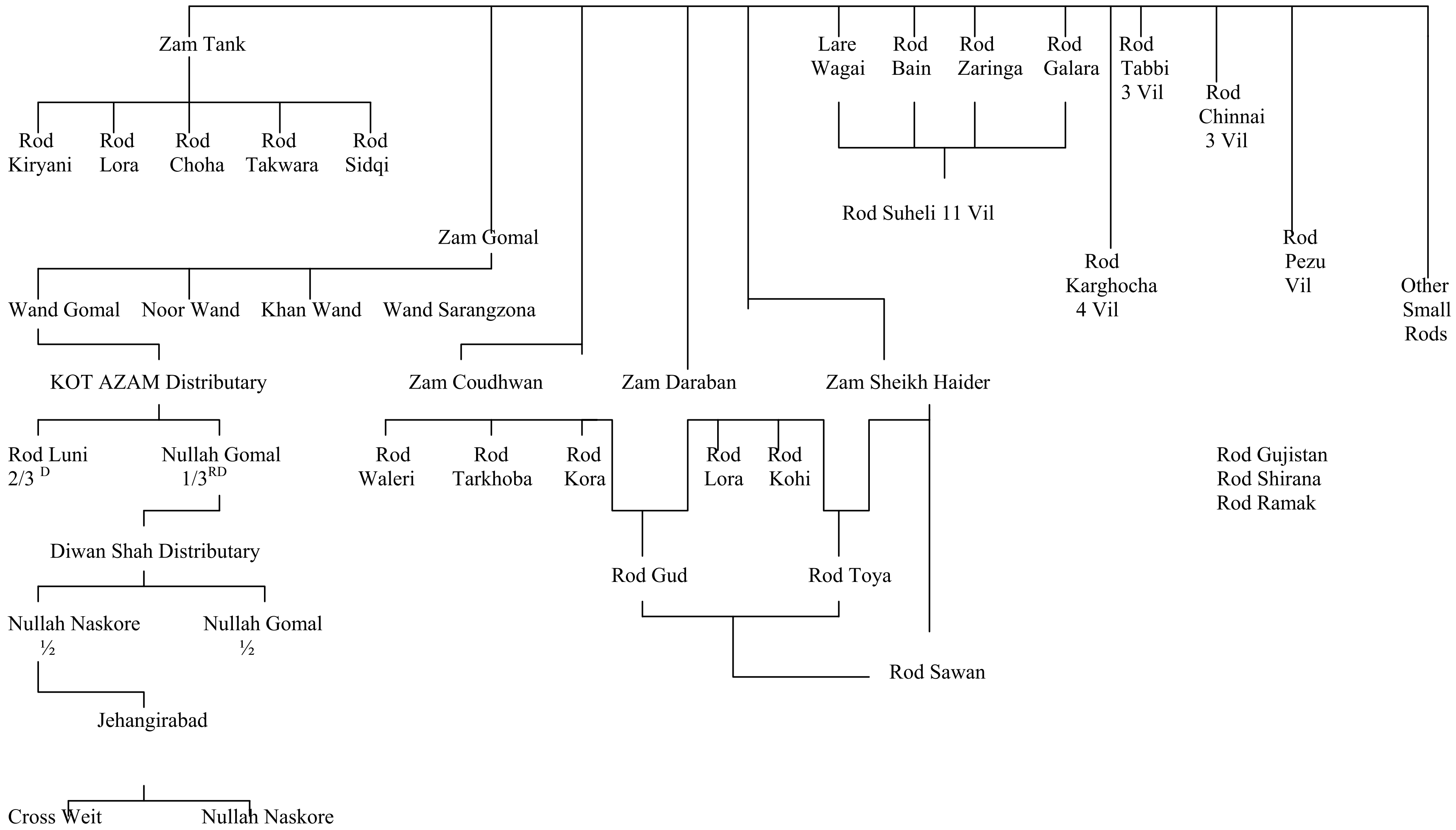

Figure 5. Schematic layout of *Rod-Kohi* systems in D. I. Khan, NWFP, Pakistan.

39

Annex. I. Seasonal aridity zones of Pakistan.

Zone	Description of the Aridity Zones
1	Humid (K*,R**)
2	Humid (K), Sub-humid (R)
3	Humid (K), Semi-arid (R)
4	Sub-Humid (K), Humid (R)
5	Sub-Humid (K,R)
6	Sub-Humid (K), Semi-arid (R)
7	Sub-Humid (K), Arid (R)
8	Sub-Humid (K), Hyper-arid (R)
9	Semi-arid (K), Humid (R)
10	Semi-arid (K,R)
11	Semi-arid (K), Arid (R)
12	Semi-arid (K), Hyper-arid (R)
13	Arid (K), Semi-arid (R)
14	Arid (K,R)
15	Arid (K), Hyper-arid (R)
16	Hyper-arid (K), Semi-arid (R)
17	Hyper-arid (K), Arid (R)
18	Hyper-arid (K,R)

* K - *Kharif* Season (May-September)
** R - *Rabi* Season (October-April)

40