Chapter1

Water Resources and Irrigation Network of Pakistan

Muhammad Arshad and Ramchand N. Oad*

Abstract

The issues of growing water scarcity have spread due to several factors, including the increasing cost of water development, degradation of soil, mining of groundwater, water pollution, and wasteful use of already developed water supplies. Pakistan has been blessed with adequate water resources, including precipitation, groundwater and surface water. Groundwater of acceptable quality has potential to provide flexibility of water supplies in canal commanded areas and to extend irrigation to rain fed areas. Major source of surface water for irrigation in Pakistan is the Indus Basin Irrigation System. Many potential dam sites exist on river Indus and its tributaries, which can make a substantial contribution to irrigation supplies for agricultural lands, through the substitution of live storage loss of 7.27 BCM for on-line reservoirs; and ensuring the irrigation water supplies for existing projects in all the provinces as per additional allocations under 1991 Water Apportionment Accord. The major rivers of Pakistan originate in the northern highlands of Himalaya, Karakoram and Hindukush mountain ranges and act as tributaries of the Indus River system, which commands an agricultural area of more than 60 mha (0.6 million km^2). Following Indus Water Treaty, the country built several link canals and barrages to divert and transfer water from its western rivers to the eastern rivers to serve the areas left unirrigated after the treaty. To utilize these river resources, over the years, several reservoirs, dams, barrages and canals have been constructed to regulate irrigation

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water supplies. This chapter, therefore, presents a summary of rivers, dams, barrages link canals and a network of canals serving the Indus Basin Irrigation System which operates to support agriculture in Pakistan.

Keywords: Indus Basin, River, Dam, Barrage, Canal, Water Allowance, Warabandi

Learning Objectives

- The primary purpose of this chapter is that the reader would learn about the historical developments and operational components of the existing irrigation system in Pakistan.
- To update the knowledge about various sources of water, such as canal water, groundwater and rainfall and their availability for agricultural production and other uses in the country.
- Learn about the rivers, water storage reservoirs and canal irrigation network of the Indus Basin Irrigation System supporting the agricultural production in Pakistan.
- Know about the available supplies of the irrigation system and water distribution at tertiary level.

1.1 Introduction

Amongst global resources, water is one of the most important natural resource. It is an essential input to domestic, municipal and industrial activities, and important requirement of agricultural production. Growing national, regional and seasonal water scarcities in the world pose severe challenges to agricultural development and food security (Shabbir et al., 2012; Shakoor et al., 2012; Shakoor, 2015). Agriculture worldwide is by far the largest water user, consuming about 80 to 90 percent of available fresh water. Water has been vital to food security and sustainability of the livelihood, especially in the developing countries. Considering the global importance of water for food security, major conflicts among the nations are just for the access to water. Increasing population in various countries, such as Pakistan, is putting pressure for the efficient use of available water supplies to enhance the crop and water productivity (Chatha et al., 2014; Javed et al., 2015; Mongat et al., 2015).

Water scarcity is a global issue that affects the population of each country. More than 1.2 billion people live in areas of physical scarcity, and about 500 million people are approaching this limit. Another 1.6 billion people, or one fourth of the world's population, face economic water shortage, where countries do not have the required infrastructure to take water from rivers and ground (FAO, 2007). Therefore, developing countries need to search methods to grow more food with the same or less consumption of water. Consequently, the world’s irrigated area would need to be increased by 29% to meet food and nutritional requirements. Thus, irrigation expansion would require construction of additional storage reservoirs and diversion facilities to increase the world’s primary water supplies by 17%. Further, the crop yields would also need to be increased by 38 percent, i.e., from a global average of 3.3 to 4.7 tons per hectare (IWMI, 2000).

As the population continues to grow in Pakistan, the country is approaching a worse water scarcity situation that evidently requires that the available supplies should be managed so that this precious resource is utilized more efficiently on a sustainable basis (Javaid et al., 2012; Arshad et al., 2013). Thus, understanding the irrigation water resources system of Pakistan in terms of its river and canal systems, operational management, availability and distribution of water to support the agricultural production is important for the professionals and planners for handling water and food security issues in the country.

1.2 Water Resources of Pakistan

Pakistan has been blessed with a variety of water resources in the form of glaciers, seasonal precipitation, groundwater and surface water through the Indus Basin Irrigation system. The potential and degree of availability of water through these resources is summarized below:

1.2.1 Glaciers

Significant part of the Indus River flow originates from Karakoram Himalaya, Western Himalaya, and Hindu Kush Mountains. The role of this runoff for the climatic characterization of the mountain catchments is well recognized, particularly, the glaciers carry great significance in the flow volume and timing of the Indus River and its tributaries, as well as on the potential impact of climate change on this water supply. The role of glaciers in the hydrologic regime of these mountains is due to the inaccessibility and altitude of Himalayan glaciers, which exist at an altitude of 4000 to 7000 meters. Estimates of the potential impact of the glaciers on flow regime are derived based on the available databases and topography obtained from satellite imagery. It is estimated that the surface area of the Upper Indus Basin is about 220,000 km^2, out of this, more than 60,000 km^2 exist above 5000 m, the estimated mean altitude of the summer season freezing level. The glaciers of the region flowing from this zone have been estimated to have 7000-8000 km^2 area below the summer-season freezing level, which is the source of the bulk of the annual glacier melt flowing into the Indus River tributaries. The glacier runoff contributes approximately 24.1 BCM to the total annual flow of the Upper Indus Basin: 17.3 BCM from the Karakoram Himalaya, 2.8 BCM from the western Himalaya, and 3.9 BCM from the Hindu Kush.

1.2.2 Rainfall

The regional distribution of average annual rainfall varies from less than 100 mm in Balochistan and Sindh provinces to more than 1500 mm in Northern mountainous areas. About 70 percent of annual rainfall is received during the monsoon period, i.e., the months of July and August. During Rabi season (October to March), it is less than 50 mm in parts of Sindh and more than 500 mm in Khyber PakhtoonKhaw (KPK) provinces. Similarly, the mean rainfall for the Kharif (April to September) season varies from 50 mm in Balochistan to more than 800 mm in the Northern Punjab and KPK. The extreme changing pattern of rainfall results in large variations in flows during the Rabi and the Kharif seasons. Due to this severe aridity, about 92% of areas of Pakistan is facing extreme shortage of water and hence classified as semi-arid to arid.

In terms of availability to crops, rainfall is neither regular nor sufficient. During monsoon, the rainfall intensity and volume is much more than that can be stored in the root zone. A large portion of the rainfall, therefore, either floods the riversides and low lying areas of riverside and results consequential miseries and losses, or flows into the sea without any beneficial use in the country. Most of the monsoon rains are also neither available for crop production nor contribute to groundwater due to runoff. About 16.5 BCM of rainwater contributes to crops in the Indus Basin Irrigation System (IBIS), which is only 13% of the average annual canal diversions (Ahmad, 2005).

1.2.3 Groundwater

Groundwater provides an alternate water resource for agriculture. It is estimated that around 33% of the world's population utilizes groundwater. Many countries, such as Pakistan, India, intensively exploit groundwater to supplement the canal water. The abstraction of groundwater has reached to its limits in much of the area of the world, especially in drought zones. The rice-wheat region (Central Punjab) of Pakistan is meeting 70% of their crop water requirements from groundwater (Arshad et al., 2008; Shakoor et al., 2015). Therefore, sustainability of groundwater resource is essential, which depends upon the relative contribution of rainfall to direct infiltration and river inflows for recharge of alluvial aquifers (Shiklomanov, 1997).

Groundwater of acceptable quality has the potential to provide flexibility of water supply in canal commanded areas and to extend irrigation to rain fed areas. If conjunctive surface and groundwater use can be implemented properly, there is a potential for further utilization of lower quality groundwater supported by careful management strategies. Consequently, one main policy issue now is to develop a legal framework for groundwater exploitation that should be environmentally sustainable and viable on long-term basis without causing undermining.

In Pakistan, most of the groundwater resources are stored in alluvial deposits formed by the Indus River and its joining tributaries starting from the Himalayan Mountains to Arabian Sea. The Indus Plain area is 1600 km long and extends over an area of 21 mha. This alluvial deposited plain has extensive unconfined aquifer, which is providing a supplemental source of water for irrigation. This groundwater reservoir has been enriched by the direct recharge from rainfall, river flow, and the continued seepage from the irrigation network of canals, distributaries and watercourses since the last 90 years (Kahlon et al., 2012). The groundwater use in different provinces of Pakistan is presented in Table 1.1. In the Punjab and Sindh, about 79 and 28% of the area is underlain by fresh groundwater, which is used as supplemental irrigation pumped through tubewells.

Table 1.1 Groundwater Budget in Different Provinces of Pakistan in Normal Year

Components	Billion Cubic Meter (BCM)

	Punjab	Sindh	KPK
Recharge components			
Recharge from rainfall	7.99	2.42	1.08
Recharge from irrigation system	25.46	18.92	2.28
Return flow from the GW abstraction	5.70	0.97	0.16
Recharge from the rivers	4.00	0.37	0.16
Total	43.15	22.68	3.84
Discharge components			
Groundwater abstraction (Public + Private)	38.00	4.30	2.18
Non-beneficial ET losses	2.00	16.96	0.30
Base flow to rivers	3.15	1.42	1.81
Total	43.15	22.68	4.29
Net change	0.00	0.00	-0.45

1.2.4 Surface Water

The agriculture sector is the one of the major users of water and its consumption will be continued to dominate over all other sectors. Out of a total of 193 BCM of water diverted from rivers, only about 130 BCM are made available annually at the farm level for irrigation. In addition, around 59 BCM are being supplemented from the groundwater resource. Direct rainfall contributes less than 15% of the water supplied to crops. Regarding, land resources, out of the cultivable land of 31 mha, only 16mha is canal commanded. Therefore, Pakistan still has an additional potential of bringing 9 mha of new land under irrigation.

According to Indus Water Treaty, signed in 1960 between India and Pakistan with the coordination of the World Bank, India was given the exclusive right to use the water of rivers Ravi, Sutlej and Bias, whereas the water of western rivers Chenab, Jhelum and Indus was given to Pakistan. This treaty included the replacement works comprising the construction of two major dams (Tarbela and Mangla), 5 barrages and 8 link canals to alleviate the problems. However, due to excessive sediments from the rivers, both dams are losing their capacity and it was estimated that their storage has been lost up to 34% (about 7 BCM, which is virtually equivalent to the storage capacity of one such major reservoir. Pakistan is heading towards a situation of acute water shortage due to increasing population pressure. Per capita surface water availability was 5650 cubic meters in 1951, which has been reduced to less than 950 cubic meters in 2015. Now, Pakistan has reached the stage of “acute water shortage” i.e., less than 1000 cubic meters per capita. Water escapes to the sea below Kotri vary from 10 to 113 BCM with an annual average of over 48 BCM. This surplus water in the rivers is only available during 70-100 days of summer. To save and beneficially utilize this available surplus water, the construction of newdams is essential for the sustainability of irrigated agriculture.

Pakistan has two cropping seasons, Kharif (Summer) and Rabi (Winter). Sowing season of Khari starts from April-June and the crops are harvested in September-October. The summer season crops include rice, sugarcane, cotton, maize, moong, mash, bajra and jowar. The sowing season of "Rabi" starts from October-November and the crops are harvested in April-May. The winter season crops include wheat, gram, lentil (masoor), tobacco, rapeseed, barley and mustard. The crop production depends on timely availability of water. During the year 2012-13, the water availability was 14% less than the normal supplies, but to compare with Kharif-2011, it was 4.4% less. The water availability during Rabi 2012-13 was estimated 39 BCM, which was 12.4% less than the normal availability, but 8.5% higher than the Rabi-2011 crop. The year wise actual availability of surface water during Kharif and Rabi seasons is given in Table 1.2.

Table 1.2 Actual Surface Water Availability

Period	Kharif (BCM)	Rabi (BCM)	Total (BCM)
Average system usage	82.5	44.7	127.2
2004-05	72.7	28.4	101.1
2005-06	87.1	37.0	124.1
2006-07	77.6	38.4	116.0
2007-08	87.1	34.3	121.4
2008-09	82.3	30.6	112.9
2009-10	82.8	30.8	113.6
2010-11	65.7	42.6	108.3
2011-12	74.3	36.2	110.5
2012-13	71.0	39.2	110.2

Source: Economic Survey of Pakistan, 2012-13

1.2.5 Irrigation and Hydropower Storages

In addition to serving the agricultural sector for meeting crop demand, the water resources are also important for power generation. The national demand of electricity has been growing and would continue to grow rapidly due to increase in population and industrial growth in the country. Presently, the hydel and thermal mix generation capacity in the country is 28:72, against the potential requirement of 70:30 for the economic development. Table 1.3 gives the water storage reservoirs with power generation facilities on various rivers. Although the thermal generation initially helped in overcoming load shedding, yet it resulted in an increase in power tariff. Therefore, construction of hydropower generation units through multipurpose storages is a viable option to keep the electricity cost within affordable limits. In view of the situation, WAPDA prepared a Vision 2025 program for the development of water and power resources of Pakistan. The proposed water storage reservoirs and existing water storage reservoirs with their capacities are given in Table 1.4.

1.3 Irrigation Network of Pakistan

The major source of water for irrigation in Pakistan is the Indus River and its tributaries, including Jhelum, Chenab and Kabul rivers. The total canal supplies delivered by the system during 1960-61 were 105 BCM and the irrigated area was about 10.4 mha. The construction of dams enabled the country to enhance capability of river flow regulation. After attaining regulation in storage facilities, canal head diversions progressively increased, which also increased the recharge to groundwater. Presently, the irrigation system is utilizing annually a total of 129.7 BCM of river water diverted through the canal system. There is a potential to further

Table 1.3 Existing Water Storage Reservoirs

Dams and Lakes	River	Height of dam (m)	Live storage (BCM)	Power (MW)	Purpose*
Terbela	Indus	147.8	11.38	3478	I, P
Mangla	Jhelum	115.8	5.90	1000	I, P
Chashma	Indus	-	0.75	-	I, P
Warsak	Kabul	76.2	0.05	240	I, P
Baran Dam	Kurram	32.6	0.04	4	I, P
Hub	Hub	46	0.93	-	I, W
Khanpur	Haro	50.9	0.11	-	I, W
Tanda	KohatToi	35	0.07	-	I
Rawal	Kurang	34.7	0.05	-	W
Simply Dam	Soan	65.5	0.02	-	W
BKD Dam	Pishin	10.7	0.05	-	I
Hamal Lake	-	-	0.09	-	I
Manchar Lake	Indus	-	0.92	-	I
Kinjhar Lake	Indus	-	0.39	-	I, W
Chotiari Lake	Indus	-	0.95	-	I

I- Irrigation, P- Power, W- Water Supply
Source: WAPDA, 2002

Table 1.4 Proposed Water Storage Reservoirs and their Capacities

Proposed Dams	River	Height of dam (m)	Live storage (BCM)	Power (MW)	Purpose*
Yugo	Syhok	164.5	5.90	1000	I, P
Skardu	Indus	230.1	18.99	4000	I, P
Bhasha	Indus	201.1	6.98	4500	I, P
Kalabagh	Indus	79.3	7.46	3600	I, P
Kalam	Swat	137.1	0.32	110	I, P
Mir Khani	Chitral	124.9	0.71	150	I, P
Khazana	Panjkora	115.8	0.68	110	I, P
Munda	Swat	213.2	0.82	740	I, P
		Total	21.90	13070	

I- Irrigation, P- Power
Source: WAPDA, 2002

increase the irrigated area by about 9.2 mha. The irrigation system of Pakistan includes 3 major storage reservoirs (Tarbela, Mangla and Chashma), 19 barrages, 82 small dams and 48 major command canals. Tarbela is the largest dam of Pakistan, which is also believed to be second largest in the world in terms of structural volume with a surface area of 240 square km, and is generating around 3500 megawatts of electricity.

During the post-Tarbela period of 24 years (1976-2000), an annual average of over 46.33 BCM of river flow escaped below the last barrage on the Indus River (Kotri) to the Arabian Sea, concentrated in about 70-90 days of summer only. No crop can be sown and taken to maturity in this short period (but the outflow could be stored for use later). Kharif crops need some water before the start of surplus flow and some water after the surplus ends. Such water availability can be possible from new storage reservoirs. Flow pattern of the Western rivers during the year is quite variable. Those carry high discharges in summer (Kharif) and disproportionately low discharges in winter (Rabi). About 88 percent of the flow occurs during the summer monsoon rains. With the help of Mangla and Tarbela dams, seasonal carry over capacity of Kharif and Rabi seasons was increased from 12to 21%.

The natural siltation is constantly reducing the capacity of the existing storages and according to an estimate this capability has now reduced from 21 to 19%. Their aggregate design gross storage was 22.01 BCM. Consequently, the available supply of canals in Rabi and Kharif for the sowing and maturing periods has been thus, progressively reducing. Development of more water storages is a dire need in the present situation.

Many potential dam sites exist on river Indus and its tributaries, which can make a substantial contribution to irrigation supplies for new irrigation projects. These projects would also contribute to the National Power Grid. Generation of relatively less expensive hydro power has assumed critical importance to keep the power tariff within affordability of consumers in view of large scale very costly induction of private thermal power in our system.

1.3.1 Major Rivers of Pakistan

River water is one of the most important sources for agriculture and generating large scale hydropower for industrial and domestic use. Nevertheless, these rivers provide ecological environments for the flora and fauna, where a great variety of plants and animal flourish. The river system of Pakistan includes more than 60 small and large rivers. The major rivers of Pakistan (Fig. 1.1) originate from Himalaya, Karakoram and Hindukush mountainous ranges and join as tributaries of the Indus River and cover an area of 0.6 million kilometers.

The Indus River and its tributaries pass through the Indian area before entering Pakistan. Since 1947, the use of river water and its distribution remained a burning issue between India and Pakistan. The Indus Water Treaty was signed in 1960 between Pakistan and India and accordingly all the water of the eastern rivers (Ravi, Sutlej and Bias)) was given to India, while the water of three western rivers (Indus, Jhelum and Chenab) was available to Pakistan. However, the continuously increasing demand for river water on one hand and inefficient use on the other hand, is putting these resources under extreme pressure. Consequently, its quality and ecosystem has been degraded badly (Khan, 2013). These rivers have been briefly discussed below.

Fig. 1.1 Indus River System of Pakistan

1.3.1.1 Indus River

The Indus River is the backbone of Pakistan's irrigation network. It originates from the Himalayas, firstly flows north westwards and then turning south to flow through Pakistan before entering the Arabian Sea through the Indus delta of Karachi. Indus River flows through the mountains of Gilgit and the KPK Province of Pakistan, and then across the fertile flood plains of the Punjab and arid deserted regions of Sindh. Indus River is the longest river of Pakistan with a total length of 3180 km (1,980 miles). The total drainage area is about 1,165,000 km^2. The annual flow is estimated at 207 km^3, and stands as twenty-first largest river in the world in terms of annual flow. In the Punjab plains, its left bank tributary is the Chenab River, which itself has four major tributaries, namely, the Jhelum, the Ravi, the Beas and the Sutlej. Its right bank tributaries include the Shyok, the Gilgit, the Kabul, the Gomal and the Kurram rivers.

In the Indus river, the flowing water level remains at its lowest from December to February and then starts rising at the end of March. The flow remains high during the summer months of April-August. The water level falls rapidly at the start of

October, when the water level subsides more gradually. Indus water plays an important role in the enhancement of agricultural productivity since long time. Following Indus Water Treaty, Pakistan Water and Power Development Authority (WAPDA) constructed several barrages and link canals to transfer water from western to eastern rivers to serve the command areas in the Punjab province. The major link canals linking the Indus, Jhelum, Chenab, Ravi and Sutlej rivers are Chashma-Jhelum, Taunsa-Punjnad, Rasul-Qadirabad, Trimun-Sidhnai, Qadirabad-Bulloki, Bulloki-Sulemanki Sidhnai-Mailsi and Mailsi-Bahawal. These canals also feed irrigation system of the lower Punjab province.

1.3.1.2 Jhelum River

The Jhelum River, which is the westernmost of the five rivers in Punjab, is a tributary to the Indus River. It originates from Vernag of Indian-occupied portion of Jammu and Kashmir. The river passes through the Northern slope of the PirPanjal Range and enters in Wular Lake. Jhelum River crosses the PirPanjal through 2100 m deep gorge with an almost vertical slope. Jhelum River is about 725 km long with highest flood discharges exceeding 28300 m^3/s. The spring snowmelt and the monsoon heavy rains from June to September are the sources of water in the river.

1.3.1.3 Chenab River

The River Chenab starts from Kulu and Kangra districts of the Himachal Pardesh state of India. After traversing about 644 km of mountainous regions, it moves toward the plains near Akhnur. River Chenab enters in Pakistan near Diawara village and flows through the alluvial plains of the Punjab for 5467 km. The Chenab River flows through Marala, Khanki, Qadirabad and Trimmu barrages. The average annual flow of this river is 30.37 BCM, out of which 23.83 BCM comes in Kharif and 6.53 BCM in Rabi (Ahmed et al., 2007).

1.3.1.4 Ravi River

Ravi River arises from Himachal Pradesh state of India and flows in Chamba, takes a turn in the southwest along the boundary of Jammu and Kashmir. The river then flows along the Pakistani border for more than 80 km and enters in Pakistan. It joins the Chenab River near Ahmadpur Sial after a course of 725 km. The water of the Ravi depends on spring snowmelt and monsoon that causes heavy rains from June to September.

1.3.1.5 Sutlej River

The longest of the five tributaries of the Indus River, Sutlej Rive originates from the north slope of the Himalayas in Langa Lake of Tibet. It passes through Himalayan gorges, crosses the Indian state of Himachal Pradesh and enters in the Punjab plain near Nangal. Continuing in a broad channel, it also receives the flow of Bias River and forms 105 km border of India and Pakistan and then enters in Pakistan. It flows for a distance of 350 km and then joins the Chenab River in the west of Bahawalpur. The flow in Sutlej is controlled by springs and summer snowmelt in the Himalayas and the rains of monsoon. The 1400 km long Sutlej is used extensively for irrigation.

1.3.2 Barrages

To utilize the river water resources for regulating and diverting irrigation water in Pakistan, barrages and canals were constructed. Some of the important barrages of Pakistan with their design discharge are given in Table 1.5. The structures built in the Indus river system and its tributaries for flow regulation are summarized in Table 1.6

Table 1.5 Barrages of Indus Basin Irrigation System in Pakistan

Barrages	Year of completion	Max. design discharge (cusecs)	Bays (No.)	Max. flood level from floor (ft)	Total design withdrawals for canal
Chashma	1971	1,100,000	52	37	26,700
Guddu	1962	1,200,000	64	26	-
Jinnah	1946	950,000	42	28	7,500
Kotri	1955	875,000	44	43	-
Sukkur	1932	1,500,000	54	30	47,530
Taunsa	1959	750,000	53	26	36,501

Table 1.6 Structures on Indus River and Tributaries

S.No.	River	Structure	Year
	Indus River		
1	Sukkar	Barrage	1932
2	Kalabagh	Barrage	1946
3	Kotri	Barrage	1954
4	Taunsa	Barrage	1959
5	Guddu	Barrage	1962
6	Chashma Jhelum River	Barrage	1971
7	Rasul	Barrage	1967
	Chenab River		
8	Marala (old)	Barrage	1912
9	Panjnad	Barrage	1932
10	Trimmu	Barrage	1939
11	Qadirabad	Barrage	1967
12	Marala (new)	Barrage	1968
	Ravi River		
13	Balloki	Weir	1913
14	Balloki	Weir (upgraded)	1965
15	Sidhnai	Barrage	1965
	Sutlej River		
16	Sulemanki	Weir	1926
17	Islam	Weir	1927
18	Mailsi	Weir	1965

1.3.3 Types of Irrigation System Canals

A canal is an artificial channel constructed to carry irrigation water from a river, dam, barrage or head work to the branch canals and distributaries and further conveyance to the irrigated fields. These canals can be classified as follows:

1.3.3.1 Permanent canals

Permanent canals are those which are fed by a permanent source of water, such as ice fed river or a reservoir. The canal is a well graded channel provided with permanent head works, regulators and distribution works.

1.3.3.2 Perennial canals

Perennial canals are permanent canals which get a continuous supply of water from a given river throughout the year. Such canals can irrigate the fields all the year around at a fairly equitable rate during the entire season of raising crops.

1.3.3.3 Non-perennial canals

Canals, which can irrigate only for a part of the year, usually during the summer season and at the beginning and the end of the winter season, are known as non-perennial canals. They originate from a river, which has no assured supply throughout the year or the supply is not sufficient for the whole year.

1.3.3.4 Inundation canals

Inundation canals are the earliest type of irrigation channels in the country. Inundation is the one in which there is no wear control system and the supply depends upon the periodical rise of water level in the river, from which it takes off. It is not provided with any headwork for diversion of the river flow, but the canal obtains a supply from open cut in the bank of the river or creeks, which are called heads. Due to the change in the river course, the heads should be changed often. A regulator is, however, provided on the canal 5 to 6 km downstream from the off-take point to control the discharge entering the canal. The surplus discharge, if any, is escaped back into the river. Inundation canals usually flow during the summer months but many remain in operation even during the winter season, depending upon the river flow to feed them. They draw large quantities of silt beneficial to crop.

These canals, like other canals, take water from the respective rivers, but the difference is that they get water when there is a flood and a rise in the water level. Therefore, the excess water is utilized in some beneficial way rather than letting it spoil. Inundation canal may be considered as seasonal, but the requirement is fulfilled by perennial canals.

1.3.3.5 Main Canal

The principal channel or a channel system off-taking from a river or a reservoir or tail reach of a feeder is designated as Main canals which is also called Main line. An irrigation channel carrying discharge above 25 cubic meters / second (cumecs) and not used for direct irrigation are called main canals. They take-off in the river and derive water through the head regulator. They act as a carrier canal to feed the branch canals and major distributaries. The main function of such a canal is to carry the total amount of irrigation water from the head and distribute it to the downstream canal system.

1.3.3.6 Branch Canals

Branch canals are irrigation channels taking off from the main canal on either side. Like the main canals, very little direct irrigation is done from them. Its discharge varies from 5 to 25 m^3/s. The discharge limit in some cases may be 10 m^3/s. Branch canals are usually feeder canals for major or minor distributaries. The main function of the branch canal is to make irrigation water available different parts of the tract for further distribution.

1.3.3.7 Major Distributaries

Distributaries which supply water to other distributaries are major distributaries. Their flow capacity lies between a branch canal and a minor distributary. They are irrigation channels taking off from the branch canals. They can also take off from the main canal but the discharge collected then is less than the branch canal. They carry a discharge varying from 0.25 to 5 cumecs. The upper limit, in some cases, is 10 cumecs. Their main function is to distribute the water to water courses through outlets provided along them. They are called 'Rajbaha'.

1.3.3.8 Minor Distributaries

They take off from the major distributaries or branch canals. They carry discharge less than 0.25 cumecs. Their main function is to reduce the length of water courses or field channels. They are provided when the length of the watercourse exceeds 3 km and are also known as 'minors'.

1.3.3.9 Watercourses or Field channels

The main watercourses are small cannels carrying water from the outlet of a distributary or a minor to the farms, whereas the Field Channels are ones that carry water from the main watercourse to the fields. The main watercourses are owned by the Irrigation Department but constructed and maintained by the irrigators. The canals, branch canals, distributaries and minors are government properties, and are also maintained by the Irrigation Department. Thus, the authority of the government ends at the main watercourses, where water is diverted to the field channels or farmer branches. The Field Channels are constructed and maintained by the farm owners. However, their capacity is the same as the main watercourse to carry full flow rate as available in the main watercourse.

1.3.4 Canal Network of Pakistan

The Indus, Jhelum and Chenab Rivers are the main sources of canal water in Pakistan, which have been provided with diversion structures, including a network of main canals, branch canals, distributaries, minors and watercourses. Although the control over the waters of rivers Ravi and Sutlej were given to India through the Indus Water Treaty 1960, yet the major portions of their commanded areas fall in Pakistan. Therefore, the canals originating from each river of the Pakistan's Indus Basin are summarized below. The flow rates in the system are maximum during summer, but minimum during winter seasons.

1.3.4.1 Canals of River Sutlej

Sutlej River has Ferozepur, Sulaimanki, Islam and Punjnad head works. However, Ferozpur headwork falls in the Indian territory. As control over water of River Sutlej was given to India by the Treaty, only the headworks and canals falling in Pakistan are considered here. The canals of Fordwah Eastern Sadiqia and Upper Pakpattan, take off from Sulemanki Barrage to irrigate the area of Nili Bar and Bahawalpur.LBC-Nil and UBC-Nil canals off-take from Islam Barrage. Similarly, Punjnad canal, Abbasia canal and abbasia Link Canal take off from Punjnad Barrage.

1.3.4.2 Canals of River Ravi

River Ravi commands 3 main canals namely, Lower Bari Doab, Upper Bari Doab and Sidhnai canal. Lower Bari Doab takes off from the BallokiHeadworks. The Upper Bari Doab is an old canal, which was constructed in 1868 but has been closed because the control of Madhupur Headworks lies with India. Sidhnai Canal originates from the Sidhnai Headworks at left bank of the river Ravi.

1.3.4.3 Canals of River Chenab

The Upper Chenab Canal (UCC) takes off from the Marala Barrage and Lower Chenab Canal (LCC) originates from the Khanki Barrage. Both the canals irrigate Rice-Wheat, Mixed and Cotton-Wheat zones of Rachna Doab. The Haveli Link Canal off-takes from Trimmu Headworks and irrigates the land in Rechna Doab.

The Lower Chenab Canal is one of the oldest and largest contiguous canal systems in the Rechna Doab area of Punjab, Pakistan. The LCC off-takes from the river Chenab at KhankiBarrage and covers the area between Qadirabad-Bulloki and Trimu-Sidhnai Link canals and small upper area of Qadirabad-Bulloki Link Canal along the river Chenab and lower area along Trimu-Sidhnai Link canal. The LCC was constructed in 1892 and initiated as weir controlled system for agriculture. Over the time, the canal was remodeled to enhance its capacity from non-perennial to perennial. Its commanded gross area is 1.42 mha with 376 cubic meter capacity to carry flow from Khanki Barrage and additional 116 cubic meters through the sub-link from the Qadirabad-Bulloki Link Canal. Administratively, LCC is divided into two command circles, i.e., Lower Chenab Canal East Circle and Lower Chenab Canal West Circle.

(i) Lower Chenab Canal East Circle

The Lower Chenab Canal East Circle (LCCE) area is bounded by Ravi River on the Eastern side and is located between the Qadirabad-Bulloki and Trimu-Sidhnai Link canals. The LCC East Circle includes the Mian Ali Branch, Upper Gugera Branch, Lower Gugera Branch and Burala Branch canals, and large network of distributaries, minors and watercourses. The Lower Chenab Canal East Circle has a gross area of 0.803 mha and culturable command area of 0.622 mha in the districts of Hafizabad, Sheikhupura, Faisalabad and Toba Tek Singh. Table 1.7 shows the salient features of various Canal Systems (LCC canal and Link canals).

Table 1.7 TheAverage Monthly Flows (m^3/s) of Various Canal Systems

Canal	LCC	QB Link	Sub-Link LCC	TS Link	Haveli
Apr	175.6	529.6	108.6	118.0	122.7
May	192.6	597.6	105.7	244.5	135.9
Jun	228.5	587.2	102.9	291.7	145.4
Jul	216.2	550.4	97.2	212.4	130.3
Aug	235.1	546.6	99.1	91.6	84.0
Sep	238.8	558.8	105.7	67.0	94.4
Oct	224.7	491.8	115.2	203.9	133.1
Nov	200.1	487.1	111.4	68.8	127.4
Dec	191.6	433.3	91.6	99.1	127.4
Jan	89.7	157.7	0.9	51.9	36.8
Feb	78.4	477.7	86.9	204.9	103.8
Mar	175.6	433.3	115.2	138.8	117.1

The circle consists of Upper Gugera Division, Lower Gugera Division and Burala Division, each containing subdivisions for the management of the irrigation network. The salient features of the LCC East Circle are given in Table 1.8.

Table 1.8 Division and Subdivision-wise Salient Features of Lower Chenab Canal East Circle

Division/ Subdivision	GCA (ha)	CCA (ha)	Channels	Outlets	Q (cumec)
Upper Gugera Division	288219	230631	60	1127	45.64
Chuharkana Subdivision	97417	70064	16	329	12.45
Mohlan Subdivision	112694	89538	25	437	17.59
Paccadala Subdivision	78108	71029	19	361	15.60
Lower Gugera Division	265786	206413	58	1046	46.93
Bhagat Subdivision	96394	75167	19	389	17.33
Buchiana Subdivision	81151	64178	21	302	13.10
Tarkhani Subdivision	88240	67068	18	355	16.50
Burala Division	248981	185390	64	960	47.07
Kanya Subdivision	77473	56114	15	302	13.05
Sultanpur Subdivision	60629	44524	14	219	11.27
Tandlianwala Subdivision	110879	84752	35	439	22.75
LCC East Circle	802986	622434	182	3133	139.64

Source: Jehangir et al., 2002

(ii) Lower Chenab Canal West Circle

The Lower Chenab Canal West Circle (LCCW) is bounded by the river Chenab on its western side and covers a large area between Qadirabad-Bulloki and Trimu-Sidhnai Link canals and a small area below Trimu-Sidhnai /Haveli Link canals. The circle includes Rakh Branch, Jhang Branch and Bhowana Branch canals with a large network of distributaries, minors and watercourses. The circle has a gross area of 0.759 mha and culturable command area of 0.58 mha in the districts of Hafizabad, Faisalabad, and Jhang. The salient features of division and subdivision are given in Table 1.9.

Table 1.9 Salient Features of Lower Chenab Canal West Circle

Division/Subdivision	GCA (ha)	CCA (ha)	Channels	Outlets	Q (cumec)
Faisalabad Division	173731	129393	54	870	27.2
Kot Khudayar Subdivision	81252	51289	27	405	13.8
Aminpur Subdivision	92479	78104	27	465	13.4
Hafizabad Division	170663	138547	40	766	29.3
Sangla Subdivision	51610	40225	20	246	7.1
Uqbana Subdivision	119053	98322	20	520	22.3
Jhang Division	299890	224620	75	1074	52.0
Dhaular Subdivision	98000	66012	25	379	10.7
Veryam Subdivision	108122	94924	26	382	24.4
Wer Subdivision	93768	63684	24	313	16.9
Khanki Division	115014	93565	31	485	27.1
Sagar Subdivision	115014	93565	31	485	27.1
LCC West Circle	759298	586125	200	3195	135.6

Source: Jehangir et al., 2002

(iv) Qadirabad-Balloki Link Canal

The Qadirabad-Bulloki Link Canal off-takes from the Qadirabad Barrage on the Chenab River and it was constructed 1960 to transfer 527 cumecs of water to the Ravi River at Balloki Headworks and to the LCC through a Sub-link Feeder canal. The canal constructed under the second phase of the Indus Basin Resettlement Plan and is 130 km long (Ahmed, 1988).

(v) Trimu-Sidhnai and Haveli Link Canals

The Trimu-Sidhnai and Haveli Link canal off-takes from the TrimuBarrage on the River Chenab, downstream of the confluence of the Jhelum River. The Trimu-Sidhnai Link Canal is 70 km long, has 312 cumecs and was constructed in1960 under the first phase of the Indus Basin Resettlement Plan (Ahmed, 1988). The Haveli Link Canal was constructed in 1930 to supply the Sidhnai Canal and has the capacity to carry 140 cumecs with command area of about 80,000 hectares.

1.3.4.4 Canals of River Jhelum

Upper Jhelum and Lower Jhelum canals lie in Chaj Doab. The Upper Jhelum canal off-takes from Mangla reservoir and it join the Chenab at Khanki and provide its surplus water to the lower Chenab Canal. The Lower Jhelum Canal off-takes from the Rasul Barrage, constructed on Jhelum River.

1.3.4.5 Canals of River Indus

The Thal canal originates from Jinnah Barrage near Kalabagh to irrigate the desert area of Thal Doab for agricultural purpose. The agricultural land of district D.G.

Khan and D.I. Khan are irrigated by link canals from Chashma, Taunsa and Guddu barrages.

1.3.5 Water allowance

Water Allowance is the quantity of irrigation water allowed for 1000 acres of culturable land. This also helps in designing an outlet for its command area. The Indus Basin Irrigation system was developed through clever engineering and human effort; it is not a natural gift. It needs good management if we want to maintain a high level of performance in the form of adequate water supplies. The details of major canals of Punjab Province with their water allowances and commanded areas are given in Table 1.10.

Table 1.10 Water Allowance and Commanded Areas of Major Canals in Punjab Province

Canal Name	Canal command area (ha)	Million ha	Acres	FSD	Water allowance
Thal Canal	1089870	1.090	2691978.9	6000	2.23
Upper Jehlum Canal	268514	0.269	663229.0	1900	2.86
Lower Jehlum Canal	706405	0.706	1744821.4	5300	3.04
Marala Ravi Canal	65852	0.066	162655.1	2000	12.30
Upper Chenab Canal	434468	0.434	1073135.3	7800	7.27
LCC (Jhang branch + Gugera)	1530379	1.530	3780036.9	12000	3.17
Raya Branch (BRBD Internal)	179098	0.179	442372.6	3100	7.01
Central Bari Doab Canal	314574	0.315	776998.8	7000	9.01
Lower Bari Doab Canal	762006	0.762	1882153.9	8000	4.25
Rangpur Canal	158088	0.158	390477.3	2700	6.91
Upper Dipalpur Canal	171826	0.172	424409.5	2100	4.95
Lower Dipalpur Canal	248314	0.248	613335.1	4000	6.52
Muzffgarh Canal	323394	0.323	798782.5	6500	8.14
Sidhnai Canal	346552	0.347	855983.1	4500	5.26
Pakpattan Canal	454748	0.455	1123228.5	6600	5.88
Fordwah	214748	0.215	530428.0	3400	6.41
Dera Ghazi Khan Canal	399739	0.400	987356.0	8500	8.61
Mailsi Canal	434955	0.435	1074337.9	6100	5.68
Sadiqia Canal	465805	0.466	1150539.2	4900	4.26
Bahawal Canal	325066	0.325	802913.6	5500	6.85
Abbasia Canal	64550	0.065	159439.1	1100	6.90
Panjnad Canal	598151	0.598	1477431.9	9000	6.09

Source: Punjab Irrigation Department

1.3.6 Warabandi

The irrigation water allocation to the farmers is managed through Warabandi (turn) system. Warabandi is a rotational way for equitable distribution of water in the irrigation system by fixed turns according to a predetermined schedule. The water is distributed in the specified year, day, time and duration of supply to each irrigator in proportion to the size of farmers' landholding in the outlet command. The cycle of warabandi starts from the head and proceeds to the tail of the watercourse. During each turn, the farmer has the right to use all the water flowing in the watercourse at his specified turn. The main canals, distributaries and minor are managed by the provincial irrigation departments and deliver water at the head of watercourses through an outlet, which is designed to provide a quantity of water proportional to the culturable command area of the watercourse.

Presently, Kacha and Pakka warabandi systems are in practice in Pakistan, which has been decided by the farmers solely on their agreement, without formal involvement of any government agency. Warabandi system is expected to achieve two main objectives, such as water use efficiency is to be and equity in distributing water per unit area among all users.

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