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Spate Irrigation: Impact of Climate Change with Specific Reference to Pakistan

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Abstract

Spate irrigation is a unique system of agriculture practiced in the piedmont plains by harvesting of floods received after rainfall in the mountains. This system is practiced in different parts of the world; in Pakistan, it is extensive in the western belt. The system is based on water distribution from head to tail. There are laws for distribution of water, but due to the magnitude of flood, it sometimes retains in the upstream and sometimes finds its way to the river. Agriculture practiced in this system depends on floods, which brings sedimentation, useful in replenishing soil fertility. Soil has the ability to hold moisture for long. The changing climatic pattern has greatly influenced the system both under droughts and floods. Livelihood of the spate farmers depends on agricultural crops and livestock. In either case of the extreme climate, they have to cope with limited options. Changing climatic pattern is responsible for extending the climatic seasons and enhancing the irrationality of floods. Construction of huge dam on the torrential watershed is a great project executed by the government for large floods, overcomes energy crisis, and has potential to irrigate land through canal. This chapter is a brief comprehension of spate irrigation under changing climate with special focus on Pakistan.

Keywords: spate irrigation, climate change, Pakistan, water rights

1. Introduction

Spate irrigation is an old system of agriculture practised in the foothill plains. The system has exclusivity as the area faces the two extremes: the drought in the dry season and huge floods in the wet seasons. There are a number of countries in the world where the spate irrigation is practised; the more obvious are Eretria, Ethiopia, Iran, Pakistan and Yemen [1]. The more extensive spate irrigation system is practised in Pakistan. In Pakistan the system extends near the Sulaiman ranges in the western part of the country.

Floods considered as catastrophe are a colossal opportunity for the spate irrigation farmers. The farmers of the area wait till the monsoon and spring floods. The livelihood of the farming community depends on these floods as a source of irrigation and also drinking water. The floods once received bring fortune to the farmers. Spate irrigation in different parts of the world is defined by different people, as discharged flood from mountainous watershed that flows through different channels in agriculture fields [2], whereas others termed spate irrigation

as flood water that flows in the torrent beds and stream from the hilly watershed and spread in cultivable fields used for growing the crops [3]. Also some of the researchers have defined spate irrigation as “Diversion and distribution of torrential floods as source of irrigation for raising the crops [4]. Locally in Pakistan the system is called as *Rodh Kohi*, derived from two Persian words *Rodh* which means riverine and *Koh* which means hilly. So in this system the rainfall received in the mountains is captured as floods in the plains. The riverine helps in the flow of water and brings it into the field. The field of spate irrigation is different from the normal field as they are larger in area and are surrounded by big embankments of 4–5 ft for retaining the water. The water once captured is allowed to infiltrate in the field till it reached the field capacity. It requires almost 2 months for infiltration of water into deep layers of soil and is used by the growing crop for the entire season. Spate irrigation is a natural system having great potential for organic cropping. As the crop are grown without the use of chemical fertilizes, herbicides and pesticides, the flood brings lots of sediments which have the natural fertility. The floods with huge magnitude usually make their way to the river, while the average and small floods are stored in the fields. The coarse size particles usually settle in the riverine and canals. While the fine silt and clay make its way to the field and build a layer of sediment greater than 50 mm per year [5, 6, 7], others have reported that it depends on the floods and may range from 1 to 50 mm year [8]. **Figure 1** shows the schematic diagram of spate irrigation.

The occupation of most of the dwellers in spate is crop farming and rearing of livestock; the farmers had the informal water user association which was previously known as the *Patidari* system, which is comprised of a *Patidar*, *Mosair* (front runner) and labourer. The main role was to labour in the watershed to divert the water by constructing stone bunds. But after the introduction of the mechanical methods of construction, the *Patidari* system was ended.

In spate irrigation after introduction of mechanization, the distribution of irrigation water and the amount of water used for agriculture have changed. The government intervention for construction of earthen bund by bulldozers provided by the Agriculture Engineering Department in Southern Khyber Pakhtunkhwa was a big assistance for the people of spate and was a step towards equal distribution, but as the agriculture engineering department was closed, the people have problems in timely construction of check dams. Now the farmers’ association at village levels is involved to construct the check dam locally called as *Gandi* and also the other communal structures related to the spate water distribution by the tractors. But the

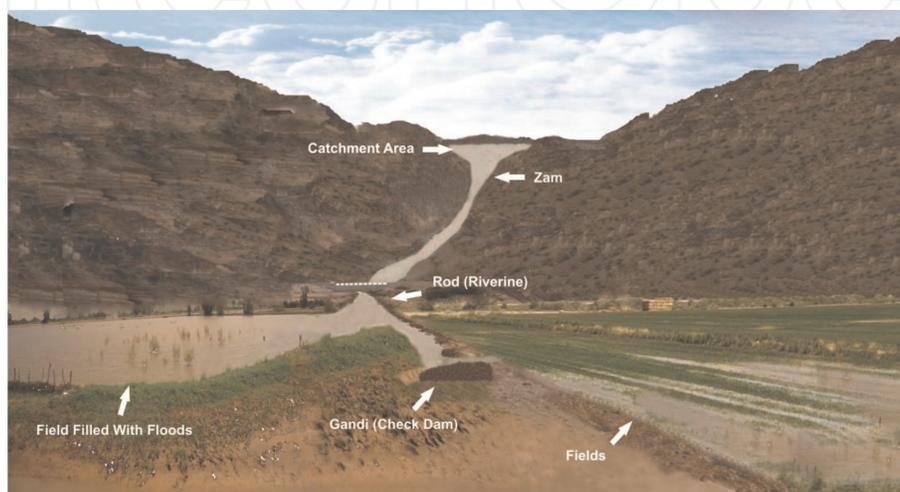


Figure 1. Schematic diagram of flood. From the mountains to the fields (courtesy Mr. Nabeel Rizwan).

problems related to tractors' build structures are that they are not as strong as those constructed by bulldozers and worn away by the great magnitude of floods. Also the mechanized agriculture is useful in leveling the land and pulverizing the soils. As each year the floods bring enormous amount of silt, and the farmers capturing huge floods also add massive amount of silt which imbalances the field. Tillage has great influence on the chemical, physical and biological characteristics of soil, and it subsequently results in better plant growth and yield [9]. Also for sustainable produce from a soil, it is important to use the tillage optimally [10].

2. Historical background of the spate irrigation system

Spate irrigation is an old system being practised in various parts of the world; the most prominent countries where the system is prevailing are Eritria, Ethiopia, Pakistan, Yemen, etc. The historical perspectives and the archeological evidences show that this system may have started 2000 years ago in the Arabian Peninsula and it covered most of the Yemen area [11]. The agriculture practices and the techniques involved in spate irrigation were spread in the Muslim world through the trade and development of the countries. In Eritria the system was introduced in its eastern part by the onset of the migrants from Yemen some centuries ago [12]. The system also prevails in other parts of African countries since 100 of years. The countries include Alegria, Ethiopia, Morocco, Sudan and Tunisia [13].

The torrential floods and spate irrigation in western Pakistan are also very old, and it goes back to 330 BC [14]. The spate irrigation was an important fragment of the early civilizations, due to the economic development.

Globally the spate irrigation is practised in different continents including South and Central Asia, Middle East, North and West Africa and Latin America. It is difficult to make an accurate estimate of the land under spate irrigation, because each year the areas under spate irrigation change.

In Eritrea the spate irrigation is carried out in Sheeb area [15]. The crops are grown without the use of fertilizers as the silt brings nutrients to the field and also increases the surface level. The investigation on quantity of silt deposited and its influence on the properties of soil revealed that in the upper stream the silt was deposited in the range of 8.3–31.6 mm year⁻¹, while in middle and downstream, it was 6.0–18.0 and 5.2–8.6 mm year⁻¹, respectively. Regarding the physical-chemical characteristics of soil, it was found that siltation brings plant nutrients, but it can be further increased by the application of manures and incorporation of plant residues after the harvest [15].

Spate irrigation is a source of living to huge number of poor people. It is estimated that approximately 13 million people are directly or indirectly linked to spate irrigation around the world. This system is practised in 20 countries in different continents of the world [16]. Spate irrigation is a very old system but the work done in this area is very little. The system has achieved some attention in the last few decades as some of the organizations have intervened into the area and carried out some interventions. In Pakistan the major issue in negligence of the area was its infrastructure; in the last few years, some of the areas have been linked to the city by the construction of roads which increased the mobility of the people. The farmers are now installing tube wells through solar system, using improved varieties of crops (wheat and gram), applying tillage operations periodically, etc. [17]. In other parts of the world, the spate farmers have carried out studies on efficiency of flood water, its diversion and distribution. It has been emphasized in the publication that distribution and diversion efficiency may be achieved by proper management practices. The effectiveness of modernized package in three major countries

practising spate was studied for 5 years, and it has been concluded that the spate farmers should use less number of irrigations, restrict the embankment length to less than 1 m, control overstretching the area under command, obey the rules for water right distribution to allow water to the downstream and enhance the water holding capacity of soil by conservation practices as mulch, tillage, crop residue management, etc. [16].

In Pakistan a very extensive area is under spate irrigation system (**Figure 2**). It spreads adjacently to the western mountain ranges. It starts from the southern part of Khyber Pakhtunkhwa including the Dera Ismail Khan and Tank district. In Balochistan province it is mostly practised in Sibi, Kachhi, Loralai, Gwadar, Awaran, Pishin, Turbat, Killa Saifullah, Dera Bugti, Lasbela, Panjgur, Mastung and Khuzdar districts. In Punjab it is mainly practised in Dera Ghazi Khan and Rajanpur districts and Larkana, Malir and Dadu districts in Sindh province (**Table 1**). In Pakistan the hydrological system is not only found in the northern region, but the western mountain regions also have the potential of 18.68 million acre feet (MAF) of water which flows to the plains through torrential floods [18]. It is found in various other countries. In this irrigation system, the floods after the rainy monsoon season in the catchment flow down as fast moving water in channels and reach the foothill plains. This water is used for growing crops after construction of big embanked field. The torrential floods are unpredictable both in magnitude and flowing velocity, due to which it possesses greater energy and thus creates problems for the farmers. The rainfall in the plains is very low (less than 250 mm year^{-1}), but the floods bring greater amount of water to plains. Irrigation used for agriculture purpose may be attained through rainfall and floods. As the region is resource poor and lacks modern techniques, so this result is wastage of huge quantity of water. Sometimes the situation gets even poorer as timely check dams are not constructed so the water cannot be diverted to the fields. Government and non-government organizations have intervened in the area for construction of local structure for management of floods, but still there is a huge work needed for the spate irrigation area.

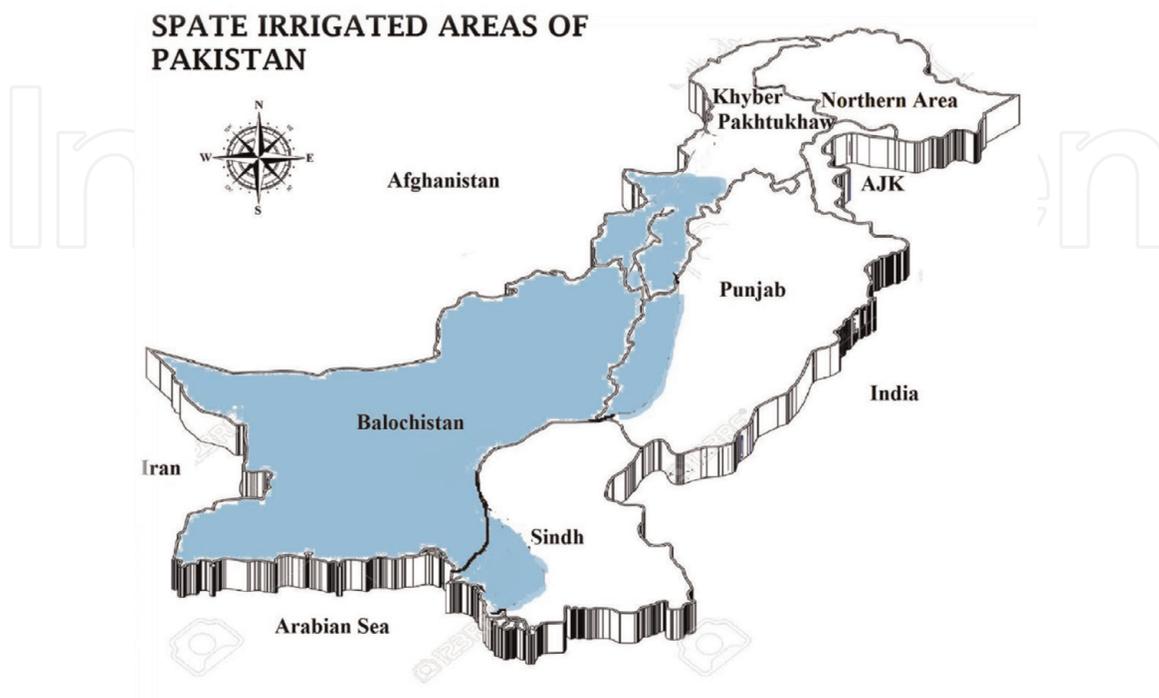


Figure 2.
Map of spate-irrigated area of Pakistan.

Province	Number of torrents	Potential area (million hectare)	Population dependent (million)	Approximate households (million)
Federal	—	0.271	—	—
Khyber Pakhtunkhwa	25	0.862	4.91	0.708
Punjab	17	0.571	2.24	0.319
Balochistan	17	4.680	5.81	0.841
Sindh	—	0.551	6.99	1.000
Pakistan	59	6.935	19.97	2.868

Sources: Agriculture Census of Pakistan, Census Organization of Pakistan, 2003; NESPAK, 1998.

Table 1.
 Province wise area under spate irrigation in Pakistan.

Ref. [19] reported that there is an inadequate data available of the spate irrigation area of Pakistan to develop a proper strategy for water management. Hence, the baseline data is very vital for the sustainable development of the spate-irrigated region. To develop and plan for the future of the system depend on the availability of data or information and also proper assessment of the water resources. The changing climatic pattern has made the assessment of the available water resources more important.

3. Problem and solution of spate irrigation

The area under spate irrigation has many problems and faces the two extreme conditions, i.e. drought and floods. In Pakistan the vast area under spate irrigation is Dera Ismail Khan (D. I. Khan) and Dera Ghazi Khan (D. G. Khan) districts, the southern-most district of Khyber Pakhtunkhwa and Punjab provinces, respectively. It is adjacent to the Sulaiman ranges, the western mountain range. There are five watersheds in the Sulaiman ranges adjacent to the D. I. Khan district, which are locally called as *Zam*. These *zams* are Tank, Gomal, Sheikh Haider and Chodhwan. In districts of DI Khan and Tank, there are 27% of the total land mass (0.687 mha) under spate irrigation system only in Khyber Pakhtunkhwa, while the rest is under canal irrigation, tube well and rainfed. There is a vast network of the small and large canal known as *Rodhs* in these two districts (**Figure 3**). There are a number of problems faced by the spate farmers in this area [20]. Some of the problems and their potential solution have been illustrated in **Table 2**.

Different researchers have reported various problems of spate irrigation; flash floods brought by the torrents are of high peak but very short duration [21]. The velocity of the flood water is high due to steep gradient and greater masses, and it results in damaging the infrastructure, irrigation channel and also the standing crop [22]. The basic constraint of the torrents' flow is the conservation or management of the flood being received [23]. In D. G. Khan district of Punjab, the spate irrigation system is satisfactorily functioning for longer time, but due to continuous siltation brought by the floods, the riverine or channel has become uneven and has affected the distribution of water and has created serious management problems [24]. The capacity of the water channel has reduced due to siltation in the channels, and this has created overflow of flood water and has caused damage to the embankments and standing field crops.

Ref. [25] stated that spate irrigation using the flood water for irrigation is the cheapest technique as compared with the other methods. They have investigated

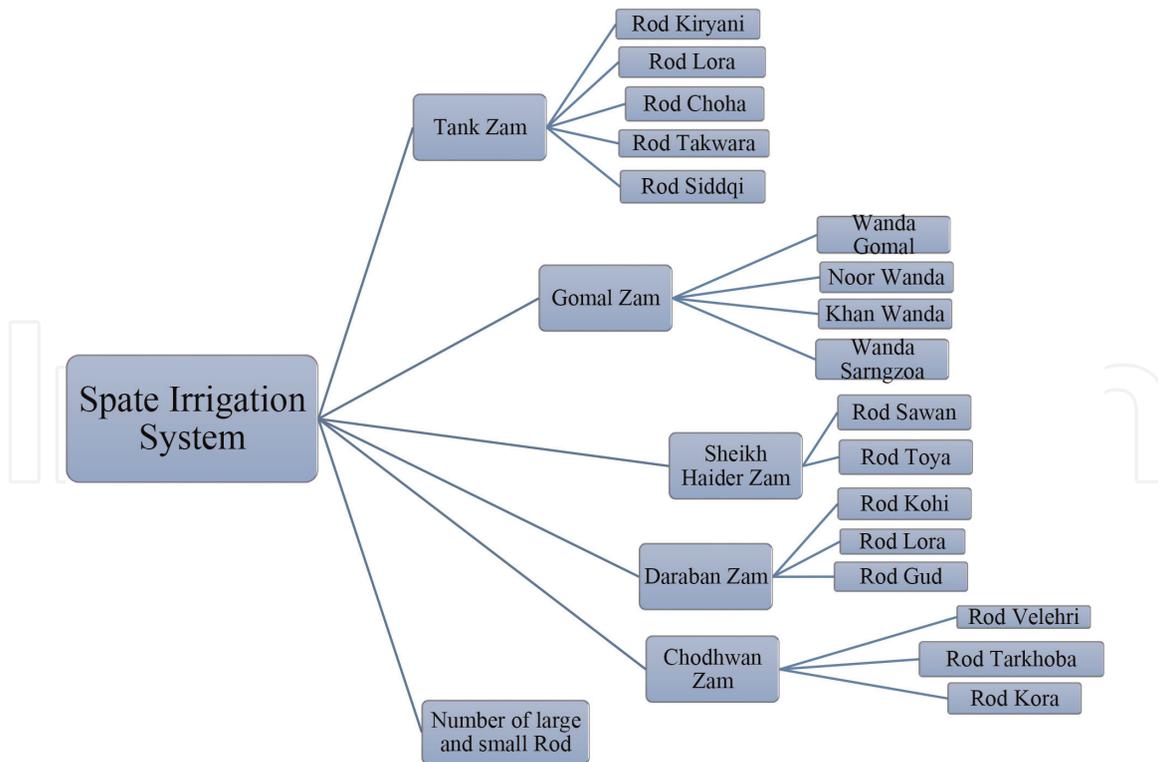


Figure 3.
The extensive system of spate irrigation of Dera Ismail Khan.

Identified problems	Potential solution
Unpredictability of the magnitude of the floods	Farmers in the spate should be prepared for the construction of check dam before time and should have fields well ready for flood harvest
Due to continuous siltation, the land is not properly leveled	The farmers should be facilitated through the government agencies in land leveling
The water distribution is uneven, and sometimes the head farmers may apply water more than once while the tail does not even receive a drop of it	The water user association functioning may help in even distribution of water between the different streams
Lack of technological development in the spate-irrigated area	The linkage between the different stakeholders is necessary for the development of area
There is less attention from the stakeholders	There is a need for the spate community to be aware to raise their voice and highlight the problems
The crops grown in the spate-irrigated area lack the access to main market	Access to market may be accomplished after the linkages are developed, and the mobility of the people enhances
The organic food produced in the spate has not gain the attention of the market or promotion	The consumers are less aware about the importance of organic products. But it is gaining importance as the health hazards and environmental problems are increasing

Source: [20].

Table 2.
The identified problems and their potential solution.

the different factors influencing the spate irrigation in Ethiopia from the year 2005; they have studied the crop choice and the requirement of irrigation. They collected data using the logit model. It was found from the study that farmers having the low

cost of production, greater capital for irrigation, own labour (family) and least rainfall may take the option of spate irrigation. Also they reported that crop choice is not affected by the market. Most of the spate farmers grow cereals and pulses as their own food security. The probability of the modern techniques in the spate irrigation may increase by spending less money on cost of production, availability of water resources, variation and climatic factor.

4. Water-agriculture balance in spate irrigation

This anomalous behaviour of water opens new windows for searching water resources. We receive water either from rainfall or from floods. Both resources are the outcomes of recycling. When climate temperatures slightly rise, it causes glaciers to melt which changes the ice into water. But this change in climate is controlled and bearable. In summer when temperatures are expected to become the highest, it then dismays the environment and brings floods. On having such situations, it becomes necessary to channelize this flood into irrigation water that can be termed as water harvest. In spate areas the inhabitant or farmers receive these floods as blessing of God, and in urban area it is not more than a menace.

In spate-irrigated areas, poverty commands and people are very hard to live. They are dependent of agriculture profession as main and sole profession. Soil is hard and barren, and water table is very low and neither so link nor black top road to link between farms to market. Although the area is responsive to many crops like wheat, gram, millet, *Sorghum*, guar, melon, *Brassica* and onion, they prefer to grow wheat and gram as second choice. An irony is that farmer cannot decide, only flood decides which crop should be sown and when to sow that crop. In Pakistan, after 2010 floods, the climate sway has been observed by the scientific community. This flood was prominent for its severity; 2010 floods are notable for their severity [26]. Projections related to the impacts of climate change warn that developing countries will be the greatest victims of climate change. The Global Climate Risk Index has rated Pakistan as the seventh most vulnerable country to be affected by climate change [27]. Imbalance environment (climate change) and over- and under-watering have depicted the significant changes amongst the common strata/people. Unusual floods in terms of time and magnitude have greatly influenced the prevailing climate and also disturbed the seasonal monsoon route. Such alteration has also made upset the rainfall schedule due to which crops are being grown either early or delayed to their actual time. Thus it can be said that farmers' sowing trend has been shifted due to changed rainfall docket. An interesting thing which has been observed in locality amongst the farmer is adoption of the people according to changed climate as well as water mood/temper. That is why they apply indigenous knowledge which they have perceived from remote ancestors for the purpose of biological control, moisture conservation from the flood water, fencing the flood, diverting flood route, converting flood water into irrigation water and handling noxious weeds and baneful pests. This native cognition also covers the cultivation method, crop choice, quality seed grading, seed storage, livestock health and crop care and their safety from diseases, pest identification and eradication.

4.1 Crops

The farmers in spate are growing different crops as source of fodder, fibre and food for earning their livelihood. The farmers in the spate-irrigated area are subsistent and wait throughout the year for harvesting water and growing crops. During the dry season, they have to migrate to the canal-irrigated area to earn their living.

Mostly the cereal crops are grown on vast area [18]. These include rabi (winter) crops such as wheat, gram and kharif (summer) sorghum, millet and melon. The comparison of yield of both flood water and perennial water revealed that the yield is low in flood-irrigated area. These cereal crops are essential for the food security and survival of the spate farmers, but there is potential for certain cash crops as cotton, sesame, guar, etc. [28]. However, there is very little choice for the farmers, as it mainly depends on the amount and time of water being received. During the monsoon floods, if the water received is huge, then wheat is the option, but if it is less in magnitude, the farmers have to grow gram. The cotton crop vanished due to more insect pest and shortage of water, whereas mung bean has disappeared due to growing of other fodder crops such as millets and sorghum. The wheat and gram are the preferred crops of the area, and the farmers and the owner try hard to get enough water to cultivate gram and wheat.

The crop yield has been fluctuated by heavy rainfall or floods and limited in no rainfall or drought. Other fields responded to fodder growth with little moisture. Under spate irrigation yield of the crops like sorghum, oilseed and wheat have been reported as 745,510 and 915.5 kg ha⁻¹, respectively [18]. The spate-irrigated land has the potential to give better yield of crops (**Table 3**) if the floods are timely available and management practices, i.e. land preparation, weeds management, pest control etc., are used.

Wheat grown in area has unique quality due to which it has captured the main focus of the farmers. The peculiarities of the local landrace of wheat is that it has greater loaf volume and greater protein content, hence having a better baking quality than the improved varieties. This wheat variety is known as dual purpose wheat, i.e. both consumed by human beings and livestock, or in other words it is used for fodder during early-growing season and also as straw after harvest. The grain yield of this landrace is comparatively low but has the potential to improve if proper environmental conditions are provided. It is meritorious in many aspects, i.e. fodder, grain and even straw is utilized which is very high. The physiology of this wheat cultivar is also praiseworthy as the seed grown at a depth of 10 cm may germinate, which indicate that it has a longer coleoptile length. As most of the farming system is based on monocropping, the farmers strive for growing wheat as it is a source of food and also seed for the coming season. The landrace has the potential to grow in dry condition as well as in the absence of fertilizer. These are the main reason that wheat is the first choice subject to the availability of water or flood whatsoever.

4.1.1 Fruits

As perennial water has been mostly available to the upstream villages, there were many orchards in the spate-irrigated areas (**Table 4**). The fruit orchards

Crop	Yield (kg ha ⁻¹)	
	Flood irrigation	Perennial irrigation
Wheat	905	1600
Gram	500	710
Millet and sorghum	610	1050
Melons	4080	5200

Table 3.

Productivity of crops grown under non-perennial and perennial spate irrigation in D.I. Khan and tank districts of KPK (agriculture census, 2006).

Farming practice	50 years ago	Now	Reason for change
Mung bean cultivation	Cultivated on few of the area which has received a lot of flood	Not cultivated any more	Mung bean requires more water, and therefore most people turned towards gram
Cotton	Cotton was grown	Not grown anymore	Pest attack and people have changed from <i>Sorghum</i> , and millets staple food to wheat, so by growing cotton land was not available for wheat
Fruit trees	Ber (<i>Ziziphus</i> sp.) is the common fruit in all villages and date palm orchards in some of the villages as Chodhwan	Very few ber trees except for the upstream perennial water receiving villages and at household	The Kuliyaat and Riwayat in which the trees are the property of landowner, and therefore the tenants did not care much for the trees
Plowing	Bullocks were used for plowing and earthen bund construction	Tractors and bulldozers are used beside the bullocks used by limited farmers	Introduction of mechanization in the 1972 onward by Agri. Engineering department and tractors became more common after provision through subsidies in 1989–1990
Tenancy pattern	The production was divided half and half with the sixth share of the owner	But now the trends of half and half share without sixth have started	To cultivate land by hired labour or temporary tenancy, the tenants do not agree for the sixth share; this is also happening in few of the area in permanent tenancy

Table 4.
Changes in spate agriculture over the 50 years.

included were date palm, grapes, mangoes, apples, ber, etc. But now most of the orchards have been turned into living places and houses; this is due to shortage and injudicious use of water and growth in population and land fragmentation. The major fruit trees found now are ber, date palm and melon. Ber is known in Pakistan as a ‘Miracle Tree’ as it has the potential to tolerate the severe drought condition. It is used as fruit and also a very good fodder tree; the shepherd in the spate-irrigated area buys the tree for its twigs and leaves [29]. The height of these trees may reach up to 10 ft. But now the population of this tree has been reduced due to scarcity of water, and also as the trees are the commodities of the owner of the land, the tenant is mostly not allowed to use the branches for their livestock, so the tenants do not look after them and even do not let them grow.

4.1.2 Vegetables

Different vegetables as bitter gourd, ladyfinger, tomato, onion, green chilies, etc. were grown in the upstream area and local market existed. Due to increasing population and easier access to the main markets, most of the vegetable gardens have been changed to living places. Conflicts of water usage to irrigate orchards have been also minimized. In the middle stream and downstream villages, they grow vegetables on the embankments for stabilization of the embankments with the crops for their own consumption. These vegetables include pumpkins and bitter gourd.

4.1.3 Trees

The native trees in spate-irrigated area are *Acacia nilotica*, *Tamarix aphylla*, *Capparis decidua*, *Prosopis cineraria*, etc. which are common but found standing alone in a huge field. In the early 1900s, *Prosopis juliflora* (mesquite) was introduced in by Mian Musa Alvi the servant of Dak bangle; he was provided the seed by the English officer for his barren land to control the land degradation. This tree has the ability to spread faster and has now occupied the whole spate area, and every day eight to ten lorries of the fuelwood obtained from this tree have been sent to urban area and therefore have proven to support the labourer class in their daily life. Due to the rapid spread of mesquite, other tree species have reduced.

4.2 Soils

The soil of spate-irrigated area is usually rich soil with native soil fertility, and the sediments brought about through the floods replenish the fertility status. The texture of soil ranges between silty clay and silty clay loam, and these have greater water holding capacity due to fine size and may retain the moisture for a longer period of time [30]. It has been observed that most of the floods received during the monsoon season (July–August) are being allowed to infiltrate in the soil layers for 2–3 months, and the surface is mulched with the soil during the late summer when the temperature is still high, but the water is strongly held that it does not evaporate. The same moisture is used for cultivation in late October, and if no supplementary rains are received, the moisture is enough for the whole crop season till harvest. Changing climatic pattern will have great influence on the water resources and will also affect the soil resources [31]. Climatic model showed that the direct impact of climate change on soil properties may be the losses of soil carbon which will also affect other soil characteristics like poor soil structure, soil strength, water holding capacity, nutrient cycling and increase in soil erosion due to less soil cover [32]. The soil structure is an important soil property in the spate-irrigated area as it affects the movement of water and nutrients, growth of plants, exchange of gases and activities of soil fauna. The soil structure of spate soil is usually improved by the addition of organic matter with receiving of floods. As the temperature of soil increases the rate of organic matter, decomposition will also increase, and it will destroy the structure of soil. The water holding capacity of soil is also linked with the soil structure; the soil having good soil structure has greater water holding capacity. The water holding capacity of soil in dryland areas like spate irrigated is very important as the moisture is mostly stored in soil and the plants can efficiently use the moisture. The productive soil has the capacity to provide nutrients to the plants, but the nutrients' mobility is mainly concerned with the organic matter decomposition and availability of moisture. The soil of spate has native fertility, and it replenished with each flood, but under extreme drought the soil surface becomes scarce in vegetative cover, and the following floods may result in greater soil erosion. As there is open grazing, the threats towards the erosion both due to water and wind increase. The local farmers usually grow vegetable on the embankment to stabilize the structures. As the dry spell and temperature increase, the rate of evaporation exceeds the rainfall which may lead to salinity and sodicity. Sodicity is the excess amount of exchangeable sodium accumulated on the surface of the soil. Crust formation on the surface of the soil is a problem faced by different soils around the world [33]. The crust formation is also very common in the spate-irrigated areas due to depositional and formational structure; this is due to the fact that the area of spate has the climate conducive to crust formation. The crust formation in spate-irrigated area may adversely affect the increase in the surface

runoff and reduction in the rate of infiltration into the soil. The crust formation reduces the germination of seedling and eventually results in the decline of crop yield. There are different solutions proposed for overcoming the problem of crust formation such as optimal tillage operations, application of manures, crop residue incorporation, mulching, seed sowing at appropriate depth, sowing on ridges, etc. Soil in this part of Pakistan is moderately to strongly calcareous with alkaline pH. Soils have sufficient potassium content and micronutrients but are mostly deficient in nitrogen and phosphorus. The fertility status of spate-irrigated soils of Dera Ismail Khan, Pakistan, in 87 soil samples collected from different locations and analyzed for various soil physico-chemical characteristics showed that 50% of the soil were of medium texture and 45.9% were clayey fine texture. There were very little soil with coarse texture (3.5%), and saturation percentage of the soil ranged between 16.2 and 67.0%; salinity and sodicity showed that 13.8% were saline, 5.8% were sodic and 74.7% were normal soils. The fertility status of the soils under investigation revealed that all the soils were deficient in nitrogen, while phosphorus was deficient in 89.4% soils, but potassium was found adequate in 70.6% of soil samples analyzed [30].

4.3 Climate change: pros and cons

Climate change is an important term that mentions the variation in climate over time; it may be due to changes in natural events or due to human activities [26]. The climate change has greatly influenced Pakistan by frequent spells of extreme events of weather, i.e. floods, glacial lake outbursts, droughts, heat waves, etc. These extreme events have made Pakistan more vulnerable to climate change and also have killed many lives. The impact of climate change on Pakistan agriculture, economy, property, etc. is well documented [34]. The heavy flood of 2010 has alone killed 1600 people, caused damage of approximately \$10 billion and flooded 38,600 square kilometres (km²) [35].

The freshwater resources of Pakistan are very small. The primary source of water is rainfall and it provides major as monsoon rains [36]. Climate change will affect the arid and hyperarid areas of Pakistan due to uncertain and erratic rainfall pattern. The rate of evapotranspiration will increase which will also enhance the water requirement of crops by 10–30% [37].

Spate irrigation and climate change are deeply intertwined, as the system in spate is wholly solely dependent on the rainfall and floods. The time and the magnitude of rainfall also matter. Mostly the timely rainfall received in monsoon and spring seasons are crucial for the summer and winter floods which are made useful for growing agricultural crops. Also the selection of crops in spate irrigation is influenced by the time and magnitude of floods received, as there are limited options for the farmers of spate regarding selection of agriculture crops. Due to untimely rainfall either early or late, the cropping season is badly affected and may lead to a fallow season or low crop yield. The yield of wheat crop may be significantly decreased by receiving greater rainfall, but marginal enhancement in the rainfall will not be going to have any considerable results of wheat [28]. Also the livestock may be affected by the climate change in two main ways, one by the reduction of fodder and forage and second directly by the temperature intensity [38].

Other climatic constraints under spate irrigation may be increased atmospheric temperatures which may lead to higher evaporation and severe moisture stressed conditions. More extreme condition may be recorded if heavy floods are received which may wear away the big embanked field and standing crops and erode the fertile soil. In Pakistan the communities which are found to be the most vulnerable to climate change are the subsistence farmers having the small landholdings [39].

Growth of crop is highly affected by the amount of water and changes in temperature; according to an estimate, the increase in temperature by 0.5–2.5°C the agriculture productivity of the crop will decline by 8–10%, and this is estimated to be the case by year 2040 [40]. The crop growth simulation model showed that the length of growing season of major crops, i.e. wheat and rice, will decrease which will result in the decrease in yield of crop. Also the climate change projection provided by the Intergovernmental Panel on Climate Change (IPCC) states that the productivity of agriculture crop in Asia is bound to decline due to heat stress and the floods and drought tend to increase.

4.4 Water rights

Water right is the legal permission to use the water, or water laws and rights pertain to the water use by water user from different water sources, i.e. canal, floods, tube well, etc. The main aim of the water rights is to avoid the conflicts on water usage and its equal distribution, avoid the wastage, etc. Under spate irrigation there are different rules for flood water and perennial water. As the flood water has huge quantity of water, so usually distribution in quantitative term is difficult, but in the case of perennial irrigation, the distribution is quantitative. Prior to mechanical intervention, the rules in spate irrigation were strictly followed, and the government supervision was also firm.

4.4.1 Flood water

The torrential flood received in the plains is unpredictable both in time and magnitude. To effectively use the flood for agriculture and minimize the conflicts amongst the spate communities, certain rules were devised. The documented rules of water distribution are locally known as the Kulyat and Riwayat-e-abpashi (formulae and customs for irrigation). The spate irrigation of D. I. Khan and D. G. Khan was first documented by the British Revenue administration in 1905 in the form of Riwayat and Kulyat-e-Abpashi [41]. These rules are still being followed. These rules follow the head-to-tail rule which is locally called as the saroba and paina. The earthen dams are built in the main riverine and used for diverting water. The upstream area irrigates their land first, and when the whole field is being irrigated, the earthen dam is breached. Kulyat and Riwayat mainly emphasize on the following main points as discussed by [41]:

1. When to breach the bunds (check dams)
2. The sequence of receiving water in the canal and field
3. Rights for second and third irrigations
4. Amount of water a farmer can store in the field

The water rights rules in the spate systems of Dera Ismail Khan and Dera Ghazi Khan under the Sulaiman range in Pakistan were prepared by the revenue period during the British colonial period. The major work was done by Mr. HN Bolton during his tenure as deputy commissioner in 1908. This system was considered as an important source of tax; therefore the Revenue Administration had interest in the system. Also the water distribution right provided an opportunity to resolve the conflicts and disputes amongst the people [28]. The rules were enforced by the Rod Kohi department. The Kulyat Rodwar has these rules written in a register having

information of all the villages, labour and also the land. Also an official was responsible for the execution of these rules, urging the farmers to rebuild the embankments and plug the eroded gullies. As according to the flood water distribution rules in Pakistan in the main riverine, the concrete structure is not allowed. Only the earthen structure is allowed; the Department of Agriculture Engineering used to provide the machinery as bulldozers, etc. for the construction of large structure which were strong enough to face the strong flood, but after the closing of agriculture engineering department, the farmers construct the structure on their own through contribution. The place for construction of structure is already demarcated; they are constructed each year on the same place. As floods are unpredictable, often the structure in the upstream is not built at proper time, so the floods make their way to the mid-stream and tail. Also the surplus water is allowed to flow to the tail after breaching of the structures. The amount or depth of irrigation to be applied is not confined; usually the farmer shows voracity in water storage, which leads to breaking of bunds, and sometimes the farmer has to remove the excess water so that the soil may come to field capacity on time for sowing of crops. In the spate irrigation rules, the farmer is allowed to irrigate for the second time if all the other fields in the area have been irrigated. But factually it is not practiced, because the influential irrigate sometimes more than two times while the tail area does not receive a drop of water. Also the number of irrigation depends on the amount of water being received after the flood. As the climatic pattern is changing, the flood-based system is also changing with severe floods in some of the years and drought in other years. The conflicts may become even worse due to water distributions with change in rainfall and flood patterns.

4.4.2 Perennial water

Perennial water is another source of water in the spate irrigation. This water is locally called as Kala Pani; it is received throughout the year in the riverine through the streams. Like the land there is ownership for irrigation water. At watershed level the water is distributed amongst the different tribes living there. If we consider the example of Chodhwan *Zam* (watershed), the largest watershed in Dera Ismail Khan District, the perennial water is distributed between the Babar and Mina Khel tribes as 7:5. These are distributed through a unit locally called *Boli*. There are 10.5 *Boli* in the share of Babar tribes, which is again distributed as 1 for orchards, 1.5 for drinking and 8 for raising crops. Each *boli* is divided amongst the *Babar* subtribe or sub-cast. These casts are Musazai, Mardanzai, Badanzai, Shakarzai, Ahmad Khel, Ibrahimzai, Safarzai and Mangalzai. Each has single *Boli*. Each *Boli* is again divided into 18–20 *wails*, and in each *wail* there are 16 *churukas*. To make it understandable, 1 *churuka* means irrigation for 45 minutes depending on the amount of water. The water rights for the perennial water are different than flood water. The water in perennial system flows throughout the year. There are a number of crops that can be grown on perennial water. The perennial water may be used for irrigation on any land depending on its availability. Usually they are grown in the areas where they do not have the flood water rights. The tenure system in the perennial irrigating land is usually 7:5 for the land and water owner and the tenant.

Climatic sway has greatly influenced the perennial water as there is less rain during some of the years which may result in less water for recharging of streams and less water for perennial. Also during the flood season, the perennial water which mixes into the flood water as the riverine for both the flood and perennial water is the same. Also the farmers in spate are turning towards digging of tube wells, and some of them have been artesian well. Due to the extensive use of these

Dera Ismail Khan		Tank			
Tehsil	Villages	Tehsil	Villages	Tehsil	Villages
Dera Ismail Khan	Isa Khan	Kulachi	Kot Zafar Baladasti	Tank	Kot Murtaza
	Yar Manji Khel		Naskor Nahura		Gomal
	Potah		Rori		Ghasha
	Sikandar Shumali		Mohabat		Gorazai
	Chadrhar		Kanor		Dabara
	Hassani		Hathala		Shiekh Sultan
	Hawasi		Gara Hayat		Toran Tattor
	Hattu		Kot Daulat		Kalu Prangi
	Teli		Gara Guldad		Pattar
	Faqira		Gara Sardar		Uttar
	Budh		Looni		Fateh Chadhrar
			Kulachi Gharbi		Shadda
			Kulachi Sharki		Mutta
			Gara Jana		Mian Khan
			Kot Attal		Jamal Korai
			Gara Ibrahim		Jamal Awan
			Gara Nadar Badar		Diyal
			Maddi		Daulat Khan
			Kot Zafar Firodasti		Mamrez Balock
			Saggu Gandapuri		Mamrez Pathan
			Gara Gul Mohd		Khair Awan
			Rakh Ranwal		Rakh Ranwal
					Ranwal
					Murma
					Bara Khel
					Kot Allah Dad
					Habib Wattoo
					Manjhi Khel
					Mashooqa
					Tei Malook
					Azami
					Nadir Ali Shah
					Safdar Ali Shah
					Baghwal
					Kahu
					Dagar Khan

Table 5.
Villages under Gomal Zam dam command area.

tube wells, there are chances of drying up of streams which may lead to declining of perennial water flow.

4.5 Construction of dams

The flows of spate have been utilized for irrigation for centuries, but to avoid losses and wastage of water, a huge storage dam has been constructed on one of the watersheds. Gomal Zam is the largest zam amongst the five with greater catchment area and greater command area. The Gomal Zam irrigated 24 villages of Tank and 60 villages of Dera Ismail Khan (**Table 5**). The Government of Pakistan has initiated construction of dam on the watershed in 2002. The dam is named after the name of watershed Gomal Zam Dam. The dam was completed in 2013. The storage capacity of the dam is 1.140 MAF. The dam provides as source of irrigation and operates under a well-controlled system. The command area under the dam is 65,200 ha. The discharge of water has enhanced the efficiency of water and reduced the threats of floods and drought in the command areas. It will also produce 17.4 MW electricity as Pakistan is also facing the energy crisis. The climate of the area is subtropical, hot in summer and cold in winter. The crops grown before the construction of dam were wheat, gram, sorghum and millet. Now there is a potential of growing other crops as cash, cereal and sugar crops. The perennial availability of water has changed cropping pattern, and also the land which was previously kept – fallow – was used for cultivation [42].

Gomal Zam dam is the first intervention in which the spate water has been stored in a huge dam, because the heavy flood in the spate irrigation was difficult to control and used to cause much of the damage to the property and also the lives. Due to greater mass and velocity of the floods, the kinetic energy becomes greater and the damage it causes is also massive. The dam has positive impact on the economics and agriculture of the area which are noteworthy. After shifting from spate to canal irrigation, the mindset needs to be changed. There are several projects which are running to equip the farmers of the command area with improved techniques such as laser leveling, extension activities, etc. Also the area below the command area which had the water right in the spate irrigation has become deprived of the water resource on one hand, and also the ecology of the area has also changed, as the area now has become rainfed.

5. Discussion and conclusion

The spate-irrigated area focused in this chapter has the diversified physiography, with mountains on the west and River Indus on the east. The area is distinguished in terms of climate, land and water resources. The climate varies from very hot summer temperature ranging from 35 to 45°C to cold winter with temperature of 5–15°C. The district was previously under the spate irrigation and has the land-form of piedmont, with vast land. After the construction of gravity canal from the Indus River known as Chashma Right Bank canal, more than half of the area become irrigated in the downstream. The western part still remains part of the spate irrigation. With the recent development, some of the influential landowners of spate have installed tube wells to irrigate the lands. But studying the hydrology of the area, it is evident that the groundwater in the spate-irrigated area is brackish. Most of the tube wells in the area are deep installation at 400–500 ft. The construction of Gomal Zam dam has also developed the area in terms of perennial irrigation.

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